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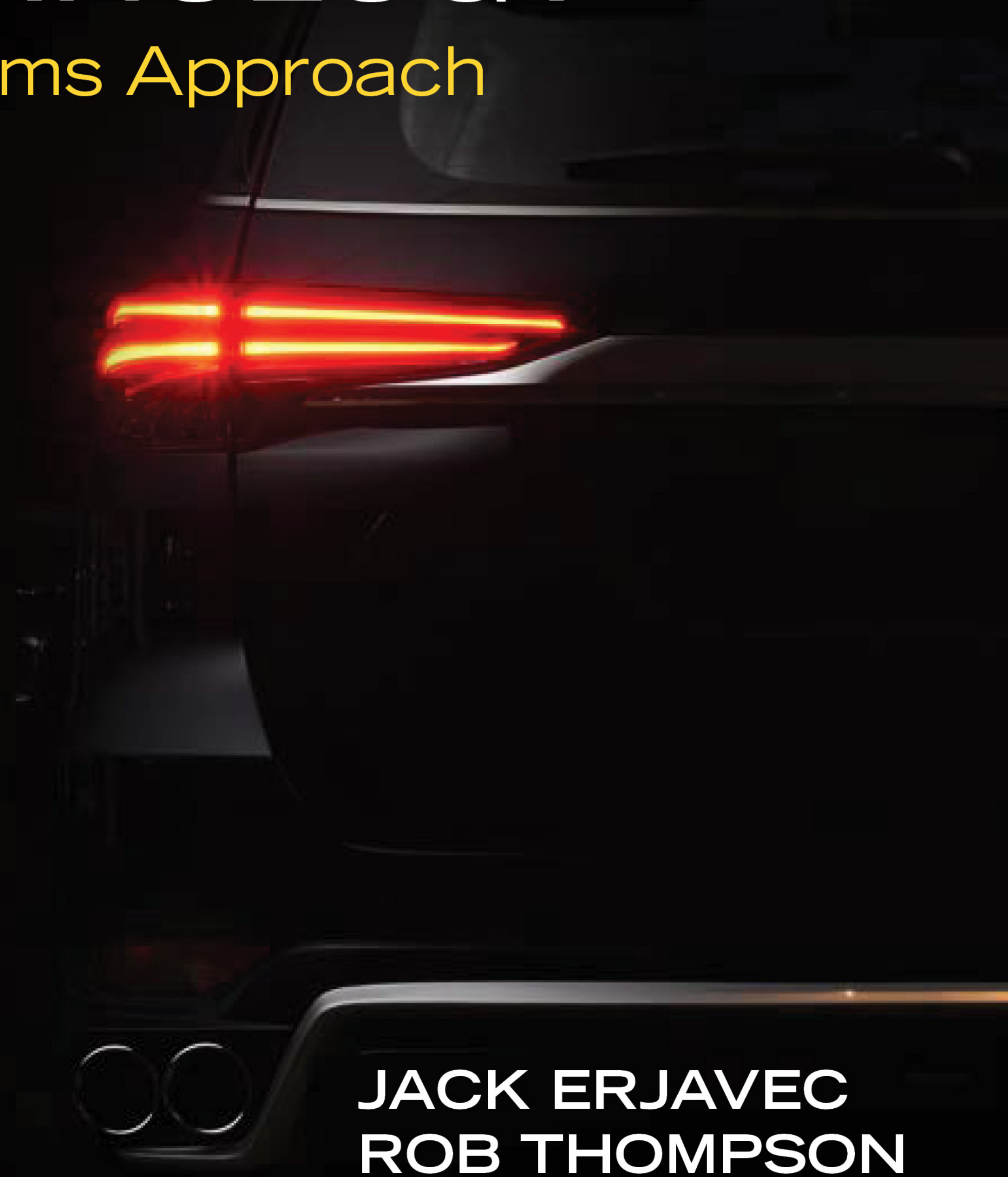
AUTOMOTIVE TECHNOLOGY

A Systems Approach

7th Edition



JACK ERJAVEC
ROB THOMPSON

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AUTOMOTIVE TECHNOLOGY

A Systems Approach

7th Edition

Jack Erjavec

Rob Thompson

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***Automotive Technology: A Systems Approach*, 7th Edition**
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Cover image(s): Photographicss/ ShutterStock.com

Library of Congress Control Number: 2018958672

ISBN: 978-1-3377-9421-3

Cengage
20 Channel Center Street
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Printed in the United States of America
Print Number: 01 Print Year: 2018

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PREFACE

About the Book

Manufacturers have made major and constant changes to the various systems of an automobile, and the integration and codependence of those systems have made becoming a successful technician more challenging than ever. This book, *Automotive Technology: A Systems Approach*, was designed and written to prepare students for those challenges. The basic premise is "with students having so much to learn in a short time, why fill the pages of a textbook with information they do not need?" The emphasis of this book is on those things that students need to know about the vehicles of today and tomorrow.

This does not mean that the pages are filled with fact after fact. Rather, each topic is explained in a logical way, slowly but surely. With more than 45 years of combined teaching experience, we believe we have a good sense of how students read and understand technical material. We also know what things draw their interest into a topic and keep it there. These things have been incorporated in the writing and features of the book.

This new edition of *Automotive Technology: A Systems Approach* represents the many changes that have taken place in the automotive industry over the past few years. With each new edition, the challenge of what to include and what to delete presents itself. We hope that we have made the right choices. of course, if we did, much of the credit is due to the feedback we have received from users of the previous edition and those who reviewed this new edition while it was in the making. They all did a fantastic job and showed that they are truly dedicated to automotive education.

New to this Edition

This seventh edition is not the sixth edition with a new cover and some new pictures. Although much of the information from the previous edition was retained, each chapter has been updated in response to the changing industry. In addition, there are some new features that should be helpful to students and their instructors. We have made sure that all of the latest ASE program standards are covered in this text. Regardless of the level of program accreditation, you will find the appropriate information in this book.

The first section of chapters gives an overview of the automotive industry, careers, working as a technician, tools, diagnostic equipment, and basic automotive systems. The content of these chapters has been updated and arranged to prepare students for the responsibilities and demands of a career as an automotive technician.

Chapter 1 explores the career opportunities in the automotive industry. This discussion has been expanded to include more information about ASE certification and testing. Chapter 2 covers workplace skills and the ways to go about seeking and selecting a job in the automotive field. This chapter goes through the process of getting a job and keeping it. It also covers some of the duties common to all automotive technicians. This chapter has been updated to include online resources.

Chapter 3 covers the science and math principles that are the basis for the operating principles of an automobile. Too often, we, as instructors assume that our students know these basics. This chapter is included to serve as a reference for those students who want to be good technicians. To do that they need a better understanding of why things happen the way they do.

Chapter 4 covers the basic systems of the automobile in a very basic approach and has been updated to include hybrid vehicles and alternative fuels. Chapters 5 through 7 cover very important issues regarding the use and care of hand tools, shop equipment, and safety issues (including bloodborne pathogens). Throughout these chapters, there is a strong emphasis on safely working on today's vehicles and the correct tools required to do so. Chapter 6 gives a brief look at the special and diagnostic tools required for working in each of the eight primary ASE certification areas. The tools discussed include all of the required tools for each area as defined by the ASE Education Foundation (formerly NATEF).

Chapter 8 covers the procedures involved in common safety inspections and preventive maintenance programs. Because the industry has more hybrid

vehicles than in previous years, basic maintenance for those vehicles has been included.

Section 2, which contains the chapters on engines, has been updated to include more coverage on the latest engine designs and technologies. There is more coverage on the theory, diagnosis, and service to alloy engines and overhead camshaft engines. There are also discussions on the latest trends, including variable valve timing and lift and cylinder disabling systems. A discussion of light-duty diesel engines and those engines used in hybrid vehicles is also part of the entire section.

It is nearly impossible to work on modern cars and trucks without a solid understanding of basic electricity and electronics as contained in Section 3. As a result, little has been deleted from those chapters while new information has been added to keep up with current technology. Coverage of all the major electrical systems has been increased to include new technologies. This includes high-voltage systems, new exterior lighting systems, adaptive systems (such as cruise control), semi-autonomous and autonomous driving technologies, and many new accessories. The rest of the section has been brought up to date with additional coverage on body computers and the use of lab scopes and graphing meters.

The entire Engine Performance section (Section 4) has been updated from the introductory chapters to those that deal with overall engine performance testing. The layout represents the approach taken by most experienced technicians. It is hoped that students will be able to grasp a global look at these systems and can become better diagnosticians. The revision of the section covers the individual engine performance systems, their operation, and how to test them with current diagnostic equipment. Added emphasis on diagnostics was the main goal of the revision of the rest of this section.

Included in this section are three chapters that deal with some of the dynamic aspects of the automotive industry. Chapter 28 is dedicated to gasoline, diesel, and other fuels. It also covers the operation and service of light-duty diesel engines, including their injection and emission control systems. Due to the increasing number of hybrid and electric vehicles on the road, this edition has an entire chapter dedicated to hybrid vehicles in addition to the information that appears in various chapters. Chapter 36 focuses on currently available electric and fuel cell vehicles.

Sections 5 and 6 cover transmissions and drivelines. All of the chapters in these sections have been updated to include more coverage on electronic controls. There is also more coverage on six-, seven-, and eight and ten-speed transmissions, automatic manual transmissions, new differential designs, and electronic automatic transmissions and transaxles. In addition, there is complete coverage on the transmissions used in today's hybrid vehicles. There is a comprehensive look at torque vectoring systems, which are becoming more common on all types of vehicles.

The suspension and steering systems section has increased coverage on electronic controls and systems. This includes the new designs of shock absorbers and four-wheel steering systems. Chapter 49 has been updated to include the latest techniques for performing a four-wheel alignment.

The Brakes section has also been updated to reflect current technology. This includes the latest antilock brake, stability control, and traction control systems.

Heating and air-conditioning systems are covered in Section 9. The content in Chapters 54 and 55 includes hybrid systems, R-1234yf components and service, as well as future refrigerants.

Organization and Goals of this Edition

This edition is still a comprehensive guide to the service and repair of our contemporary automobiles. It is still divided into nine sections that relate to the specific automotive systems. The chapters within each section describe the various subsystems and individual components. Diagnostic and service procedures that are unique to different automobile manufacturers also are included in these chapters. Because many automotive systems are integrated, the chapters explain these important relationships in great detail. It is important to note that all of latest ASE Education Alliance standards are addressed in this edition.

Effective diagnostic skills begin with learning to isolate the problem. The exact cause is easier to pinpoint by identifying the system that contains the problem. Learning to think logically about troubleshooting problems is crucial to mastering this essential skill. Therefore, logical troubleshooting techniques are discussed throughout this text. Each chapter describes ways to isolate the problem system and then the individual components of that system.

This *systems approach* gives the student important preparation opportunities for the ASE certification exams. These exams are categorized by the automobile's major systems. The book's sections are outlined to match the ASE test specifications and competency task lists. The review questions at the end of every chapter give students practice in answering ASE-style review questions.

More importantly, a *systems approach* allows students to have a better understanding of the total vehicle. With this understanding, they have a good chance for a successful career as an automotive technician. That is the single most important goal of this text.

Acknowledgments

I would like to acknowledge and thank the following dedicated and knowledgeable educators for their comments, criticisms, and suggestions during the review process:

Michael Abraham,
Porter and Chester Institute,
Woburn, MA
Donnie Ray Allen,
TTC at McMinnville,
McMinnville, TN
Curt Andres,
Mid-State Technical College,
Marshfield, WI
Wayne A. Barton,
Porter and Chester Institute,
Branford, CT
Arthur S. Bernier,
Porter and Chester Institute,
Woburn, MA
Rick Bland,
WyoTech,
Blairsville, PA
Alfred Blume,
Lincoln Technical Institute,
Philadelphia, PA
Dennis Blumetti,
Lincoln Technical Institute,
Union, NJ
Ronnie Bush,
Tennessee Technology Center at Jackson,
Jackson, TN
Arlen Crabb,
Lincoln College of Technology,
Columbia, MD
Eric Evensen,
WyoTech,
West Sacramento, CA
Jack Fetsko,
WyoTech,
Blairsville, PA
Dave Fish,
WyoTech,
Blairsville, PA
Gary Forgotson,
Lincoln Technical Institute,
Mahwah, NJ
David Foster,
Austin Community College,
Austin, TX
Gary R. Grote,
Porter and Chester Institute,
Rockyhill, CT
Carl L. Hader,
Grafton High School,
Grafton, WI
Mark Hankins,
Shoreline Community College,
Shoreline, WA
Matthew Herndon,
WyoTech,
West Sacramento, CA
Roger Ito,
WyoTech,
Sacramento, CA
Ken Jefferson,
Southeast Community College Lincoln, NE
Igor Joffe,
Lincoln Technical Institute,
Mahwah, NJ
David P. Jones,
Lincoln College of Technology,
Melrose Park, IL
Mike Keener,
WyoTech,
Blairsville, PA
John V. King,
Lincoln College of Technology,
Columbia, MD
Joe Krystopa,
Lincoln Technical Institute,
Philadelphia, PA
Calvin Lofton,
WyoTech,
Long Beach, CA
Jack Longress,
WyoTech,
Laramie, WY
Philip Lowry,
Lincoln Technical Institute,
Whitestone, NY
Louis Luchsinger,
Lincoln Technical Institute,
Union, NJ
Larry Marshall,
Lawson State Community College,
Bessemer, AL
Kevin McCurry,
North Georgia Technical College,
Clarkesville, GA
James Melby,
Porter and Chester Institute,
Belchertown, MA
Brian Noel,
Cosumnes River College,
Sacramento, CA
Paul O'Connell,
Riverside City College,
Riverside, CA
Joseph A. Oliva,
Lincoln Technical Institute,
Whitestone, NY
Marvin Olson,
Fort Peck Community College,
Poplar, MT
Vernon Ouellette,
Porter and Chester Institute,
Branford, CT
Douglas Peterson,
Lincoln Technical Institute,
Philadelphia, PA
David Reynolds,
Lincoln College of Technology,
Indianapolis, IN
Eric Rising,
WyoTech,
Blairsville, PA
Steven Russo,
Lincoln Technical Institute,
Union, NJ
Mike Sarver,
WyoTech,
Blairsville, PA
Paul Schenkel,
WyoTech,
West Sacramento, CA
Terry Lynn Shaffer,
Bates Technical College,
Tacoma, WA
Michael Shephard,
Lincoln Technical Institute,
Union, NJ
Timothy Shockley,
WyoTech,
Sacramento, CA
Frank Spirig,
Lincoln Technical Institute,
Union, NJ
Wendell Soucy,
Porter and Chester Institute,
Enfield, CT
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Porter and Chester Institute,
Enfield, CT
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WyoTech,
Blairsville, PA
Tom Velardi,
Lincoln Technical Institute,
Whitestone, NY
James Warga,
Lincoln Technical Institute,
Mahwah, NJ
Glen F. Weiss,
Lincoln Technical Institute,
Philadelphia, PA
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About the Author

Jack Erjavec has become a fixture in the automotive textbook publishing world. He has many years of experience as a technician, educator, author, and editor and has authored or coauthored more than forty automotive textbooks and training manuals. Mr. Erjavec holds a Master of Arts degree in Vocational and Technical Education from Ohio State University. He spent 20 years at Columbus State Community College as an instructor and administrator and has also been a long-time affiliate of the North American Council of Automotive Teachers, including serving on the board of directors and as executive vice-president. Jack was also associated with ATMC, SAE, ASA, ATRA, AERA, and other automotive professional associations.

Rob Thompson started his teaching career as an adjunct faculty member at Columbus State Community College while still working full-time as a technician. Since 1995, he has taught the high school automotive technology program that he himself graduated from a long time ago. Rob has an associate of applied science degree in automotive technology, has been a board member and is a past-president of the North American Council of Automotive Teachers (NACAT). Rob has ASE Master and Advanced Level Technician certifications.

FEATURES OF THE TEXT

Learning how to maintain and repair today's automobiles can be a daunting endeavor. To guide the readers through this complex material, we have built in a series of features that will ease the teaching and learning processes.

Objectives

Each chapter begins with the purpose of the chapter, stated in a list of objectives. Both cognitive and performance objectives are included in the lists. The objectives state the expected outcome that will result from completing a thorough study of the contents in the chapters.

The Three Cs

New in the previous edition and updated for this edition is the feature called *The Three Cs*. The Three Cs, meaning the *concern, cause, and correction*, are used to help technicians identify the concern or customer complaint, the underlying reason or cause of the concern, and how to correct the problem. The chapter openers in Sections 2 through 9 each contain a Three Cs scenario where the reader is presented with a shortened repair order (RO) and customer concern. Within the chapter, information regarding the concern's possible causes and corrections are provided. Finally, at the end of the chapter, the cause and correction to the scenario are presented to the reader, with rationale notes about any special considerations regarding the diagnosis and repair. In many of The Three Cs scenarios, the details are taken from real-world situations. We hope this feature will be useful in providing a real-world look at how vehicles are presented to technicians and how customer concerns are resolved.

Cautions and Warnings

Instructors often tell us that shop safety is their most important concern. Cautions and warnings appear frequently in every chapter to alert students to important safety concerns.

Shop Talk

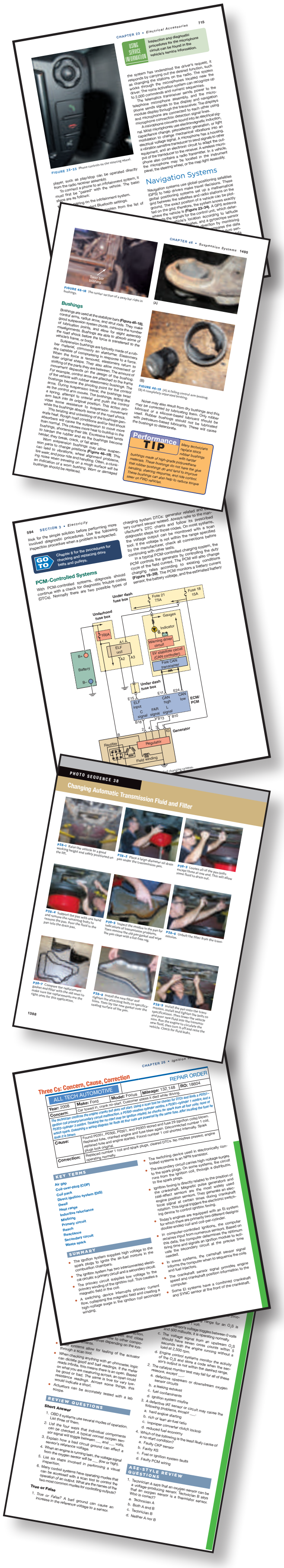
These features are sprinkled throughout each chapter to give practical, commonsense advice on service and maintenance procedures.

Customer Care

Creating a professional image is an important part of shaping a successful career in automotive technology. The customer care tips were written to encourage professional integrity. They give advice on educating customers and keeping them satisfied.

Tool Care

The Tool Care feature discusses proper use and care of common tools so that they can remain functioning and usable for years to come.



Using Service Information

Learning to use available service information is critical to becoming a successful technician. The source of information varies from printed material to online materials. The gathering of information can be a time-consuming task but nonetheless is extremely important. We have included a feature that points the student in the right direction to find the right information.

Performance Tips

This feature introduces students to the ideas and theories behind many performance-enhancing techniques used by professionals.

"Go To" Feature

This feature is used throughout the chapters and tells the student where to go in the text for prerequisite and additional information on the topic.

Photo Sequences

Step-by-step photo sequences illustrate practical shop techniques. The photo sequences focus on techniques that are common, need-to-know service and maintenance procedures. These photo sequences give students a clean, detailed image of what to look for when they perform these procedures. This was a popular feature of the previous editions, so we now have a total of 51.

Procedures

This feature gives detailed, step-by-step instructions for important service and maintenance procedures. These hands-on procedures appear frequently and are given in great detail because they help to develop good shop skills and help to meet competencies required for ASE certification.

Key Terms

Each chapter ends with a list of the terms that were introduced in the chapter. These terms are highlighted in the text when they are first used, and many are defined in the glossary.

Summary

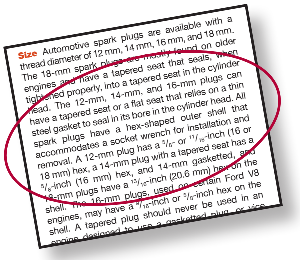
Highlights and key bits of information from the chapter are listed at the end of each chapter. This listing is designed to serve as a refresher for the reader.

Review Questions

A combination of short-answer essay, true or false, and multiple-choice questions make up the end-of-chapter review questions. Different question types are used to challenge the reader's understanding of the chapter's contents. The chapter objectives are used as the basis for the review questions.

ASE-Style Review Questions

In any chapter that relates to one of the ASE certification areas, there are ten ASE-style review questions that relate to that area. Some are quite challenging and others are a simple review of the contents of the chapter.



Metric Equivalents

Throughout the text, all measurements are given in UCS and metric increments.

Supplements

The Automotive Technology package offers a full complement of supplements:

Tech Manual

The Tech Manual offers students opportunities to strengthen their comprehension of key concepts and to develop their hands-on, practical shop experience. Each chapter includes Concept Activities and Job Sheets, which are directly correlated to ASE Education Foundation tasks. Service information report sheets and review questions are also included to offer a rounded approach to each lesson.

Instructor Resources

The Instructor Resources (on CD and companion website) for the seventh edition include the following components to help minimize instructor prep time and engage students:

- **PowerPoint**—Chapter outlines with images, animations, and video clips for each textbook chapter.
- **Computerized Test Bank in Cognero**—Hundreds of modifiable questions for exams, quizzes, in-class work, or homework assignments in an online platform.
- **Image Gallery**—Access to hundreds of images from the textbook that can be used to easily customize the PowerPoint outlines.
- **Photo Sequences**—Each of the Photo Sequences from the textbook are provided within PowerPoint for easy classroom projection.
- **End-of-Chapter Review Questions**—Word files of all textbook review questions are provided for easy distribution to students.
- **Instructor's Manual**—An electronic version of the Instructor's Manual provides lecture outlines with teaching hints, answers to review questions from the textbook, and answers to *Tech Manual* questions, as well as guidelines for using the *Tech Manual*. A correlation chart to the current ASE Education Foundation Standards provides references to topic coverage in both the text and *Tech Manual*.
- **ASE Education Foundation Correlations**—The current ASE Education Foundation Automobile Standards are correlated to the chapter and page numbers of the core text and all relevant *Tech Manual* job sheets.
- **Job Sheet Template**—For instructors who develop their own job sheets, a template is provided to help with their formatting.

Mindtap for Automotive

MindTap is a personalized teaching experience with relevant assignments that guide students to analyze, apply, and improve thinking, allowing you to measure skills and outcomes with ease.

- *Personalized Teaching:* Becomes YOURS with a Learning Path that is built with key student objectives. Control what students see and when they see it—match your syllabus exactly by hiding, rearranging, or adding you own content.
- *Guide Students:* Goes beyond the traditional “lift and shift” model by creating a unique learning path of relevant readings, multimedia, and activities that move students up the learning taxonomy from basic knowledge and comprehension to analysis and application.
- *Measure Skills and Outcomes:* Analytics and reports provide a snapshot of class progress, time on task, engagement and completion rates.

CHAPTER 1

CAREERS IN THE AUTOMOTIVE INDUSTRY

OBJECTIVES

- Describe the various types of jobs available in the automotive industry.
- Explain how computer technology has changed the way vehicles are built and serviced.
- Explain why the need for qualified automotive technicians is increasing.
- Describe the major types of businesses that employ automotive technicians.
- List some of the many job opportunities available to people with a background in automotive technology.
- Describe the different ways a student can gain work experience while attending classes.
- Describe the requirements for ASE certification as an automotive technician and as a master auto technician.

The Automotive Industry

Each year millions of new cars and light trucks are produced and sold in North America **(Figure 1–1)**. The automotive industry's part in the total economy of the United States is second only to the food industry. Manufacturing, selling, and servicing these vehicles are parts of an incredibly large, diverse, and expanding industry.

Forty years ago, America's "big three" automakers—General Motors Corporation, Ford Motor Company, and Chrysler Corporation—dominated the auto industry. This is no longer true. The industry is now a global industry **(Table 1–1)**. Automakers from Japan, Korea, Germany, Sweden, and other European and Asian countries compete with companies in the United States for domestic and foreign sales.

Several foreign manufacturers, such as BMW, Honda, Hyundai, Mercedes-Benz, Nissan, Toyota, and Volkswagen, operate assembly plants in the United States and Canada. Automobile manufacturers have joined together, or merged, to reduce costs and increase market share. In addition, many smaller

FIGURE 1–1 Ford's F-150 pickup has been the best-selling vehicle in America for many years.

auto manufacturers have been bought by larger companies to form large global automobile companies. Most often the ownership of a company is not readily identifiable by the brand name.

This cooperation between manufacturers has given customers an extremely wide selection of vehicles to choose from. This variety has also created new challenges for automotive technicians, based on one simple fact: Along with the different models come different systems.

The Importance of Auto Technicians

The automobile started out as a simple mechanical beast. It moved people and things with little regard to the environment, safety, and comfort.

TABLE 1–1 FACTS ABOUT THE PASSENGER CARS AND LIGHT- AND MEDIUM-DUTY TRUCKS SOLD IN NORTH AMERICA (ALL FIGURES ARE APPROXIMATE).

Manufacturer	Owned by	Common Brands	Country of Origin	Annual Sales
BMW AG	Shareholders 53% and Family 47%	BMW, Mini, and Rolls-Royce	Germany	350 thousand
Chrysler Group	Fiat 59% and UAW 41%	Chrysler, Dodge, and Ram	Italy and North America	2.2 million
Daimler AG	Aabar Investments 8%, Kuwait Investments 7%, Renault-Nissan 3%, and Shareholders 81%	Bentley, Daimler Trucks & Buses, Mercedes-Benz, and Smart	Germany	478 thousand
Fiat S.P.A.	Family 30% and Shareholders 70%	Abarth, Alfa Romeo, Chrysler, Ferrari, Fiat, Lancia, and Maserati	Italy	33 thousand
Ford Motor Company	Family 40% and Shareholders 60%	Ford and Lincoln	North America	2.4 million
Fuji Heavy Ind. Ltd.	Shareholders 81%, Toyota 16%, Suzuki 2%, and Fuji 1%	Subaru	Japan	647 thousand
Geely Automotive	Li Shu Fu 50% and Shareholders 50%	Volvo	China	81 thousand
General Motors	UAW Trust 10%, Canada DIC 9% and Shareholders 81%	Buick, Cadillac, Chevrolet, GMC, and Holden	North America	3 million
Honda Motor Co.	Shareholders 80%, Japan Trustee Bank 8%, and Master Trust Bank of Japan, Moxley & Co., and JP Morgan Chase 4% each	Acura and Honda	North America and Japan	1.5 million
Hyundai Motor Co.	Shareholders 74%, Hyundai Mobis 21%, and Chung Mong-Koo 5%	Hyundai and Kia	Korea	1.3 million

TABLE 1–1 *(continued)*

Manufacturer	Owned by	Common Brands	Country of Origin	Annual Sales
Mazda Motor Corp.	Shareholders 80%, Japan Trustee Bank and Chase Manhattan 5% each, and Master Trust of Japan, Mitori Bank Corp., and Ford Motor Co. 4% each	Mazda	Japan	289 thousand
Mitsubishi Motors	Shareholders 71% and Mitsubishi Corp. 29%		Japan	103 thousand
Nissan Motor Corp.	Shareholders 52%, Renault SA 44%, Nissan 1%, and Daimler 3%	Nissan and Infiniti	Japan	1.6 million
Porsche Auto Holding	Volkswagen AG	Porsche	Germany	55 thousand
Tata Motors	Tata 35%, Indian Banks 14%, and Shareholders 50%	Jaguar, Rover, and Tata	India	128 thousand
Toyota Motor Corp.	Shareholders 85%, Toyota 9%, and Others 6%	Daihatsu, Isuzu, Lexus, Scion, Telsa, and Toyota	Japan	2.4 million
Volkswagen AG	Porsche 54%, Lower Saxony 20%, Qatar Holding 17%, and Shareholders 10%	Audi, Bentley, Bugatti, Lamborghini, and Volkswagen	Germany	500 thousand

Through the years, these concerns have provided the impetus for design changes. One area that has affected automobile design the most is the same area that has greatly influenced the rest of our lives, electronics. Today's automobiles are sophisticated electronically controlled machines. To provide comfort and safety while being friendly to the environment, today's automobiles use the latest developments of many different technologies—mechanical and chemical engineering, hydraulics, refrigeration, pneumatics, physics, and, of course, electronics.

An understanding of electronics is a must for all automotive technicians **(Figure 1–2)**. The needed level of understanding is not that of an engineer; rather, technicians need a practical understanding of electronics. In addition to having the mechanical skills needed to remove, repair, and replace faulty or damaged components, today's technicians also must be able to diagnose and service complex electronic systems.

Computers and electronic devices are used to control the operation of nearly all systems of an automobile. Because of these controls, today's automobiles use less fuel, perform better, and run cleaner than those in the past. The number of electronically controlled systems on cars and trucks increases each year. There are many reasons for the heavy insurgence of electronics into automobiles. Electronics are based on electricity and electricity moves at the speed of light. This means the operation of the various systems can be monitored and changed very quickly. Electronic components have no moving parts, are durable, do not require periodic adjustments, and are very light. Electronics also allow the various systems to work together, which increases the efficiency of each system, and therefore the entire vehicle.

The application of electronics has also led to the success of hybrid and electric vehicles **(Figure 1–3)**. A hybrid vehicle has two separate sources of power. Those power sources can work together to move the vehicle or power the vehicle on their own. Today's hybrid vehicles are moved by electric motors and/or a gasoline engine. Hybrid vehicles are complex machines and all who work on them must be

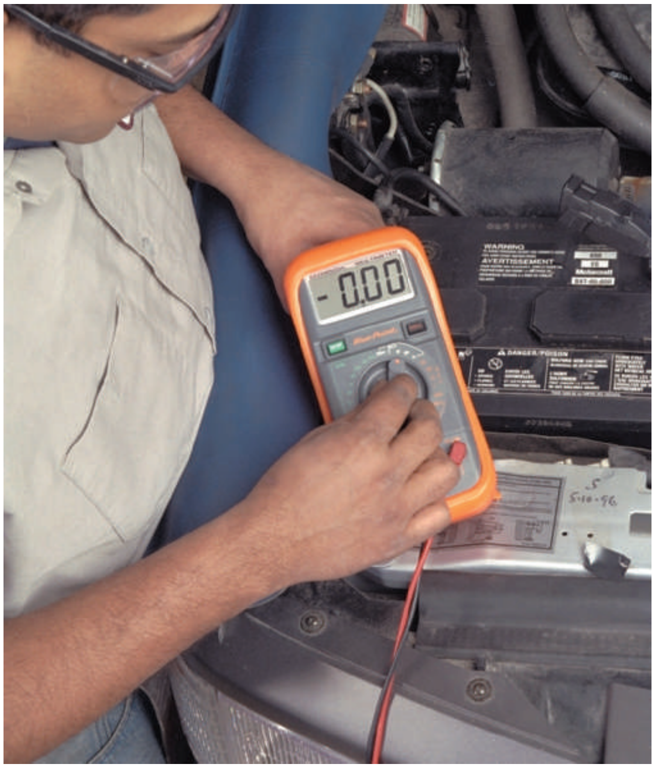


FIGURE 1–2 An understanding of electronics is a must for all automotive technicians.

properly trained. Advanced electronics has also led to the resurgence of pure electric vehicles, with over 150,000 new electric vehicles sold in the United States in 2016 alone.

The design of today's automobiles is also influenced by legislation. Throughout history, automobile manufacturers have been required to respond to new laws designed to make automobiles safer and cleaner running. In response to these laws, new systems and components are introduced. Anyone desiring to be a good technician and have a successful career must regularly update his or her skills to keep up with the technology.

Legislation has not only influenced the design of gasoline-powered vehicles, it has also led to a wider use of diesel engines in passenger vehicles. By mandating cleaner diesel fuels, the laws have opened the door for clean burning and highly efficient diesel engines. Many states have laws that require owners to have their vehicles exhaust tested on an annual basis. Some states require automobiles to pass an annual or biannual inspection.

FIGURE 1–3 A charging station at a new car dealership.

The Need for Quality Service

The need for good technicians continues to grow. Currently there is a great shortage of qualified automotive technicians. This means there are, and will be, excellent career opportunities for good technicians. Good technicians are able to diagnose and repair problems in today's automobiles **(Figure 1–4)**.

Car owners demand that when things go wrong, they should be "fixed right the first time." The primary reason some technicians are unable to fix a particular problem is simply that they cannot find the cause of the problem. Today's vehicles are complex and a great amount of knowledge and understanding is required for good diagnostic skills. Today's technicians must be able to identify and solve problems the first time the vehicle is brought into the shop.

FIGURE 1–4 Good technicians are able to follow specific manufacturers' diagnostic charts and interpret the results of diagnostic tests.

The Need for Ongoing Service

Electronic controls have not eliminated the need for routine service and scheduled maintenance **(Figure 1–5)**. In fact, they have made it more important than ever. But electronic systems can automatically make adjustments to compensate for some problems, a computer cannot replace worn parts. A computer cannot tighten loose belts or change dirty coolant or engine oil. Simple problems such as these can set off a chain of unwanted events in an engine control system. Electronic controls are designed to help a well-maintained vehicle operate efficiently. They are not designed to repair systems.

Electronic systems are based on the same principles as a computer. In fact, these systems rely on computers to control the operation of a component or system. Instead of a keyboard, automotive electronic systems rely on sensors or inputs. These send information to the computer. The computer receives the inputs and through computer logic causes a component to change the way it is operating. These controlled outputs are similar to your computer screen or printer.

Each automobile manufacturer recommends that certain maintenance services be performed according to a specific schedule. These maintenance procedures are referred to as **preventive maintenance (PM)** because they are designed to prevent problems. Scheduled PM normally includes oil and filter changes; coolant and lubrication services; replacement of belts and hoses; and replacement of spark plugs, filters, and worn electrical parts **(Figure 1–6)**.

If the owner fails to follow the recommended maintenance schedule, the vehicle's warranty might

FIGURE 1–5 Regular preventive maintenance (PM) is important for keeping electronic control systems operating correctly. A common part of PM is changing the engine's oil and filter.

5,000 MILES OR 6 MONTHS

- Replace engine oil and oil filter
- Reset service reminder indicator display
- Rotate tires
- Visually inspect brake linings and fluid level
- Inspect wiper blades
- Check windshield washer fluid level and system
- Check tires and spare wheel for pressure and wear

Additional items for special operating conditions

- Rotate tires and reset TPMS
- Inspect ball joints and dust covers
- Inspect drive shaft boots
- Inspect air filter
- Inspect steering linkage and boots
- Re-torque drive shaft bolt
- Tighten nuts and bolts on chassis

15,000 MILES OR 18 MONTHS

(Same as 5,000 miles and 6 months) ***Plus:***

- Inspect battery and cables
- Check and replenish coolant level
- Clean or replace cabin air filter
- Replace fuel filter
- Lubricate hinges
- Rotate tires and reset TPMS
- Inspect the following:
  - Engine for leaks
  - Exhaust for leaks
  - Transmission for leaks
  - Final drive(s) for leaks
  - Drive belts
  - All lighting
  - Horn operation
  - Ball joints and dust covers
  - Drive shaft boots
  - Drive axle play
  - Water drain for A/C
  - Engine air filter
  - Steering linkage and boots
  - Re-torque drive shaft bolt
  - Tighten nuts and bolts on chassis

30,000 MILES OR 36 MONTHS

(Same as 5,000 miles and 6 months) ***Plus:***

- Replace cabin filter
- Rotate tires and reset TPMS
- Replace engine air filter
- In addition, inspect the following:
  - Brake lines and hoses
  - Differential oil
  - Engine coolant
  - Exhaust pipes and mountings
  - Fuel lines and connections, fuel tank band and fuel tank vapor system hoses
  - Fuel tank cap gasket
  - Radiator core and condenser
  - Steering gear box
  - Steering linkage and boots
  - Transmission fluid or oil

Additional items for special operating conditions

(Same as 5,000 miles and 6 months)

45,000 MILES OR 54 MONTHS

(Same as 15,000 miles and 18 months)

Additional items for special operating conditions

(Same as 6,000 miles and 6 months)

60,000 MILES OR 72 MONTHS

(Same as 15,000 miles and 18 months) ***Plus:***

- Inspect:
  - Drive belts
  - Engine valve clearance

Additional items for special operating conditions

(Same as 6,000 miles and 6 months) ***Plus:***

- Replace differential oil
- Replace transmission oil or fluid

75,000 MILES OR 84 MONTHS

(Same as 15,000 miles and 18 months) ***Plus:***

- Check power-steering fluid
- Inspect:
  - Drive belts
  - Engine valve clearance

Additional items for special operating conditions

(Same as 6,000 miles and 6 months)

FIGURE 1–6 A typical preventive maintenance schedule.

not cover problems that result. For example, if the engine fails during the period covered by the warranty, the warranty may not cover the engine if the owner does not have proof that the engine's oil was changed according to the recommended schedule and with the correct oil.

Warranties A new car warranty is an agreement by the auto manufacturer to have its authorized dealers repair, replace, or adjust certain parts if they become defective. This agreement typically lasts until the vehicle has been driven 36,000 miles (58,000 km), and/or has been owned for 3 years. However, some manufacturers offer warranties that cover some systems as long as 100,000 miles (161,000 km) or 10 years.

The details of most warranties vary with the manufacturer, vehicle model, and year. Most manufacturers also provide a separate warranty for the powertrain (engine, transmission, and so on) that covers these parts for a longer period than the basic warranty. There are also additional warranties for other systems or components of the vehicle.

Often, according to the terms of the warranty, the owner must pay a certain amount of money called the **deductible**. The manufacturer pays for all repair costs over the deductible amount.

Battery and tire warranties are often prorated, which means that the amount of the repair bill covered by the warranty decreases over time. For example, a battery with a 72-month warranty fails after 60 months. The original price of the battery is divided by 72 and the cost per month is then multiplied by the months remaining in the warranty period. Some warranties are held by a third party, such as the manufacturer of the battery or tires. Although the manufacturer sold the vehicle with the battery or set of tires, their warranty is the responsibility of the maker of that part.

There are also two government-mandated warranties: the Federal Emissions Defect Warranty and the Federal Emissions Performance Warranty. The Federal Emissions Defect Warranty ensures that the vehicle meets all required emissions regulations and that the vehicle's emission control system works as designed and will continue to do so for 2 years or 24,000 miles. The warranty does not cover problems caused by accidents, floods, misuse, modifications, poor maintenance, or the use of leaded fuels. The systems typically covered by this warranty are:

- Air induction
- Fuel metering
- Ignition
- Exhaust
- Positive crankcase ventilation
- Fuel evaporative control
- Emission control system sensors

The Federal Emissions Performance Warranty covers the catalytic converter(s) and engine control module for a period of 8 years or 80,000 miles (129,000 km). If the owner properly maintains the vehicle and it fails an emissions test approved by the Environmental Protection Agency (EPA), an authorized service facility will repair or replace the emission-related parts covered by the warranty at no cost to the owner. Some states, such as California, require the manufacturers to offer additional or extended warranties.

The manufacturers of hybrid vehicles typically have a warranty on the vehicle's battery that covers 8 to 10 years and up to 100,000 miles (161,000 km). This is important because the batteries may cost thousands of dollars.

All warranty information can be found in the vehicle's owner's manual. Whenever there are questions about the warranties, carefully read that section in the owner's manual. If you are working on a vehicle and know that the part or system is covered under a warranty, make sure to tell the customer before proceeding with your work. Doing this will save the customer money and you will earn his or her trust.

Career Opportunities

Automotive technicians can enjoy careers in many different types of automotive businesses **(Figure 1–7)**. Because of the skills required to be a qualified technician, there are also career opportunities for those who do not want to repair automobiles the rest of their lives. The knowledge required to be a good technician can open many doors of opportunity.

Dealerships New car dealerships **(Figure 1–8)** serve as the link between the vehicle manufacturer and the customer. They are privately owned businesses. Most dealerships are franchised operations, which means the owners have signed a contract with particular auto manufacturers and have agreed to sell and service their vehicles.

The manufacturer usually sets the sales and service policies of the dealership. Most warranty repair work is done at the dealership. The manufacturer then pays the dealership for making the repair. The manufacturer also provides the service department at the dealership with the training, special tools, equipment, and information needed to repair its vehicles. The manufacturers also help the dealerships get service business. Often, their commercials

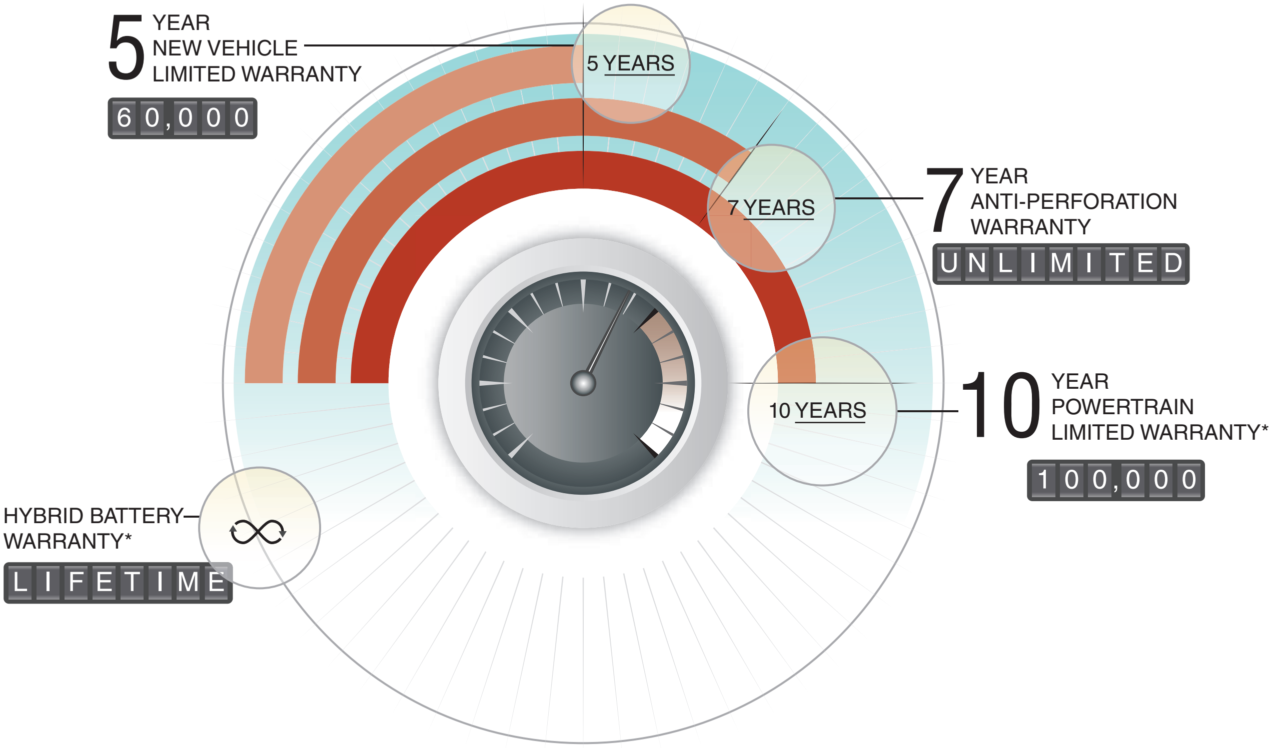


FIGURE 1–7 An example of different warranties all on one vehicle.

stress the importance of using their replacement parts and promote their technicians as the most qualified to work on their products.

Working for a new car dealership can have many advantages. Technical support, equipment, and the opportunity for ongoing training are usually excellent. At a dealership, you have a chance to become very skillful in working on the vehicles you service. However, working on one or two types of vehicles does not appeal to everyone. Some technicians want diversity.

Independent Service Shops Independent shops **(Figure 1–9)** may service all types of vehicles or may specialize in particular types of cars and trucks, or specific systems of a car. Independent shops outnumber dealerships by six to one. As the name states, an independent service shop is not associated with any particular automobile manufacturer. Many independent shops are started by technicians eager to be their own boss and run their own business.

FIGURE 1–8 Dealerships sell and service vehicles made by specific auto manufacturers.

FIGURE 1–9 Full-service gasoline stations are not as common as they used to be, but they are a good example of an independent service shop.

FIGURE 1–10 A bay in an independent service shop.

An independent shop may range in size from a two-bay garage with two to four technicians to a multiple-bay service center with twenty to thirty technicians. A bay is simply a work area for a complete vehicle **(Figure 1–10)**. The amount of equipment in an independent shop varies; however, most are well equipped to do the work they do best. Working in an independent shop may help you develop into a well-rounded technician.

Specialty shops specialize in areas such as engine rebuilding, transmission overhauling, and air conditioning, brake, exhaust, cooling, emissions, and electrical work. A popular type of specialty shop is the "quick lube" shop, which takes care of the PM of vehicles. It hires lubrication specialists who change fluids, belts, and hoses in addition to checking certain safety items on the vehicle.

The number of specialty shops that service and repair one or two systems of the automobile have steadily increased over the past 10 to 20 years. Technicians employed by these shops have the opportunity to become very skillful in one particular area of service.

Franchise Repair Shop A great number of jobs are available at service shops that are run by large companies such as Firestone, Goodyear, and Midas. These shops do not normally service and repair all of the systems of the automobile. However, their customers do come in with a variety of service needs. Technicians employed by these shops have the opportunity to become very proficient in many areas of service and repair.

FIGURE 1–11 Independent repair shops are often affiliated with a large business. In these arrangements, the shops are still run independently.

Some independent shops may look like they are part of a franchise but are actually independent. Good examples of this type of shop are the NAPA service centers **(Figure 1–11)**. These centers are not controlled by NAPA, nor are they franchises of NAPA. They are called NAPA service centers because the facility has met NAPA's standards of quality and the owner has agreed to use NAPA as the primary source of parts and equipment.

Store-Associated Shops Other major employers of auto technicians are the service departments of department stores. Many large stores that sell automotive parts often offer certain types of automotive services, such as brake, exhaust system, and wheel and tire work.

Fleet Service and Maintenance Any company that relies on several vehicles to do its business faces an ongoing vehicle service and PM problem. Small fleets often send their vehicles to an independent shop for maintenance and repair. Large fleets, however, usually have their own PM and repair facilities and technicians **(Figure 1–12)**.

Utility companies (such as electric, telephone, or cable TV), car rental companies, overnight delivery services, and taxicab companies are good examples of businesses that usually have their own service departments. These companies normally purchase their vehicles from one manufacturer. Technicians who work on these fleets have the same opportunities and benefits as technicians in a dealership. In fact, the technicians of some large fleets are authorized to do warranty work for the manufacturer. Many good career opportunities are available in this segment of the auto service industry.

FIGURE 1–12 Large fleets usually have their own preventive maintenance and repair facilities and technicians.

Job Classifications

The automotive industry offers numerous types of employment for people with a good understanding of automotive systems.

Service Technician

A service technician **(Figure 1–13)** diagnoses vehicle problems, performs all necessary tests, and competently repairs or replaces faulty components. The skills to do this job are based on a sound understanding of auto technology, on-the-job experience, and continuous training in new technology as it is introduced by auto manufacturers.

Individuals skilled in automotive service are called technicians, not mechanics. There is a good reason for this. *Mechanic* stresses the ability to repair and service mechanical systems. While this skill is still very much needed, it is only part of the technician's overall job. Today's vehicles require mechanical knowledge plus an understanding of other technologies, such as electronics, hydraulics, and pneumatics.

A technician may work on all systems of the car or may become specialized. Specialty technicians concentrate on servicing one system of the automobile, such as electrical, brakes **(Figure 1–14)**, or transmission. These specialties

FIGURE 1–13 A service technician troubleshoots problems, performs all necessary diagnostic tests, and competently repairs or replaces faulty components.

FIGURE 1-14 Specialty technicians work on only one vehicle system, such as brakes.

require advanced and continuous training in that particular field.

In many automotive shops, the technician also has the responsibility for diagnosing the concerns of the customer and preparing a cost estimate for the required services.

Often individuals begin their career as a technician in a new car dealership by performing new car preparation, commonly referred to as "new car prep." The basic purpose of new car prep is to make a vehicle ready to be delivered to a customer. Each dealership has a list of items and services that are performed prior to delivery. Some of the services may include removing the protective plastic from the vehicle's exterior and interior and installing floor mats. At times, new car prep includes tightening certain bolts that may have been intentionally left loose for shipping. New car prep is a great way for a new technician to become familiar with the vehicles sold at the dealership.

Shop Foreman

The **shop foreman** is the one who helps technicians with more difficult tasks and serves as the quality control expert. In some shops, this is the role of the lead tech. For the most part, both jobs are the same. Some shops have technician teams. On these teams, there are several technicians, each with a different level of expertise. The lead tech is sort of the shop foreman of the team. Lead techs and shop foremen have a good deal of experience and excellent diagnostic skills.

Service Advisor

The person who greets customers at a service center is the **service advisor (Figure 1–15)**, sometimes called a service writer or consultant. Service advisors need to have an understanding of all major systems of an automobile and be able to identify all major components and their locations. They also must be able to describe the function of each of those components and be able to identify related components. A good understanding of the recommended service and maintenance intervals and procedures is also required. With this knowledge they are able to explain the importance and complexity of each service and are able to recommend other services.

A thorough understanding of warranty policies and procedures is also a must. Service advisors

FIGURE 1-15 A service advisor's main job is to record the customer's concerns.

must be able to explain and verify the applicability of warranties, service contracts, service bulletins, and campaign/recalls procedures.

Service advisors also serve as the liaison between the customer and the technician in most dealerships. They have responsibility for explaining the customer's concerns and/or requests to the technician plus keeping track of the progress made by the technician so the customer can be informed. At times, automotive technicians or students of automotive service programs desire a change in career choices but want to stay in the service industry. Becoming a service writer, advisor, or consultant is a good alternative. This job is good for those who have the technical knowledge but lack the desire or physical abilities to physically work on automobiles.

Many of the requirements for being a successful technician apply to being a successful service consultant. However, being a service consultant requires greater skill levels in customer relations, internal communication and relations, and sales. Service consultants must communicate well with customers, over the telephone or in person, in order to satisfy their needs or concerns. Most often this involves the completion of a repair order, which contains the customer's concerns and information and a cost estimate.

Accurate estimates are not only highly appreciated by the customer, but they are also required by law in nearly all states. Writing an accurate estimate requires a solid understanding of the automobile, good communications with the technicians, and good reading and math skills.

Most shops use computers to generate the repair orders and estimates and to schedule the shop's workload. Therefore, having solid computer skills is a must for service advisors.

Service Manager

The service manager is responsible for the operation of the entire service department at a large dealership or independent shop. Normally, customer concerns and complaints are handled by the service manager. Therefore, a good service manager has good people skills in addition to organizational skills and a solid automotive background.

In a dealership, the service manager makes sure the manufacturers' policies on warranties, service procedures, and customer relations are carried out. The service manager also arranges for technician training and keeps all other shop personnel informed and working together.

Service Director

Large new car dealerships often have a service director who oversees the operation of the service and parts departments as well as the body shop. The service director has the main responsibility of keeping the three departments profitable. The service director coordinates the activities of these separate departments to ensure efficiency.

Many service directors began their career as technicians. As technicians they demonstrated a solid knowledge of the automotive field and had outstanding customer relations skills and good business sense. The transition from technician to director typically involves promotion to various other managerial positions first.

Parts Counterperson

A parts counterperson **(Figure 1–16)** can have different duties and is commonly called a parts person or specialist. Parts specialists are found in nearly all automotive dealerships and auto parts retail and wholesale stores. They sell auto parts directly to customers and hand out materials and supplies to technicians working in automotive service facilities and body shops. A parts counterperson must be friendly, professional, and efficient when working with all customers, both on the phone and in person.

Depending on the parts store or department, duties may also include delivering parts, purchasing parts, maintaining inventory levels, and issuing parts to customers and technicians. Responsibilities include preparing purchase orders, scheduling deliveries, assisting in the receipt and storage of parts

FIGURE 1–16 A parts counterperson has an important role in the operation of a store or dealership.

and supplies, and maintaining contact with vendors. An understanding of automotive terminology and systems and good organizational skills are a must for parts counterpersons.

This career is an excellent alternative for those who know about cars but would rather not work on them. Much of the knowledge required to be a technician is also required for a parts person. However, a parts specialist requires a different set of skills. Most automotive parts specialists acquire the sales and customer service skills needed to be successful primarily through on-the-job experience and training. They may also gain the necessary technical knowledge on the job or through educational programs and/or experience. To better understand the world of the parts industry refer to **Figure 1–17**, which defines the common terms used by parts personnel.

Parts Manager

The parts manager is in charge of ordering all replacement parts for the repairs the shop performs. The ordering and timely delivery of parts is extremely important for the smooth operation of the shop. Delays in obtaining parts or omitting a small but crucial part from the initial parts order can cause frustrating holdups for both the service technicians and customers.

Most dealerships and large independent shops keep an inventory of commonly used parts, such as filters, belts, hoses, and gaskets. The parts manager is responsible for maintaining this inventory.

Related Career Opportunities

In addition to careers in automotive service, there are many other job opportunities directly related to the automotive industry.

Parts Distribution

The **aftermarket** refers to the network of businesses **(Figure 1–18)** that supplies replacement parts to independent service shops, car and truck dealerships, fleet operations, and the general public.

Vehicle manufacturers and independent parts manufacturers sell and supply parts to approximately a thousand warehouse distributors throughout the United States. These **warehouse distributors (WDs)** carry substantial inventories of many part lines.

Warehouse distributors serve as large distribution centers. WDs sell and supply parts to parts wholesalers, commonly known as jobbers.

Jobbers sell parts and supplies to shops and do-it-yourselfers. Jobbers often have a delivery service that gets the desired parts to a shop shortly after it ordered them. Some parts stores focus on individual or walk-in customers. These businesses offer the do-it-yourselfers repair advice, and some even offer testing of old components. Selling good parts at a reasonable price and offering extra services to their customers are the characteristics of successful parts stores. Many jobbers operate machine shops that offer another source of employment for skilled technicians. Jobbers or parts stores can be independently owned and operated. They can also be part of a larger national chain **(Figure 1–19)**. Auto manufacturers have also set up their own parts distribution systems to their dealerships and authorized service outlets. Parts manufactured by the original vehicle manufacturer are called **original equipment manufacturer (OEM)** parts.

Opportunities for employment exist at all levels in the parts distribution network, from warehouse distributors to the counter people at local jobber outlets.

Marketing and Sales

Companies that manufacture equipment and parts for the service industry are constantly searching for knowledgeable people to represent and sell their products. For example, a sales representative working for an aftermarket parts manufacturer should have a good knowledge of the company's products. The sales representative also works with WDs, jobbers, and service shops to make sure the parts are being sold and installed correctly. They also help coordinate training and supply information so that everyone using their products is properly trained and informed.

Other Opportunities

Other career possibilities for those trained in automotive service include automobile and truck recyclers, insurance company claims adjusters, auto body shop technicians, and trainers for the various manufacturers or instructors for an automotive training or educational program **(Figure 1–20)**. The latter two careers require solid experience and a thorough understanding of the automobile. It is not easy being

ACCOUNTS RECEIVABLE	Money due from a customer.	PERPETUAL INVENTORY	A method of keeping a continuous record of stock on-hand through sales receipts and/or invoices.
BACK ORDER	Parts ordered from a supplier that have not been shipped to the store or shop because supplier has none in their inventory.	PHYSICAL INVENTORY	The process whereby each part is manually counted and the number on-hand is written on a form or entered into a computer.
BILL OF LADING	A shipping document acknowledging receipt of goods and stating terms of delivery.	PROFIT	The amount received for goods or services above the shop's or store's cost for the part or service.
CORE CHARGE	A charge that is added when a customer buys a remanufactured part. Core charges are refunded to the customer when he or she returns a rebuildable part.	PURCHASE ORDER	A form giving someone the authority to purchase goods or services for a company.
DEALERS	The jobber's wholesale customers, such as service stations, garages, and car dealers, who install parts in their customers' vehicles.	REMANUFAC-TURED PART	A part that has been reconditioned to its original specifications and standards.
DISCOUNT	The amount of savings being offered to a customer, this is normally expressed as a percentage.	RESTOCKING FEE	The fee charged by a store or supplier for having to handle a returned part.
DISTRIBUTOR	A large volume parts stocking business that sells to wholesalers.	RETAIL	Selling merchandise to "walk-in" trade (do-it-yourselfers).
FREIGHT CHARGE	A charge added to special order parts to cover their transportation to the store.	RETURN POLICY	A policy regarding the return of unwanted and unneeded parts. Return policies may include restocking fees or prohibit the return of certain parts.
GROSS PROFIT	The selling price of a part minus its cost (called referred to the margin).	SELLING PRICE	The price at which a part is sold. This price will vary according to the type of customer (retail or wholesale) that is purchasing the part.
INVENTORY	The parts a store or shop has in its possession for resale.	SPECIAL ORDER	An order placed whenever a customer purchases an item not normally kept in stock.
INVENTORY CONTROL	A method of determining amounts of merchandise to order based on supplies on-hand and past sales of the item.	STOCK ORDER	A process by which the store orders more stock from its suppliers in order to maintain its inventory.
INVOICE	The record of a sale to a customer.	STOCK ROTATION	Selling the older stock on-hand before selling the newer stock.
LIST PRICE	The suggested selling price for an item.	TURNOVER	The number of times each year that a business buys, sells, and replaces a part.
MARGIN	Same as gross profit.	VENDOR	The supplier.
MARK-UP	The amount a business charges for a part above the actual cost of the part.	WARRANTY RETURN	A defective part returned to the supplier due to failure during its warranty period.
NO-RETURN POLICY	A store policy that certain parts cannot be returned after purchase. It is common to have a no-return policy on electrical and electronic parts.	WAREHOUSE DISTRIBUTOR	The jobber's supplier who is the link between the manufacturer and the jobber.
ON-HAND	The quantity of an item that the store or shop has in its possession.	WHOLESALE PRICE	The business' price to large volume customers.

FIGURE 1–17 Some of the common terms used by parts personnel.

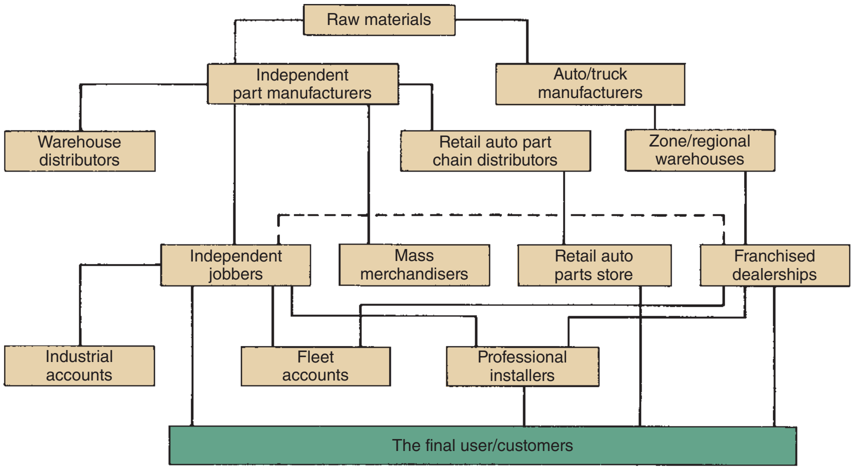


FIGURE 1–18 The auto parts supply network.

FIGURE 1–19 Many parts stores are part of a national corporation with stores located across the country.

an instructor or trainer; however, passing on knowledge can be very rewarding. Undoubtedly, there is no other career that can have as much impact on the automotive service industry as that of a trainer or instructor.

Training for a Career in Automotive Service

Those interested in a career in auto service can receive training in formal school settings—secondary, postsecondary, and vocational schools; and technical or community colleges, both private and public.

Student Work Experience

There are many ways to gain work experience while you are a student. You may already be involved in one of the following; if not, consider becoming involved in one of these programs.

FIGURE 1–20 A career possibility for an experienced technician is that of a trainer for the various manufacturers or instructors for an automotive program.

Job Shadowing Program In this program you follow an experienced technician or service writer. The primary objective is to expose you to the "real world," to see what it takes to be a successful technician or service writer. By job shadowing, you will also become familiar with the total operation of a service department.

Mentoring Program This program is not the most common program, but it can be one of the most valuable. In a mentoring program, you experience the duties and responsibilities of a technician while you have someone who is successful to use as an expert. Your mentor has agreed to stay in contact with you, to answer questions, and to encourage you. When you have a good mentor, you have someone who may be able to explain things a little differently than the way things are explained in class. A mentor may also be able to give real life

examples of why some of the things you need to learn are important.

Cooperative Education and Apprenticeship Programs These programs are typically 2 years in length. One year is spent in school and the other in a dealership or service facility. This does not mean that 1 solid year is spent in school; rather in a cooperative program you spend 8 to 12 weeks at school, and then work for 8 to 12 weeks. The switching back and forth continues for 2 years. Not only do you earn an hourly wage while you are working, you also earn credit toward your degree or diploma. Your work experiences are carefully coordinated with your experiences at school; therefore, it is called a cooperative program—industry cooperates with education. Examples of this type of program are the Chrysler CAPS, Ford ASSET, GM ASEP, and Toyota T-Ten (in Canada these are called T-TEP) programs.

An apprenticeship program combines work experiences with education. The primary difference between the two programs is that in an apprenticeship program students attend classes in the evening after completing a day's work. During this rigorous training program, you receive a decent hourly wage and plenty of good experience. You start the program as a helper to an experienced technician and can begin to do more on your own as you progress through the program. In both cases, while you work you get a chance to practice what you learned in school.

Part-Time Employment The success of this experience depends on you and your drive to learn. Working part-time will bring you good experience, some income, and a good start in getting a great full-time position after you have completed school. The best way to approach this is to find a position and service facility that will allow you to grow. You need to start at a right level and be able to take on more difficult tasks when you are ready. The most difficult challenge when working part-time is to keep up with your education while you are working. Many times work may get in the way, but if you truly want to learn, you will find a way to fit your education around your work schedule.

Postgraduate Education A few manufacturer programs are designed for graduates of postsecondary schools. These programs train individuals to work on particular vehicles. For example, BMW's Service Technician Education Program (STEP) is a scholarship program for the top graduates of automotive postsecondary schools. Students in the program apply what they learned in their 2-year program and learn to diagnose and service BMW products. BMW says this program is the most respected and intense training program of its kind in the world. For more information go to http://www.bmwstep.com.

The Need for Continuous Learning

Training in automotive technology and service does not end with graduation nor does the *need to read* end. A professional technician constantly learns and keeps up to date. In order to maintain your image as a professional and to keep your knowledge and skills up to date, you need to do what you can to learn new things. You need to commit yourself to lifelong learning.

There are many ways in which you can keep up with the changing technology. Short courses on specific systems or changes are available from the manufacturers and a number of companies that offer formal training, such as Federal Mogul, NAPA, AC Delco, and local parts jobbers. There are also many online sources available, from companies like those listed above to many that specialize in technician training. It is wise to attend update classes as soon as you can. If you wait too long, you may have a difficult time catching up with the ever-changing technologies.

In addition to taking classes, you can learn by reading automotive magazines or the newest editions of automotive textbooks. A good technician takes advantage of every opportunity to learn.

ASE Certification

The National Institute for **Automotive Service Excellence (ASE)** has established a voluntary certification program for automotive, heavy-duty truck, and auto body repair technicians along with parts specialist certifications. In addition to these programs, ASE also offers individual testing in the areas of automotive and heavy-duty truck parts, service consultant, alternate fuels, advanced engine performance, and a variety of other areas. This certification system combines voluntary testing with on-the-job experience to confirm that technicians have the skills needed to work on today's more complex vehicles. ASE recognizes two distinct levels of service capability—the automotive technician and the master automotive technician. The master automotive technician is certified by ASE in all major automotive systems.

To become ASE certified, a technician must pass one or more tests that stress system diagnosis and repair procedures. The eight basic certification areas in automotive repair follow:

1. Engine repair
2. Automatic transmission/transaxle
3. Manual transmissions and drive axles
4. Suspension and steering
5. Brakes
6. Electrical systems
7. Heating and air conditioning
8. Engine performance (driveability)

After passing at least one exam and providing proof of 2 years of hands-on work experience, the technician becomes ASE certified. Retesting is necessary every 5 years to remain certified. A technician who passes one examination receives an automotive technician shoulder patch. The master automotive technician patch is awarded to technicians who pass all eight of the basic automotive certification exams **(Figure 1–21)**.

ASE also offers advanced-level certification in some areas. The most common advanced certification for automobile technicians is the L1 or Advanced Engine Performance. Individuals seeking this certification must be certified in Electricity and Engine Performance before taking this exam. Another advanced certification is the Electronic Diesel Engine Diagnosis Specialist (L2). To receive this certification, a technician must be currently certified in one of the ASE Diesel Engine areas and one of the ASE Electrical/Electronic Systems areas.

ASE also offers specialist certifications. For example, you can become certified in Undercar–Exhaust Systems, Light Vehicle Diesel, Engine Machining, Alternative Fuels, Collision Repair, or as a Parts Counterperson or a Service Consultant. Go to: *www.ase.com* for more information.

FIGURE 1–21 ASE certification shoulder patches worn by (*left*) automotive technicians and (*right*) master automotive technicians.

As mentioned, ASE certification requires that you have 2 years of full-time, hands-on working experience as an automotive technician. You may receive credit toward this 2-year experience requirement by completing formal training in one or a combination of high school or post–high school education, short technical courses, and cooperative or apprenticeship programs.

In 2012, ASE began offering ASE Student Certification tests. These are computer-based tests available in the spring and fall each year for students enrolled in any automotive technology program. Tests are available for automotive, collision repair and refinishing, and medium/heavy-duty truck. Each certification is valid for 2 years from the date taken.

ASE Tests

ASE tests are designed to check your understanding of how automotive systems and components operate as well as your ability to diagnose problems and determine the correct repairs. Certification tests contain between 40 and 75 multiple-choice questions. Question types include the following:

- Direct, most likely, or completion questions
- Technician A/Technician B questions
- *Except* or *least likely* questions

The questions are written by a panel of technical service experts, including domestic and import vehicle manufacturers, repair and test equipment and parts manufacturers, working automotive technicians, and automotive instructors. All questions are pretested and quality checked on a national sample of technicians before they are included in the actual test. Many test questions force the student to choose between two distinct repair or diagnostic methods. Examples of these questions are included at the end of each chapter.

When taking ASE-style tests, first read the entire question to determine what the subject or intent of the question is about. Next, try to eliminate possible choices based on your knowledge and experience and choose the answer that seems the most likely. Technician A/Technician B questions can be treated as two separate True/False questions; is Technician A correct? Yes or No. Is Technician B correct? Yes or No. Once you have answered all the questions, you

can go back and review your answers before submitting the test. Be careful to not overthink and talk yourself out of an answer by thinking of all possible exceptions to the question.

ASE Education Foundation Program Accreditation

While each automotive program is different, most share some similarities. Many high school programs and many post-secondary schools have been evaluated and are accredited by the ASE Education Foundation. To become accredited by the ASE Education Foundation, a program must show documentation of what is covered in the program and the amount of time spent in each of the ASE areas. The programs must also pass an onsite evaluation. Accredited programs display the sign shown in **Figure 1–22**. This means the school is teaching the competencies and to the standards prescribed by ASE. Because of this standardization, all of the core skills taught in each and every certified program is the same. More information can be found at www.asealliance.org.

FIGURE 1–22 A sign showing an automotive program is ASE certified.

KEY TERMS

Aftermarket
Automotive Service Excellence (ASE)
Deductible
Jobbers
Original equipment manufacturer (OEM)
Preventive maintenance (PM)
Service advisor
Shop foreman
Warehouse distributors (WDs)

SUMMARY

- The auto industry is a global industry involving vehicle and parts manufacturers from many countries.
- Electronic controls are found in most auto systems, including engines, transmissions, brakes, steering systems, and suspensions. Preventive maintenance is extremely important in keeping today's vehicles in good working order.
- New car dealerships, independent service shops, specialty service shops, fleet operators, and many other businesses are in great need of qualified service technicians.
- A solid background in auto technology may be the basis for many other types of careers within the industry. Some examples are parts management, collision damage appraisal, sales, and marketing positions.
- Training in auto technology is available from many types of secondary, vocational, and technical schools. Auto manufacturers also have cooperative programs with schools to ensure that graduates understand modern systems and the equipment to service them.
- The National Institute for Automotive Service Excellence (ASE) actively promotes professionalism within the industry. Its voluntary certification program for automotive technicians and master automotive technicians helps guarantee a high level of quality service.
- The ASE certification process involves both written tests and credit for on-the-job experience. Testing is available in many areas of auto technology.

REVIEW QUESTIONS

Short Answer

1. List at least five different types of businesses that hire technicians. Describe the types of work these businesses handle and the advantages and disadvantages of working for them.
2. Name the different ways to gain work experience while you are a student.
3. Explain the implied difference between someone who is called a mechanic and one who is called an automotive technician.
4. Explain the basic requirements for becoming a successful automotive technician.

Multiple Choice

1. Which of the following have had a significant impact on the automotive industry?
   a. Emission laws
   b. Electronics
   c. New technologies
   d. All of the above
2. Individuals often begin a career as an automotive technician in a new car dealership by ___, which is a good way for a new technician to become familiar with the vehicles sold at the dealership.
   a. working at the parts counter
   b. performing new car prep
   c. being a service advisor
   d. serving as the lead tech
3. Technician A says a hybrid vehicle uses two different power sources. Technician B says a hybrid vehicle may use either a gas engine or electric motor to drive the wheels. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. The government-mandated warranty that specifically covers the catalytic converter(s) and engine control module is the ___.
   a. Federal Emissions Defect Warranty
   b. Federal Powertrain Warranty
   c. Federal Emissions Performance Warranty
   d. Extended Federal Exhaust Warranty
5. Which of the following is typically included in a scheduled preventive maintenance program?
   a. Oil and filter changes
   b. Coolant and lubrication services
   c. Replacement of filters
   d. All of the above
6. In a large new car dealership, the individual who oversees the operation of the service department, parts department, and body shop is the ___.
   a. service manager
   b. service director
   c. shop foreman
   d. parts manager
7. Repair work performed on vehicles still under the manufacturer's warranty is usually performed by ___.
   a. independent service shops
   b. dealerships
   c. specialty shops
   d. Either A or B
8. Which of the following businesses perform work on only one or two automotive systems?
   a. Dealerships
   b. Independent service shops
   c. Specialty shops
   d. Fleet service departments
9. Normally, whose job is it to greet the customer and complete the repair or work order?
   a. Service manager
   b. Parts manager
   c. Automotive technician
   d. Service advisor
10. Technician A says that *all* an individual needs to do in order to become certified by ASE in a particular area is to pass the certification exam in that area. Technician B says that the questions on an ASE exam often force the test taker to choose between two distinct repair methods. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

11. To be successful, today's automotive technician must have ___.
    a. an understanding of electronics
    b. the ability to repair and service mechanical systems
    c. the dedication to always be learning something new
    d. All of the above
12. A technician must have a minimum of ___ year(s) of hands-on work experience to get ASE certification.
    a. 1
    b. 2
    c. 3
    d. 4
13. An experienced technician who passes all eight basic ASE automotive certification tests is certified as a(n) ___.
    a. automotive technician
    b. master automotive technician
    c. service manager
    d. parts manager
14. Technician A says battery warranties are often prorated. Technician B says some warranties have a deductible. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
15. Wholesale auto parts stores that sell aftermarket parts and supplies to service shops and the general public are called ___.
    a. warehouse distributors
    b. mass merchandisers
    c. jobbers
    d. freelancers
16. Ongoing technical training and support is available from ___.
    a. aftermarket parts manufacturers
    b. auto manufacturers
    c. online resources
    d. All of the above

WORKPLACE SKILLS

CHAPTER 2

OBJECTIVES

- Develop a personal employment plan.
- Seek and apply for employment.
- Prepare a resume and cover letter.
- Prepare for an employment interview.
- Accept employment.
- Understand how automotive technicians are compensated.
- Understand the proper relationship between an employer and an employee.
- Explain the key elements of on-the-job communications.
- Be able to use critical thinking and problem-solving skills.
- Explain how you should look and act to be regarded as a professional.
- Explain how fellow workers and customers should be treated.

This chapter gives an overview of what you should do to get a job and how to keep it. The basis for this discussion is respect—respect for yourself, your employer, fellow employees, your customers, and everyone else. Also included in this discussion are the key personal characteristics required of all seeking to be successful automotive technicians and employees.

Seeking and Applying for Employment

Becoming employed, especially in the field in which you want a career, involves many steps. As with many things in life, you must be adequately prepared before taking the next step toward employment. This discussion suggests ways you can prepare and what to expect while taking these steps.

Employment Plan

An employment plan is nothing more than an honest appraisal of yourself and your career hopes. The plan should include your employment goals, a timetable for reaching those goals, and a prioritized list of potential employers or types of employers. You may need to share your employment plan with someone while you are seeking employment, so make sure it is complete. Even if no one else will see it, you should be as thorough as possible because it will help keep you focused during your quest for employment.

Think about the type of job you want and do some research to find out what is required to get that

job. Evaluate yourself against those requirements. If you do not meet the requirements, set up a plan for obtaining the needed skills. Also, consider the working conditions of that type of job. Are you willing and able to be a productive worker in those conditions? If not, find a job that is similar to your desires and pursue that career.

Self-Appraisal To begin the self-appraisal part of your employment plan, ask yourself:

- Why am I looking for a job?
- What specifically do I hope to gain by having a job?
- What do I like to do?
- What am I good at?
- Which of my skills would I like to use in my job?
- What skills do I currently have that would make me employable?

By honestly answering these questions, you should be able to identify the jobs that will help you meet your goals. If you are just seeking a job to pay bills or buy a car and have no intention of turning this job into a career, be honest with yourself and your potential employer. If you are hoping to begin a successful career, realize you will probably start at the bottom of the ladder to success. You must also realize that how quickly you climb the ladder is your responsibility. An employer's responsibility is merely to give you a fair chance to climb it.

Identifying Your Skills Honestly evaluate yourself and your life to determine what skills you have. Even if you have never had a job, you still have skills and talents that can make you a desirable employee. Make a list of all of the things you have learned from your school, friends, and family and through television, volunteering, books, hobbies, and so on. You may be surprised by the number of skills you have. Identify these skills as being either technical or personal skills.

Technical skills include things you can do well and enjoy, such as:

- Using a computer
- Working with tools, machines, or equipment
- Doing math problems
- Maintaining or fixing things
- Figuring out how things work
- Making things with your hands
- Working with ideas and information
- Solving puzzles or problems
- Studying or reading
- Doing experiments or researching a topic
- Expressing yourself through writing

Personal skills are also called soft skills and are things that are part of your personality. These are things you are good at or enjoy doing, such as:

- Working with people
- Caring for or helping people
- Working as a member of a team and independently
- Leading or supervising others
- Following orders or instructions
- Persuading people
- Negotiating with others

By identifying these skills, you will have created your personal skills inventory. From the inventory you should match your skills and personality to the needs and desires of potential employers. The inventory will also come in handy when marketing yourself for a job, such as when preparing your resume and cover letter and during an interview.

Identifying Job Possibilities

One of the things you identified in your employment plan was your preferred place to work. This may have been a specific business or a type of business, such as a new car dealership or independent shop. Now your task is to identify the companies that are looking for someone. There are many ways of doing this, including the following:

- Checking your school's job posting board or with a placement coordinator
- Searching job websites, such as monster.com and indeed.com
- Checking the employment web pages of local business for job openings **(Figure 2–1)**

You can also ask people you know who already work in the business. If there is nothing available in the business you prefer, look for openings in the type of business that was second on your priority list.

Do not limit your job search to just looking at help wanted ads or websites. If you are interested in working at a particular shop, visit the shop and talk to people who work there. Speak with the manager about being in an automotive program and about current or forthcoming job openings. If a job is not currently available, you may be able to intern in the

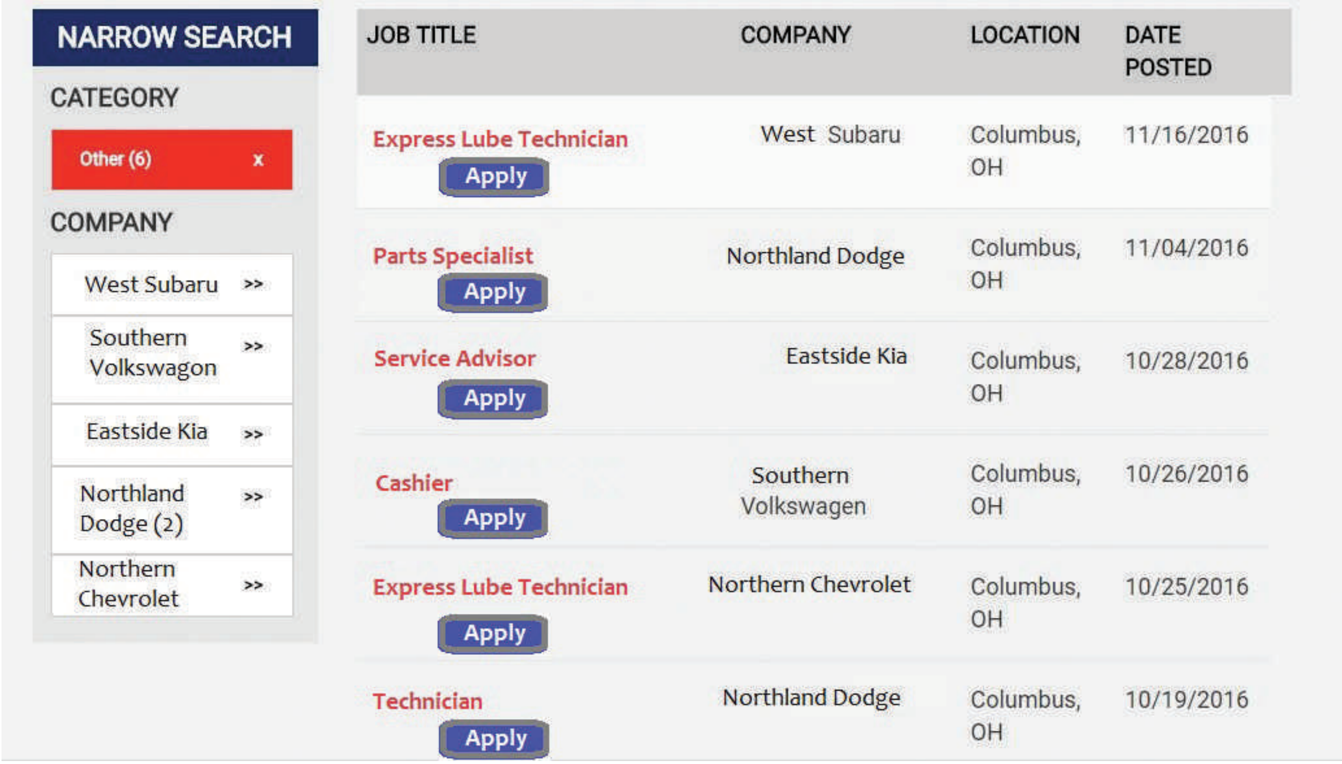


FIGURE 2-1 Check the employment or career sections of websites for businesses that are looking for technicians.

shop, without pay, but as a way to gain experience and to be ready when the next opening occurs.

Carefully look at the description of the job. Make sure you meet the qualifications for the job before you apply. For example, if you have a drug problem and the ad states that all applicants will be drug tested, you should not bother applying and should concentrate on breaking the habit. Even if the ad says nothing about testing for drug use, you should know that there is no place for drugs at work and continued drug use will only jeopardize your career.

Driving Record Your driving record is something you must also be aware of, and you probably are. If you have a poor record, you may not be considered for a job that requires operating a vehicle. In the same way that a driving record affects your personal car insurance, the employer's insurance costs can also increase because of your poor driving record. A bad driving record or the loss of a driver's license can get in the way of getting or keeping a job.

Also, if you have been convicted or have been arrested, be prepared to let the employer know what happened and what you learned from the experience. If you have been convicted of a felony, the employer must know. Failure to disclose this will cost you the job.

Preparing Your Resume

Your **resume** and cover letter are your own personal marketing tools and may be an employer's first look at you. Although not all employers require a resume, you should prepare one for those that do. Preparing a resume also forces you to look at your qualifications for a job. That alone justifies having a resume.

Keep in mind that although you may spend hours writing and refining your resume, an employer may only take a minute or two from his or her busy schedule to look it over. With this in mind, put together a resume that tells the employer who you are in such a way that he or she wants to interview you.

A resume normally includes your contact information, career objective, skills and/or accomplishments, work experience, education, and a statement about references. There are different formats you can follow when designing your resume. If you have limited work experience, make sure the resume emphasizes your skills and accomplishments rather than work history. Even if you have no work experience, you can sell yourself by highlighting some of the skills and attributes you identified in your employment plan.

When listing or mentioning your attributes and skills, express them in a way that shows how they

relate to the job you are seeking. For instance, if you practice every day at your favorite sport so that you can make the team, you may want to describe yourself as being persistent, determined, motivated, and goal-oriented. Another example is if you have ever pulled an all-nighter to get an assignment done on time, it can mean that you work well under pressure and always get the job done. Another example would be if you keep your promises and do what you said you would do, you may want to describe yourself as reliable, a person who takes commitment seriously.

Identifying your skills may be a difficult task, so have your family and/or friends help you. Keep in mind that you have qualities and skills that employers want. You need to recognize them, put them in a resume, and tell them to your potential employer. Do not put the responsibility of figuring out who you are on the employers—tell them.

Figure 2–2 is an example of a basic resume for an individual seeking an entry-level position as a technician.

Putting Together an Effective Resume Follow these guidelines while preparing and writing your resume:

- Make sure your resume is neat, uncluttered, and easy to read.
- Use quality white paper.
- Keep it short—one page is best.

Jack Erjavec
1234 My Street
Somewhere, OZ 99902
123-456-7890

Performance oriented student, with an excellent reputation as a responsible and hard-working achiever, seeking a position as an entry-level automotive technician in a new car dealership.

Skills and Attributes

- People oriented
- Motivated
- Committed
- Honest
- Reliable
- Creative problem-solver
- Good hand skills

Work Experience

2015–2017 Somewhere Soccer Association (Assistant coach)
- Instructed and supervised junior team
- Performed administrative tasks as the Coach required

2013–2017 Carried out various odd jobs within the community
- Washing and waxing cars, picking up children from school, raking leaves, cutting grass

Education

Somewhere Senior High School, graduated in 2017
Somewhere Community College, currently enrolled in the Automotive Technology Program

Extracurricular Activities

2014–2017 Active member of the video game club
2016–2017 Member of the varsity soccer team

Hobbies and activities

Reading auto-related magazines, going to races, doing puzzles, working on cars with family and friends.

References

Available upon request.

FIGURE 2–2 A sample of a resume for someone who has little work experience.

- Let the resume tell your story, but do not try to oversell yourself.
- Use dynamic words to describe your skills and experience, such as accomplished, achieved, communicated, completed, created, delivered, designed, developed, directed, established, founded, instructed, managed, operated, organized, participated, prepared, produced, provided, repaired, and supervised.
- Choose your words carefully; remember that the resume is a look at you.
- Make sure all information is accurate.
- Make sure the information you think is the most important stands out and is positioned near the top of the page.
- Design your resume with a clean letter type (font) and wide margins (1½ inches on both sides is good) so that it is easy on the eyes.
- Only list the "odd" jobs you had if they are related to the job you are applying for.
- Do not repeat information.
- Proofread the entire resume to catch spelling and grammatical errors. If you find them, fix them and print a new, clean copy.

Digital Portfolios

Digital portfolios or online resumes are increasingly becoming more common as people and business move from paper to digital communication. A digital portfolio typically contains a personal mission statement, your resume, references, and examples of your work. Examples of your work may include pictures or short videos of you performing certain tasks as evidence of your skills and knowledge. Other evidence may include examples of assignments you did particularly well on or scanned copies of certifications you have acquired.

Many web hosting sites, such as Wix.com, Weebly, and VisualCV, offer free basic web pages and resume building services. When building your site, a simple, clean, and uncluttered look is more professional looking and easier to read than one crammed with images, crazy colors and fonts. You want potential employers visiting your site to be able to quickly and easily learn about you and your skills and not have to strain to read the content.

References

A **reference** is someone who will be glad to tell a potential employer about you. A reference can be anyone who knows you, other than a family member or close friend. Employers contact references to verify or complete their picture of you. Make a list of three to five people you can use as references, including their contact information. If you do not supply references, the potential employer may assume that you cannot find anyone who has anything nice to say about you. You probably will not be considered for the job.

Choose your references wisely. Teachers (past and present), coaches, and school administrators are good examples of who you can ask to be a reference. People you have worked for or have helped are also good references. Try also to get someone whose opinion is respected, such as a priest, minister, or elder in your church or someone you know well who holds a high position.

Always talk to your references first, and get permission to give their names and telephone numbers to an employer. If they do not seem comfortable with giving you a reference, take the hint and move on to someone else. If someone is willing to provide you with a written reference, make several copies of the letter so that you can attach them to your resume and/or job application. Give copies of your resume to those on your reference list. Make sure to bring your reference list when applying for a job.

Preparing Your Cover Letter

A cover letter **(Figure 2–3)** should be sent with every resume you mail, e-mail, fax, or personally deliver. A cover letter gives you a chance to point out exactly why you are perfect for the job. You should not send out the same cover letter to all potential employers. Adjust the letter to match the company and position you are applying for. Yes, this means a little more work, but it will be worth it. Address the letter to the person doing the hiring. Do NOT use "Dear Sir, Dear Madam, or To Whom it may concern." If the job posting does not give the hiring person's name, you can normally find who to send the resume to by calling the employer and asking to whom to address your cover letter. You can also try checking other business information sites to determine the name of the person conducting the interviewing.

A good cover letter is normally made up of three paragraphs, each with its own purpose.

First Paragraph In the first paragraph, tell the employer that you are interested in working for the company, the position you are interested in, and why. Make sure you let the employer know that you know something about the company and what the job involves. Also include a statement of how you found out about the open position, which could be a help wanted ad, a job posting at school, and/or a referral by someone who works for the company.

Jack Erjavec
1234 My Street
Somewhere, OZ 99902

March 24, 2018

Mrs. Need Someone
Service Manager, Exciting New Cars
56789 Big Dealer Avenue
Somewhere, OZ 99907

Re: application for an entry level automotive technician position

Dear Mrs. Someone:

Your ad in the March 14th edition of the Dogpatch for an automotive technician greatly interested me, as this position is very much in line with my immediate career objective–a career position as an automotive technician in a new car dealership. Because of the people and cars featured at your dealership, I know working there would be exciting.

I have tinkered with cars for most of my life and am currently enrolled in the Automotive Technology program at Somewhere Community College. I chose this program because you are on the advisory council and I knew it must be a good program. I have good hand skills and work hard to be successful. My being on the varsity soccer team for four years should attest to that. I also enjoy working with people and have developed excellent communication skills. The position you have open is a perfect fit for me. A resume detailing my skills and work experience is attached for your review.

I would appreciate an opportunity to meet with you to further discuss my qualifications. In the meantime, many thanks for your consideration, and I look forward to hearing from you soon. I can be reached by phone at 123-456-7890, most weekdays after 2:30 PM. If I am unable to answer the phone when you call, please leave a message and I will return your call as soon as I can. Thanks again.

Sincerely,

Jack Erjavec

encl.

FIGURE 2–3 An example of a cover letter that can be sent with the resume in Figure 2–2.

Second Paragraph In this paragraph, sell yourself by mentioning one or two of your job qualifications and describe them in more detail than you did in your resume. Make sure you expand on the material in your resume rather than simply repeat it. Point out any special training or experience you have that directly relates to the job. When doing this, give a summary without listing the places and dates. This information is listed in your resume so simply refer to the resume for details. This summary is another opportunity for you to let the employer know that you understand what they do, what the job involves, and how you can help them.

Third Paragraph Typically this paragraph is the end or closing of the letter. Make sure you thank the employer for taking the time to review your resume and ask him or her to contact you to make an appointment for an interview. Make sure you give a phone number where you can be reached. If you have particular times when it is best to contact you, put those times in this paragraph. Make sure you have a clear and understandable message on your telephone's answering machine, just in case you miss the employer's call. Also, have an organized work area around the phone so that you can accurately schedule any interview appointments.

Guidelines for Writing an Effective Cover Letter Follow these guidelines while preparing and writing your cover letter:

- Address the letter to a person, not just a title. If you do not know the person's name, call the company and ask for the correct spelling of the person's name and his or her title.

- Make sure the words you use in the letter are upbeat.
- Use a natural writing style, keeping it professional but friendly.
- Try hard not to start every sentence with "I"; make some "you" statements.
- Check the letter for spelling and grammatical errors. This is a critical step!
- Type the letter on quality paper and make sure it is neat and clean.
- Make sure you sign the letter before sending it.

Contacting Potential Employers

Unless the help wanted ad or job posting tells you otherwise, it is best to drop your resume and cover letter off in person (preferably to the person who does the hiring). When you are doing this, make sure the employer knows who you are and the job you want. Make sure you are prepared for what happens next. You may be given an interview right then. You may be asked to fill out an application. If so, fill it out.

Before you leave, thank the employer and ask if you can call back in a few days if you do not hear from him. If you do not hear back within a week, call to make sure the employer received your resume. If you are told that the job is filled or that no jobs are available, politely thank him for considering you. Ask if it is okay for you to stay in touch in case there is a future job opening.

Employment Application

An application for employment is a legal document that summarizes who you are. It is also another marketing tool for you. Filling out the application is the first task the employer has asked you to do, so do it thoroughly and carefully. Make sure you are prepared to fill out an application before you go. Take your own pen and a paperclip so that you can attach your resume to the application. Make sure you have your reference list. When filling out the application, neatly print your answers.

Read over the entire application before filling it out. Make sure you follow the directions carefully. Read through the application before you fill in the blanks, this gives you a better chance of filling it out neatly and correctly. A messy application or one with crossed out or poorly erased information tells employers you may not care about the quality of your work.

By following the directions on the application and providing the employer with the information asked for, you are demonstrating that you have the ability to read, understand, and follow written instructions, rules, and procedures. When answering the questions, be honest. When you have completed the application, sign it and attach your cover letter and resume to it.

Many companies use electronic applications, which may be only electronic versions of a paper application. Depending on the company, you may complete the application from anywhere or it may require you to complete one at the place of employment. Some companies use online applications that can be linked with Facebook, Google+, and LinkedIn accounts. This form of application may also ask you to upload a current resume. In some cases, online applications also serve as a type of personality test, asking you value or judgment questions designed to determine what type of person you are. It is important to note that many employers will check applicants out on Facebook and other social websites as part of their decision making process. If you have questionable content on your Facebook page or elsewhere, you should consider removing it before beginning your job search.

The Interview

Typically if employers are interested in you, you will be contacted to come in for an interview. This is a good sign. If they were not impressed with what they know of you so far, they will not ask for an interview. Knowing this should give you some confidence as you prepare for the interview.

Although an interview does not last very long, it is a time when you can either get the job or lose it. Get ready for the interview by taking time to learn as much as you can about the company. Think of some of the reasons the company should hire you. When doing this, think of how both of you would benefit. Think of questions you might ask the interviewer to show you are interested in the job and the business. Then make a list of questions that you think the employer might ask. Think about how you should answer each of them and practice the answers with your family and friends. Some of the more common interview questions include:

- What can you tell me about yourself?
- Why are you interested in this job?
- What are your strengths and weaknesses?
- If we employ you, what will you do for us?
- Would you ever lie to me?
- Do you have any questions about us or the job?

Tips for a Successful Interview

- Before the interview, think about what days and hours you can work and when you can start working.
- Make sure you take your social security card (or SIN card), extra copies of your resume, a list of your references and their contact information, as well as copies of any letters of recommendation you may have.
- Take paper and a pen to the interview so that you can take notes. Often the interviewer will be doing the same.
- Try to relax right before the interview.
- Be on time (early is good) for the interview. If you are not exactly sure how to get to the business or what types of problems you may face getting there (such as traffic jams or construction), make a trip there 1 or 2 days before the interview. If you must be late, or if you cannot make it to the interview, call the employer as soon as possible and explain why. Ask if you can arrange for a new interview time.
- Show up looking neat and professional. Wear something more formal than what you would wear on the job.
- Turn your cell phone off or leave it in your car. Don't let your interview be ruined by repeated phone interruptions or wild ringtone or alert sounds.
- When you are greeted by the interviewer, look him or her in the eyes, introduce yourself and be ready to shake hands. Do it firmly but do not show off how strong your grip is!
- Listen closely to the interviewer and look at the interviewer while he or she talks.
- Answer all questions carefully and honestly. If you do not have an immediate answer, think about it before you open your mouth. If you do not understand the question, restate the question in the way you understand it. The interviewer will then know what question you are answering.
- Never answer questions with a simple "yes" or "no." Answer all questions with examples or explanations that show your qualities or skills.
- Market yourself but do not lie about or exaggerate your abilities.
- Show your desire and enthusiasm for the job, but try to be yourself; that is, not too shy or too aggressive.
- Never say anything negative about other people or past employers.
- Do not be overly familiar with the interviewer and do not use slang during the interview, even if the interviewer does.
- Restate your interest in the job and summarize your good points at the end of the interview.
- Ask the interviewer if you can call back in a few days.

After the Interview

After the interview, go to a quiet place and reflect on what just took place. Think about what you did well and what you could have done better. Write these down so that you can refer to them when you are preparing for your next interview.

Within 3 days after the interview, contact the interviewer, thanking him or her for his or her time. Make sure you remind the interviewer of your interest and qualifications. Take advantage of this additional chance to market yourself but do not be overly aggressive when doing this. And, do not beg for the job!

Remember, finding a job takes time and seldom do you land a job on your first attempt. If you do not get a job offer as a result of a first interview, do not give up. Do your best not to feel depressed or dejected. Simply realize that, although you are qualified, someone with more experience was chosen. Send a thank-you letter anyway; this may prompt the interviewer to think of you the next time a similar job becomes available.

Review your cover letter, resume, and interview experience. Identify anything that can improve your marketing tools. Do not feel shy about asking the employer who did not hire you what you could have done better. Discuss your job hunt with your family and friends who will provide support and encouragement. Explore other options. Do not rule out volunteering or job shadowing as a means of connecting with the workplace.

If you do get a job offer, do not be afraid to discuss the terms and conditions before accepting. Find out, or confirm, things such as what you will be doing, the hours you will be working, how you will be paid, and what to do when you report to work the first day. If you have any concerns, do not hesitate to share them with someone whose opinion you respect before committing yourself to the job. Do not commit to the job and then change your mind a few days later. Think seriously about the job before you accept or decline it.

Accepting Employment

When you accept the job, you are entering into an agreement with the employer. That agreement needs to be honored. Make sure you are ready to start

working. You need to have transportation to and from work and the required tools and clothes for the job.

Typically before you begin to work, or at least before you get paid, you will fill out state and federal income tax forms. These forms give the company authorization to deduct income taxes from your wages. When you are an employee, the company must deduct those taxes. One form you will fill out is the employee withholding allowance certificate form, called the W-4. This form tells the employer how much, according to a scale, should be deducted from your pay for taxes. Basically the form asks how many exemptions you would like to claim. What you should claim depends on many things, and it is best that you seek advice from someone before you fill this in. In fact, do this well before you arrive to fill out the form.

Compensation

Automotive technicians can be paid in a number of ways. When deciding on whether or not to accept a job, make sure you understand how you will be paid. Keep in mind that the employer agrees to pay you in exchange for your work, the quality of which is unknown before you start to work. When you accept employment, you accept the terms of compensation offered to you. Do not show up on the first day of work demanding more. After you have started working, progressed on the job, and made the company money, you can ask for more.

Hourly Wages Most often, new or apprentice technicians are paid a fixed wage for every hour they work **(Figure 2–4)**. The amount of pay per hour depends on the business, your skill levels, and the work you will be doing. While collecting an hourly wage, you have a chance to learn the trade and the business. Time is usually spent working with a master technician or doing low-skilled jobs. As you learn more and become more productive, you can earn more. Many shops pay a good hourly rate to their productive technicians. Some have bonus plans that allow technicians to make more when they are highly productive. Nearly all service facilities for fleets pay their technicians an hourly wage.

Commission When technicians are paid on a **commission** basis, they receive a minimum hourly wage plus a percentage of what the shop receives for

SMART Autmotive Repair

Period:	10/14/2016	Employee Name	Rob Thompson	Employee ID	0U812
Tax Status	1	Federal Allowance (From W-4)	0	Hours Worked	32
Hourly Rate	$12.00	Overtime Rate	$18.75	Sick Hours	0
Social Security Tax	$23.81	Federal Income Tax	$29.70	Vacation Hours	0
Medicare Tax	$3.20	State Tax	$5.57	Overtime Hours	0
Insurance Deduction	$0.00	Other Regular Deduction	$3.20	Gross Pay	$384.00
Total Taxes and Regular Deductions	$65.48	Other Deduction	$0.00	Total Taxes and Deductions	$67.85
				Net Pay	$318.52

SMART Automotive Repair, INC.
5150 Speed Way
Columbus, Ohio 43224

Advice number: 0000458852
Pay date: 10/21/2016

Deposited to the account of	account number	transit ABA	amount
Rob Thompson	xxxxxx5341	xxxx xxxx	$ 318.52

THIS IS NOT A CHECK

NON-NEGOTIABLE

FIGURE 2–4 Automotive technicians can be paid in a number of ways.

performing various services. This pay system can work well for technicians who are employed in a shop whose business fluctuates through the year. This system, along with the “flat-rate” system, is often referred to as incentive pay systems.

Flat-Rate **Flat-rate** is a pay system in which a technician is paid for the amount of work, meaning labor hours, he or she does. The flat-rate system favors technicians who work in a shop that has a large volume of work. Although this pay plan offers excellent wages, it is not recommended for new and inexperienced technicians.

Every conceivable service to every different model of vehicle has a flat-rate time. These times are assigned by the automobile manufacturers. The times are based on the average time it takes for a team of technicians to perform the service on new vehicle models. Flat-rate times **(Figure 2–5)** are listed in a labor guide, which can be a manual or be available on a computer. As you can see from Figure 2–5, flat-rate times are broken down into tenths of an hour. A job that pays for 3.1 hours means you will be paid for 3 hours and 6 minutes regardless of how long it took to complete the job. To explain how this system works, suppose a technician is paid $15.00 per hour flat-rate. If a job has a flat-rate time of 3.1 hours, the technician will be paid $46.50 for the job, regardless of how long it took to complete it. Experienced technicians beat the flat-rate time nearly all of the time. Their weekly pay is based on the time “turned in,” not on the time spent. If the technician turns in 60 hours of work in a 40-hour workweek, he or she actually

	Skill Level	Warranty Time	Standard
(1) HUB & BEARING, R&R			
All Models (2WD)			
One Side	B	(0.8)	1
Both Sides	B	(1.5)	1.9

Parts

	Mfg. Part No.	Price (MSRP)*
HUB & BEARING		
All Models		
1/2 Ton		
w/Crew Cab	15946732	$509.50
w/o Crew Cab	15233111	$453.46

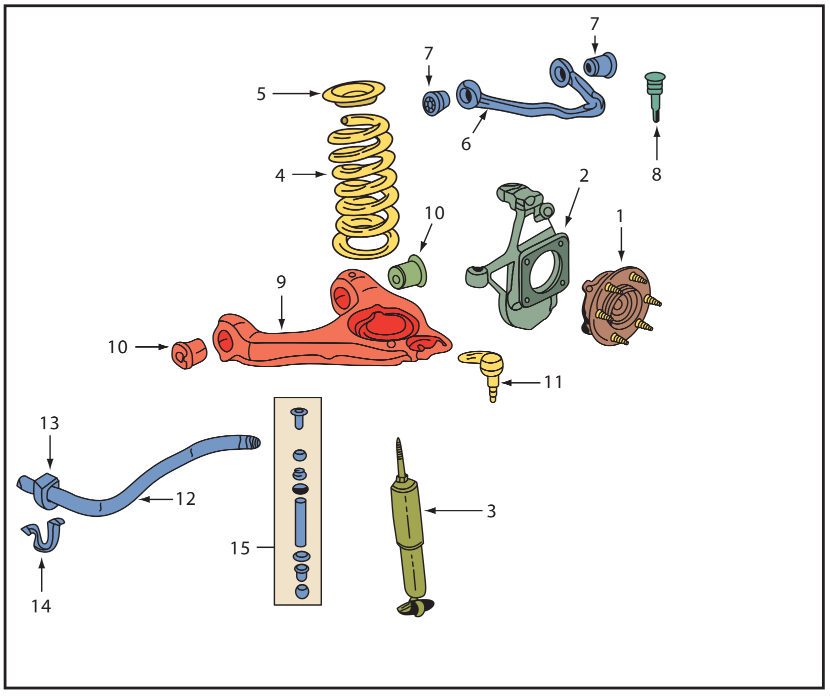


FIGURE 2–5 When you are paid flat-rate, you are paid for the times listed in a labor guide.

earns $22.50 each hour worked. However, if the technician turns in only 30 hours in the 40-hour week, the hourly pay is $11.25.

The flat-rate times from the manufacturers are also used for warranty repairs. Once a vehicle gets a little older, it takes a little longer to service it. This is because dirt, rust, and other conditions make the services more difficult. Because of this, the flat-rate times for older vehicles are longer. Because nondealership service facilities normally work on "out-of-warranty" vehicles, therefore older vehicles, the flat-rate times are about 20 percent higher than those for a newer vehicle.

At times, a flat-rate technician will be paid for the amount of time spent on the job. This is commonly referred to as "straight" or "clock" time. Straight time is paid when a service procedure is not listed in the flat-rate manual and when the customer's concern requires more than normal diagnostic time.

Team System The team system is a variation of the flat-rate system. The technicians on a team are paid according to the total hours the team completes. The team is comprised of A, B, and C technicians, their designations are based on their skill levels. There is normally one "A" tech who normally does advanced diagnostics. An A tech receives the highest compensation on the team. One or two "B" techs are also on the team. These are techs that can handle somewhat difficult diagnostics and most repairs. They are paid at a lower flat-rate wage than the A tech. There are also "C" techs and normally there are two. These techs are typically apprentices and are capable of doing normal services and minor repairs. As a technician's skills improve, they can move up the ladder and improve their pay.

To give an example of compensation, let's say a four-tech team turned in a total of 144 hours for the week. That means each tech will be paid for 36 hours. If the A tech was paid $15 per hour, his total compensation would be $540.00. The B tech earns $12 per hour and would earn $432.00 dollars for the week. The two C techs earn $9.00 per hour and each would make $324.00.

Benefits Along with the pay, the employer may offer benefits, sometimes called "fringe benefits." The cost of the benefits may be paid for by the business, or you may need to pay a share or all of the costs. There is no common benefit package for automotive technicians. Common benefits include:

- Health insurance
- Retirement plans
- Paid vacations
- Paid sick days
- Uniforms and uniform cleaning services
- Update training

When accepting employment, make sure you understand the benefits and seek help in choosing which you should participate in.

Total Earnings Depending on the business, you may be paid weekly, every two weeks, or twice a month. The total amount of what you earn is called your **gross pay**. This is not your "take home" or **net pay**. Your net pay is the result of subtracting all taxes and benefit costs from your gross pay. These deductions may include:

- Federal income taxes
- State income taxes
- City income taxes
- Federal Insurance Contribution Act (FICA) taxes—this is commonly known as social security taxes
- Your contribution toward health insurance
- Uniform costs

You should expect that your net pay will be approximately 70 percent of your gross pay. This means that if your gross pay for a week's work is $500.00, the amount you take home after deductions would be around $350.00. Of course that 70 percent number is a general rule; your actual net percentage may be higher or lower depending on many factors, such as where you live and work and if you have any deductions for dependents.

Working as a Technician

Once you have the job, you need to keep it. Your performance during the first few weeks will determine how long you will stay employed and how soon you will get a raise or a promotion. Make sure you arrive to work on time. If you are going to be late or absent, call the employer as soon as you can. Once you are at work:

- Be cheerful and cooperative with those around you.
- Do not spend talking or texting when you should be working.
- Find out what is expected of you and do your best to meet those expectations.

- Make sure you ask about anything you are not sure of, but try to think things out for yourself whenever you can.
- Show that you are willing to learn and to help out in emergencies.

A successful automotive technician has a good understanding of how the various automotive systems work, has good hand skills, has a desire to succeed, and has a commitment to be a good employee. The required training is not just in the automotive field. Because good technicians spend a great deal of time working with service manuals, good reading skills are a must. Technicians must also be able to accurately describe what is wrong to customers and the service advisor. Often these descriptions are done in writing; therefore, a technician also needs to be able to write well.

Employer-Employee Relationships

Being a good employee requires more than job skills. When you become an employee, you sell your time, skills, and efforts. In return, your employer has certain responsibilities:

- **Instruction and Supervision.** You should be told what is expected of you. Your work should be observed and you should be told if your work is satisfactory and offered ways to improve your performance.
- **Good Working Conditions.** An employer should provide a clean and safe work area as well as a place for personal cleanup.
- **Benefits.** When you were hired, you were told what fringe benefits you can expect. The employer should provide these when you are eligible to receive them.
- **Opportunity and Fair Treatment.** You should be given a chance to succeed and possibly advance within the company. You and all other employees should be treated equally, without prejudice or favoritism.

On the other side of this business relationship, you have responsibilities to the employer, including:

- **Regular Attendance.** A good employee is reliable. Businesses cannot operate successfully unless their workers are on the job.
- **Following Directions.** As an employee, you are part of a team. Doing things your way may not serve the best interests of the company.
- **Team Membership.** A good employee works well with others and strives to make the business successful.
- **Responsibility.** Be willing to answer for your behavior and work habits.
- **Productivity.** Remember that you are paid for your time as well as your skills and effort. You have a duty to be as effective as possible when you are at work.
- **Loyalty.** Loyalty is expected by any employer. This means you are expected to act in the best interests of your employer, both on and off the job.

Communications

Employers value employees who can communicate. Effective communications include listening, reading, speaking, and writing. Communication is a two-way process. The basics of communication are simply sending a message and receiving a response.

To be successful, you should carefully follow all oral and written directions that pertain to your job. If you do not fully understand them, ask for clarification. You also need to be a good listener. Like other things in life, messages can appear to be good, bad, or have little worth to you. Regardless of how you rate the message, you should show respect to the person giving the message. Look at the person while he or she is speaking and listen to the message before you respond. In order to totally understand the message, you may need to ask questions and gather as many details as possible. Do not try to control the conversation, and give listeners a chance to speak. *Hint:* Try to put yourself in the other person's shoes and listen without bias.

Obviously, when you read something, you are receiving a message without the advantage of seeing the message sender. Therefore, you must take what you read at face value. This is important because being able to read and understand the information and specifications given in service information is necessary for automotive technicians **(Figure 2–6)**.

Do your best to think through the words you use to convey a message to the customer or your supervisor. Pay attention to how they are listening and adjust your words and mannerisms accordingly. When writing a response, think about to whom the message is for and adjust your words to match their abilities and attitudes. Also, keep in mind that more

2012 4-cylinder Honda Accord Specifications

Item	Measurement	Qualification	Standard or New	Service Limit
Generator	Output	At 13.5 V and normal engine temperature	105 A	
	Coil (rotor) resistance	At 68 °F (20 °C)	3.4–3.8 Ω	
	Slip ring O.D.		14.4 mm (0.567 inches)	14.0 mm (0.551 inches)
	Brush length		10.5 mm (0.413 inches)	1.5 mm (0.059 inches)
Starter	Output		1.8 kW	
	Commutator mica depth		0.50–0.90 mm (0.0197–0.0354 inches)	0.20 mm (0.0079 inches)
	Commutator runout		0.02 mm (0.0008 inches) max.	0.05 mm (0.0020 inches)
	Commutator O.D.		28.9–29.0 mm (1.138–1.142 inches)	28.0 mm (1.102 inches)
	Brush length		15.0–16.0 mm (0.591–0.630 inches)	9.0 mm (0.354 inches)
	Brush spring tension		22.3–27.3 N (5.00–6.13 ft.-lb)	
Radiator cap	Opening pressure		93–123 kPa (13.5–17.8 psi)	
Engine oil	Capacity	Engine overhaul	5.1 L (5.4 US qt)	
		Oil change including filter	4.0 L (4.2 US qt)	
		Oil change without filter	3.8 L (4.0 US qt)	

FIGURE 2-6 Being able to read and understand the information and specifications given in service information is a must for automotive technicians.

than one person may read it, so think of others' needs as well.

Proper telephone etiquette is also important. Most businesses will tell you how to answer the phone, typically involving the name of the company followed by your name. Make sure you listen carefully to the person calling. When you are the one making the call, make sure you introduce yourself and state the purpose of the phone call. Again, the key to proper phone etiquette is respect.

Nonverbal Communication

In all communications, some of the true meaning is lost. In many cases, the heard message is often far different from the one intended. Because the words spoken are not always understood or are interpreted incorrectly because of personal feelings, you can alter the meaning of words significantly by changing the tone of your voice. Think of how many ways you can say "no"; you could express mild doubt, terror, amazement, anger, and other emotions.

It is important that you realize that a major part of communication is nonverbal. **Nonverbal communication** is the things you do while communicating. Pay attention to your nonverbal communication as well as to that of others.

Nonverbal communication includes such things as body language and tone. Body language includes facial expression, eye movement, posture, and gestures. All of us read people's faces; we interpret what they say or feel. We also look at posture to give us a glimpse of how the other person feels about the message. Posture can indicate self-confidence, aggressiveness, fear, guilt, or anxiety. Similarly, we

look at how they place their hands or give a handshake.

Many scholars have studied body language and have defined what certain behaviors indicate. Some divide postures into two basic groups:

- *Open/closed* is the most obvious. People with their arms folded, legs crossed, and bodies turned away are signaling that they are rejecting or are closed to messages, whereas people fully facing you with open hands and both feet planted on the ground are saying they are open to and accepting the message.
- *Forward/back* indicates whether people are actively or passively reacting to the message. When they are leaning forward and pointing toward you, they are actively accepting or rejecting the message. When they are leaning back, looking at the ceiling, doodling on a pad, or cleaning their glasses, they are either passively absorbing or ignoring the message.

Solving Problems and Critical Thinking

Anyone who can think critically and logically to evaluate situations is very desirable. **Critical thinking** is the art of being able to judge or evaluate something without bias or prejudice. When diagnosing a problem, critical thinkers are able to locate the cause of the problem by responding to what is known, not what is supposed.

Good critical thinkers begin solving problems by carefully observing what is and what is not happening. Based on these observations, something is declared as a fact. For example, if the right headlamp of a vehicle does not light and the left headlamp does, a critical thinker will be quite sure that the source of the problem is related to the right headlamp and not the left one. Therefore, all testing will be centered on the right headlamp. The critical thinker then studies the circuit and determines the test points. Prior to conducting any test, the critical thinker knows what to test and what the possible test results would indicate.

Critical thinkers solve problems in an orderly way and do not depend on chance. They come to conclusions based on a sound reasoning. They also understand that if a specific problem exists only during certain conditions, there are a limited number of causes. They further understand the relationship between how often the problem occurs and the probability of accurately predicting the problem. Also, they understand that one problem may cause other problems and they know how to identify the connection between the problems.

Solving problems is something we do every day. Often the problems are trivial, such as deciding what to watch on television. Other times they are critical and demand much thought. At these times, thinking critically will really pay off. Although it is impossible to guarantee that critical thinking will lead to the correct decision, it will lead to good decisions and solutions.

Diagnosis

The word **diagnosis** is used to define one of the major duties of a technician. Diagnosis is a way of looking at systems that are not functioning properly and finding out why. It is not guessing, and it is more than following a series of interrelated steps in order to find the solution to a specific problem. Solid diagnosis is based on an understanding of the purpose and operation of the system that is not working properly.

In service manuals, there are diagnostic aids given for many different problems. These are either symptom based or flow charts. **Flow charts** or decision trees **(Figure 2–7)** guide you through a step-by-step process. As you answer the questions given at each step, you are told what your next step should be. Symptom-based diagnostic charts **(Figure 2–8)** focus on a definition of the problem and offer a list of possible causes of the problem. Sometimes the diagnostic aids are a combination of the two—a flow chart based on clearly defined symptoms.

When these diagnostic aids are not available or prove to be ineffective, good technicians conduct a visual inspection and then take a logical approach **(Figure 2–9)** to finding the cause of the problem. This relies on critical thinking skills as well as system knowledge. Logical diagnosis follows these steps:

1. **Verify that the problem exists.** After interviewing the customer, take the vehicle for a road test and try to duplicate the problem, if possible.
2. **Do some preliminary checks.** Research all available information to determine the possible causes of the problem. Try to match the exact problem with a symptoms chart or think about what is happening and match a system or some components to the problem.

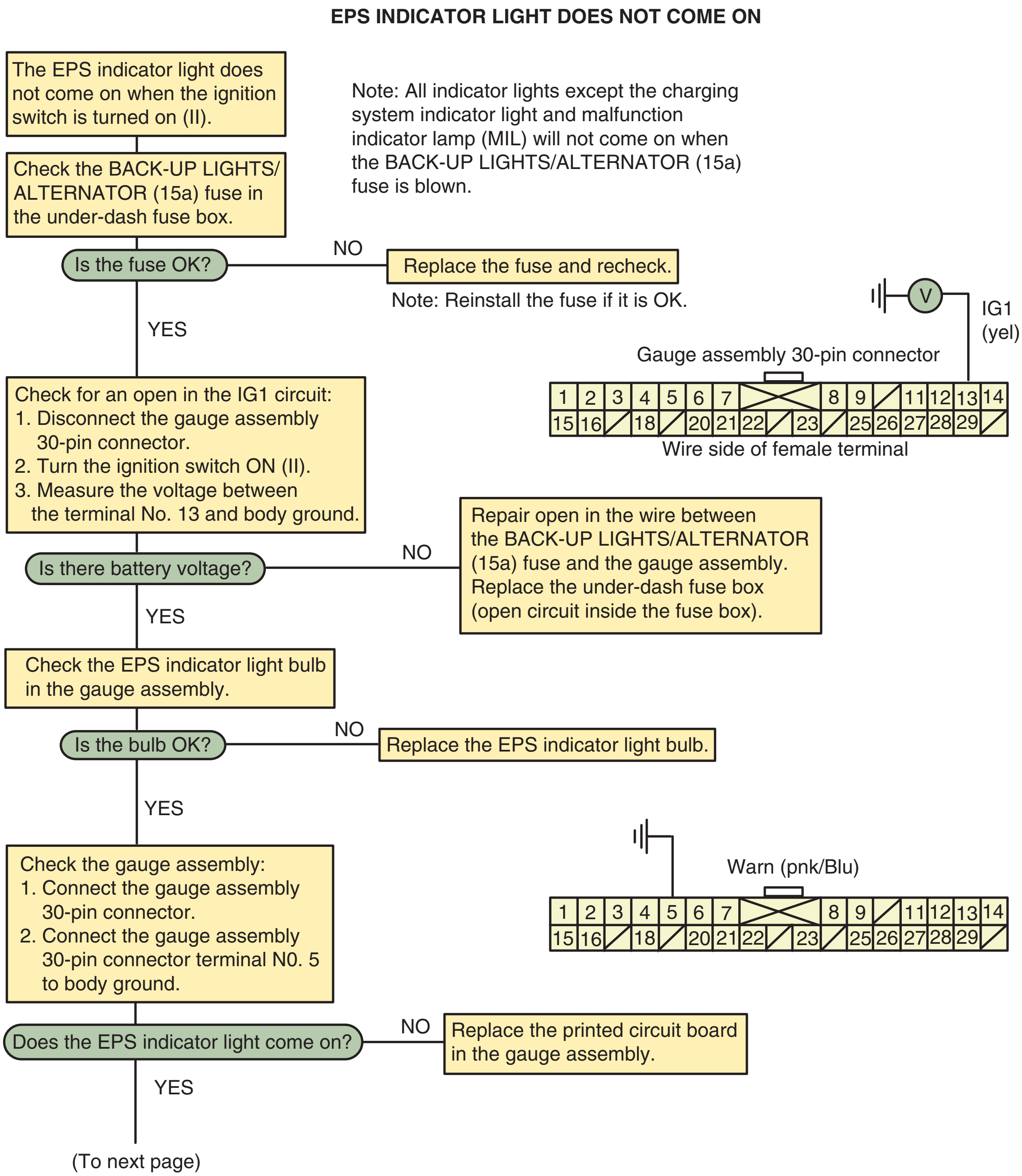


FIGURE 2-7 A typical decision tree for diagnostics.

3. **Thoroughly define what the problem is and when it occurs.** Pay strict attention to the conditions present when the problem happens. Also pay attention to the entire vehicle; another problem may be evident to you that was not evident to the customer.
4. **Conduct a visual inspection.** Look at all possible sources of the concern.
5. **Diagnose the concerned systems.** Conduct the necessary tests to determine what components are good and which ones are not operating normally.
6. **Locate and repair the problem.** Once you have identified the cause of the concern, follow the recommended procedures for making the repair.
7. **Verify the repair.** Never assume that your work solved the original problem. Go back to step 2 and see if the problem or concern still exists before returning the vehicle to the customer.

Problem	Probable Cause(s)
Ratcheting noise	The return spring for the parking pawl is damaged, weak, or misassembled
Engine speed sensitive whine	Torque converter is faulty Faulty pump
Popping noise	Pump cavitation—bubbles in the ATF Damaged fluid filter or filter seal
Buzz or high-frequency rattle Whine or growl	Cooling system problem Stretched drive chain Broken teeth on drive and/or driven sprockets Nicked or scored drive and/or driven sprocket bearing surfaces Pitted or damaged bearing surfaces
Final drive hum	Worn final drive gear assembly Worn or pitted differential gears Damaged or worn differential gear thrust washers
Noise in forward gears	Worn or damaged final drive gears
Noise in specific gears	Worn or damaged components pertaining to that gear
Vibration	Torque converter is out of balance Torque converter is faulty Misaligned transmission or engine Output shaft bushing is worn or damaged Input shaft is out of balance The input shaft bushing is worn or damaged

FIGURE 2-8 A symptom-based diagnostic chart.

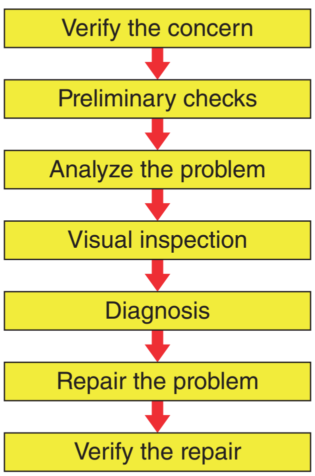


FIGURE 2-9 To diagnose a concern logically, these are the steps that should be taken.

Professionalism

The key to effective communications is respect. You should respect others and others should respect you. However, respect cannot be commanded; it must be earned. As a technician, you can earn respect in many ways. All of these result from the amount of professionalism you display. Professionalism is best shown by having a positive attitude, displaying good behavior, and accepting responsibility.

A good technician is a highly skilled and knowledgeable individual. A professional demonstrates the following:

- Self-esteem, pride, and confidence
- Honesty, integrity, and personal ethics

- A positive attitude toward learning, growth, and personal health
- Initiative, energy, and persistence to get the job done
- Respect for others
- A display of initiative and assertiveness
- The ability to set goals and priorities in work and personal life
- The ability to plan and manage time, money, and other resources to achieve goals
- The willingness to follow rules, regulations, and policies
- The willingness to fulfill the responsibilities of your job
- Assuming responsibility and accountability for your decisions and actions
- The ability to apply ethical reasoning
- The desire to learn something new every day, whether by reading a magazine or a book, watching a video, or even watching a car-related TV show

Coping with Change

Your professionalism is also evident by how you react to change. Unfortunately, work environments never stay the same. New rules and regulations, supervisors, fellow employees, business owners, and vehicle systems are all potential sources of stress. Rather than focusing on the negatives of these changes, you should identify the positives. This will help you minimize stress. If you feel stress, do what you can to relieve it. Activities such as walking, running, or playing sports help reduce stress. When you are stressed, it is difficult to be a productive worker. Therefore, do your best to put things in perspective and do some critical thinking to identify what you can do to change the situation that is causing the stress.

When the source of stress is related to your job, spend time to decide whether the stressful situation can be changed or not. If it cannot and you feel you can no longer cope with it, it may be wise to find employment elsewhere.

If you decide that leaving your job is the best solution, do it professionally. Do not simply stop showing up for work or walk up to the employer and say "I quit!" The best way to quit a job is to write a letter of resignation and personally present it to the employer. The letter should state why you are leaving the company. Be careful not to attack the business, the employer, or fellow workers. You can simply say you are looking at other opportunities or have found another job. Bad-mouthing the business is a sure way of losing a good work reference—one that you may need for your next job. The letter should also include the last day you intend to work. Your last day should be approximately 2 weeks after you notify the employer. At the end of your letter of resignation, thank the employer for the opportunity to work for him or her and for the personal growth experiences they provided for you.

Interpersonal Relationships

As an employee, you have responsibilities to your fellow workers. You are a member of a team. Teamwork means cooperating with and caring about other workers. All members of the team should understand and contribute to the goals of the business. Keep in mind that if the business does not make money, you may not have a job in the future. Your responsibility is more than simply doing your job. You should also:

- Suggest improvements that may make the business more successful.
- Display a positive attitude.
- Work with team members to achieve common goals.
- Exercise "give and take" for the benefit of the business.
- Value individual diversity.
- Respond to praise or criticism in a professional way.
- Provide constructive praise or criticism.
- Resolve conflicts in a professional way.
- Identify and react to any intimidation or harassment.

Customer Relations

Good customer relations are important for all members of the team. You should make sure you listen and communicate clearly **(Figure 2–10)**. Be polite and organized, particularly when dealing with customers on the telephone. Always be as honest as you possibly can.

Present yourself as a professional. Professionals are proud of what they do and they show it. Always dress and act appropriately and watch your language, even when you think no one is near.

Respect the vehicles you are working on. They are important to your customers. Always return the vehicles to their owners clean and in an undamaged condition. Remember, a vehicle is the second largest expense a customer has. Treat it that way. It does

FIGURE 2-10 Good customer relations are important; make sure you always listen and communicate clearly.

not matter if you like the vehicle. It belongs to the customer; treat it respectfully.

Explain the repair process to the customer in understandable terms. Whenever you are explaining something to a customer, make sure you do it in a simple way without making the customer feel stupid. Always show customers respect and be courteous to them. Not only is this the right thing to do, but it also leads to loyal customers.

KEY TERMS

- Commission
- Critical thinking
- Diagnosis
- Flat-rate
- Flow charts
- Gross pay
- Net pay
- Nonverbal communication
- Reference
- Resume

SUMMARY

- An employment plan is an honest appraisal of yourself and your career goals.
- A reference is someone who will be glad to tell a potential employer about you and your work habits.
- A resume and cover letter are personal marketing tools and may be the first look at you an employer has.
- A resume normally includes your contact information, career objective, skills and/or accomplishments, work experience, education, and a statement about references.
- A cover letter gives you a chance to point out exactly why you are perfect for a particular job.
- An application form is a legal document that summarizes who you are.
- Good preparation for an employment interview will result in a good experience.
- Automotive technicians are typically paid an hourly wage or on the flat-rate system.
- As part of an employment agreement, your employer also has certain responsibilities to you, and you have responsibilities to the employer.
- Effective communications include listening, reading, speaking, and writing.
- Nonverbal communication is a key part of sending and receiving a message and includes such things as body language and tone.
- Employers value someone who can think critically and act logically to evaluate situations and who has the ability to solve problems and make decisions.
- Diagnosis means finding the cause or causes of a problem. It requires a thorough understanding of the purpose and operation of the various automotive systems.
- Diagnostic charts found in service manuals can aid in diagnostics.
- Professionalism is best displayed by having a positive attitude, displaying good behavior, and accepting responsibility.
- New rules and regulations, supervisors, fellow employees, vehicle systems, and vehicles are all potential sources of stress, and your professionalism will be measured by how well you cope.
- Teamwork means cooperating with and caring about other workers.
- Good customer relations is a quality of good technicians and is based on respect.

REVIEW QUESTIONS

Short Answer

1. What type of information should go into your employment plan?
2. Explain three types of pay systems used for technicians.
3. What should be included in the three main paragraphs of a cover letter?
4. If you decide that leaving your job is the best way to relieve stress at work, describe the steps you should take to end your employment.
5. Describe the seven basic steps for logical diagnosis.
6. List the characteristics of a good resume.

True or False

1. *True or False?* When you feel stress from your job and also feel that the situation will not change, you should seek employment elsewhere.
2. *True or False?* When you are filling out an application, you should make it clear how much you want to be paid.
3. *True or False?* Critical thinking is the art of being able to judge or evaluate something with bias or prejudice.
4. *True or False?* The business you decide to work for will pay for all of the benefits you receive.
5. *True or False?* A technician on the flat-rate system is paid for how long he or she spends working on a particular job.

Multiple Choice

1. Which of the following is *not* a recommended step for accurate diagnosis of a problem?
   a. Gather as much information as you can about the problem.
   b. Thoroughly define the problem.
   c. Replace system components and identify the cause of a problem through the process of elimination.
   d. Research all available information and knowledge to determine the possible causes of the problem.
2. Which of the following behaviors does *not* show that you are a responsible person?
   a. Having set goals and priorities in your work and personal life.
   b. Showing a willingness to follow rules, regulations, and policies.
   c. Showing a willingness to share the consequences of your mistakes with others.
   d. Using ethical reasoning when making decisions.
3. Which of the following is *not* the right thing to do when you are being interviewed for a job?
   a. Show up looking neat and in the clothing more formal than what you would wear on the job.
   b. Think carefully about your responses before answering questions.
   c. To avoid saying too much or offending the interviewer, answer as many questions as you can with a simple yes or no.
   d. Listen closely to the interviewer and look at the interviewer while he or she talks.
4. Which of the following is *not* a characteristic of a good employee?
   a. Reliable
   b. Responsible
   c. Overly sociable
   d. Loyal
5. Applicant A goes to a quiet place immediately after an interview and reflects on what just took place. Applicant B sends a letter of thanks to the interviewer if he has not heard back from the employer within 2 weeks. Who is doing the right thing?
   a. A only
   b. B only
   c. Both A and B
   d. Neither A nor B
6. Technician A always looks at people while they are speaking and listens to their message before responding. Technician B always looks at customers when they are speaking to show she is interested in what they are saying. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. Technician A always speaks to customers with his arms folded across his chest because he does not know what else to do with them. Technician B always tries to fully comprehend the message by asking questions about it and gathering as many details as possible. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. Which of the following would *not* be considered a soft skill?
   a. Enjoying solving puzzles or problems
   b. Caring for or helping people
   c. The ability to work independently
   d. Taking care to follow orders or instructions
9. When identifying individuals to use as references while seeking employment, consider all of the following *except*:
   a. Someone who knows and whose opinion is respected, such as a priest, a minister, or an elder in your church
   b. A family member or close friend
   c. Past and present teachers, coaches, and school administrators
   d. People you have worked for or have helped

CHAPTER 3

BASIC THEORIES AND MATH

OBJECTIVES

- Describe the states in which all matter exists.
- Explain what energy is and how energy is converted.
- Explain the forces that influence the design and operation of an automobile.
- Describe and apply Newton's laws of motion to an automobile.
- Define friction and describe how it can be minimized.
- Describe the various types of simple machines.
- Explain the difference between torque and horsepower.
- Explain the behavior of gases.

This chapter contains many of the things you have learned or will learn in other courses. The material is not intended to take the place of those other courses but rather to emphasize the knowledge you need to gain employment and be successful in an automotive career. Many of the facts presented in this chapter will be addressed again in greater detail according to the topic. Make sure you understand the contents of this chapter.

Matter

Matter is anything that occupies space. All matter exists as a gas, liquid, or solid. Gases and liquids are considered fluids because they move or flow easily and easily respond to pressure. A gas has neither a shape nor volume of its own and tends to expand without limits. A liquid takes a shape and has volume. A solid is matter that does not flow.

Atoms and Molecules

All matter is made up of countless tiny particles called **atoms**. A substance with only one type of atom is referred to as an **element**. Over 100 elements are known to exist; 92 occur naturally and the rest have been manufactured in laboratories **(Figure 3–1)**. The atom is the smallest particle of an element and has all of the chemical characteristics of that element.

Small, positively charged particles called protons are located in the center, or nucleus, of each atom. In most atoms, the nucleus also contains neutrons.

Group:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period	**1A**	**2A**	**3B**	**4B**	**5B**	**6B**	**7B**	**8B**			**1B**	**2B**	**3A**	**4A**	**5A**	**6A**	**7A**	**8A**
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	[43] Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	[104] Unq	[105] Unp	[106] Unh	[107] Uns	[108] Uno	[109] Une	[110] Uun	[111] Uuu	[112] Uub	[113] Uut	[114] Uuq	[115] Uup	[116] Uuh	[117] Uus	[118] Uuo

***Lanthanides:**	57 La	58 Ce	59 Pr	60 Nd	[61] Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
****Actinides:**	89 Ac	90 Th	91 Pa	92 U	[93] Np	[94] Pu	[95] Am	[96] Cm	[97] Bk	[98] Cf	[99] Es	[100] Fm	[101] Md	102 No	103 Lr

LEGEND:

Alkali metals	Noble gases
Alkaline earth metals	Halogens
Other metals	Other nonmetals
Semiconductors	No data available

FIGURE 3–1 The periodic table of the elements with each element's natural state shown.

Neutrons have no electrical charge, but they add weight to the atom. The positively charged protons tend to repel each other, and this repelling force could destroy the nucleus. The presence of the neutrons with the protons cancels the repelling action and keeps the nucleus together. Electrons are small, very light particles with a negative electrical charge. Electrons move in orbits around the atom's nucleus. Elements are listed on the atomic scale, or periodic chart, according to the number of protons and electrons they have. For example, hydrogen is number 1 on this scale, and copper is number 29.

A proton is about 1,840 times heavier than an electron. Therefore, electrons are easier to move than protons. While the electrons are orbiting, centrifugal force tends to move them away from the nucleus. However, the attraction between the positively charged protons and the negatively charged electrons holds the electrons in their orbits.

Atoms of different elements have different numbers of protons, electrons, and neutrons. Some of the lighter elements have the same number of protons and neutrons, but many of the heavier elements have more neutrons than protons.

A hydrogen (H) atom is the simplest atom. It has one proton and one electron **(Figure 3–2)**. A copper (Cu) atom has 29 protons and 29 electrons. Electrons of different energy levels orbit the nucleus at different distances called rings or shells. The electrons of a Cu atom orbit in four different rings around the nucleus. Because two, eight, and eighteen electrons are the maximum number of electrons in the first three electron rings next to the nucleus, the fourth ring has one electron **(Figure 3–3)**. The outer ring of electrons is called the valence ring, and the number of electrons in the valence ring determines the electrical characteristics of the element.

A single atom of some elements does not exist. An example of this is oxygen, whose symbol is O. Pure oxygen exists only as a pair of oxygen atoms and has a symbol of O_2. This is a molecule of oxygen. A **molecule** is the smallest particle of an element or compound. A molecule can be made of one type or different types of atoms. A compound contains two

SHOP TALK

Although you may never need to know this, here is a simple explanation of how many electrons can be in each ring around the nucleus of an atom. The basic formula for determining how many electrons can be in a ring is simply as follows: Take the number of the ring and multiple it by itself and then multiply that by 2. For example, the first ring—$1 \times 1 = 1$ and $1 \times 2 = 2$, therefore the first ring can hold 2 electrons; the third ring—$3 \times 3 = 9$ and $9 \times 2 = 18$, therefore the third ring can hold 18 electrons; the seventh ring—$7 \times 7 = 49$ and $49 \times 2 = 98$, therefore the seventh ring can hold 98 electrons; and so forth.

or more different types of atoms. Oxygen atoms readily combine with atoms of other elements to form a compound. Many other atoms also have this same characteristic.

Water is a compound of oxygen and hydrogen atoms. The chemical symbol for water is H_2O. This symbol indicates that each molecule of water

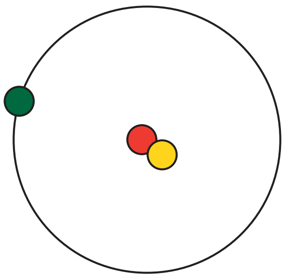


FIGURE 3-2 A hydrogen atom has one proton (red), one neutron (yellow), and one electron (green).

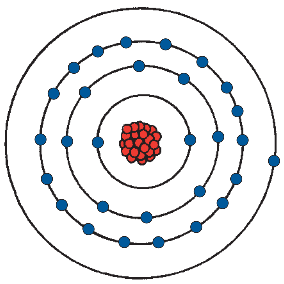


FIGURE 3-3 A copper atom.

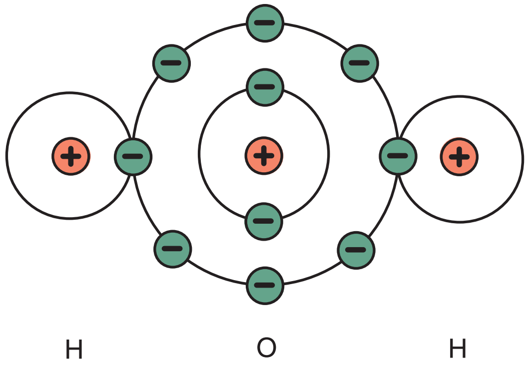


FIGURE 3-4 A molecule of water.

contains two atoms of hydrogen and one atom of oxygen **(Figure 3–4)**.

Ions

An **ion** is an atom or molecule that has lost or gained one or more electrons. As a result, it has a negative or positive electrical charge. A negatively charged ion has more electrons than it has protons. The opposite is true of positively charged ions, which have fewer electrons than protons. Ions are denoted in the same way as other atoms and molecules except for a superscript symbol or number that shows the electrical charge and the number of electrons gained or lost. For example, ionized hydrogen has a positive charge (H^+) and ionized oxygen has a negative charge (O^{2-}) is called an oxide.

Plasma Considered by scientists as the fourth state of matter, **plasma** refers to an ionized gas that has about an equal amount of positive ions and electrons. The electrons travel with the nucleus of the atoms, but can move freely and are not bound to it. The gas at this point no longer behaves as a gas. It now has electrical properties and creates a magnetic field, which radiates light and other forms of electromagnetic energy. It typically takes the form of gas-like clouds and is the basis of most stars. In fact, our sun is really just a large piece of plasma. Plasmas are the most common form of matter in the universe. Plasma in the stars and in the space between them occupies nearly 99 percent of the visible universe. Everyday examples of plasma include the excited gas found in neon and fluorescent lights.

Behavior of the States

The particles of a solid are held together in a rigid structure. When a solid dissolves into a liquid, its particles break away from this structure and mix evenly in

the liquid, forming a solution. When they are heated, most liquids **evaporate**, which means atoms or molecules break free from the body of the liquid to become gas particles. When all of the liquid has evaporated, a solid is left behind. The particles of the solid are normally arranged in a structure called a crystal.

Absorption and Adsorption Not all solids dissolve in a liquid; rather, the liquid is either absorbed or adsorbed. The action of a sponge is the best example of absorption. When a dry sponge is put into water, the water is absorbed by the sponge. The sponge does not dissolve; the water merely penetrates into the sponge and the sponge becomes filled with water. There is no change to the atomic structure of the sponge, nor does the structure of the water change. If we take a glass and put it into water, the glass does not absorb the water. The glass, however, still gets wet as a thin layer of water adheres to the glass. This is adsorption. Materials that *absorb* fluids are **permeable** substances. **Impermeable** substances, such as glass, *adsorb* fluids. Some materials are impermeable to most fluids, whereas others are impermeable to just a few.

Energy

Energy may be defined as the ability to do work. Because all matter consists of atoms and molecules in constant motion, all matter has energy. Energy is not matter, but it affects the behavior of matter. Everything that happens requires energy, and energy comes in many forms.

Each form of energy can change into other forms. However, the total amount of energy never changes; it can only be transferred from one form to another, not created or destroyed. This is known as the "principle of the conservation of energy."

Engine Efficiency

Engine efficiency is a measurement of the amount of energy put into the engine and the amount of energy available from the engine. It is expressed in a percentage. The formula for determining efficiency is: (output energy ÷ input energy) × 100.

A Look at History **Albert Einstein, in his theory of relativity, proposed an equation for energy that many have heard of but few understand. He stated that energy equals mass times the speed of light squared or $E = m \times c^2$.**

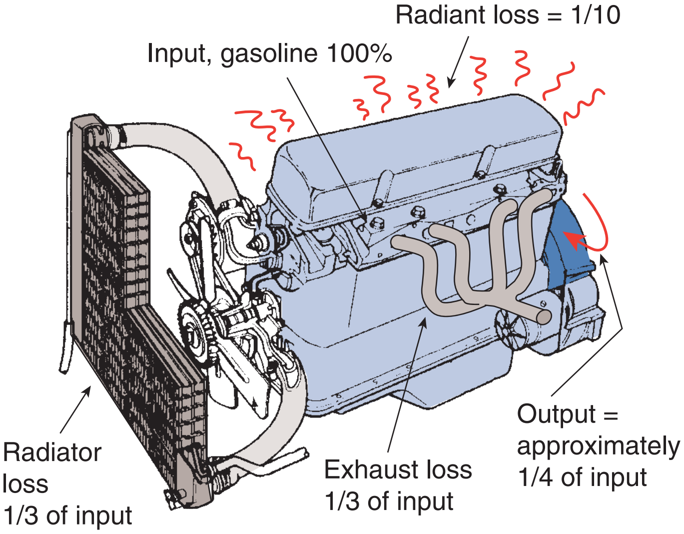


FIGURE 3–5 A gasoline engine wastes or loses most of the energy it receives.

Other aspects of the engine are expressed in efficiency. These include mechanical efficiency, volumetric efficiency, and thermal efficiency. They are expressed as a ratio of input (actual) to output (maximum or theoretical). Efficiencies are always less than 100 percent. The difference between the efficiency and 100 percent is the percentage lost. For example, if 100 units of energy are put into an engine and 28 units were used to power the vehicle, the efficiency is 28 percent. This means 72 percent of the energy received was wasted or lost **(Figure 3–5)**.

Kinetic and Potential Energy

When energy is released to do work, it is called **kinetic energy**. Kinetic energy may also be referred to as energy in motion **(Figure 3–6)**. Stored energy is called **potential energy**.

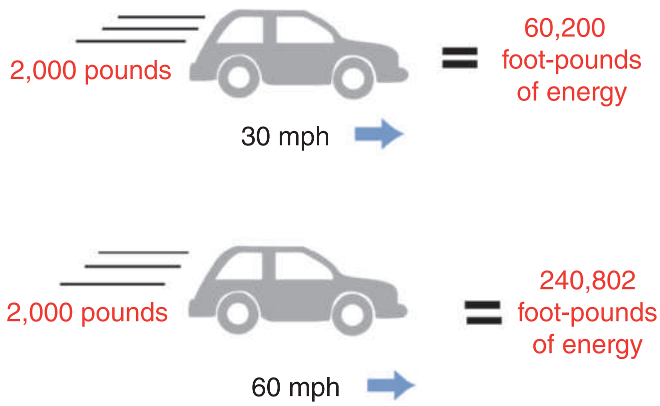


FIGURE 3–6 The kinetic energy of a moving vehicle increases exponentially with its speed.

There are many automotive systems that have potential energy and, at times, kinetic energy. The ignition system is a source of high electrical energy. The heart of the ignition system is the ignition coil, which has much potential energy. When it is time to fire a spark plug, that energy is released and becomes kinetic energy as it creates a spark across the gap of a spark plug.

Energy Conversion

Energy conversion occurs when one form of energy is changed to another. Because energy is not always in the desired form, it must be converted to a form that can be used. Some of the most common energy conversions are discussed here.

Chemical to Thermal Energy Chemical energy in gasoline or diesel fuel is converted to thermal energy when the fuel burns in the engine cylinders.

Chemical to Electrical Energy The chemical energy in a battery **(Figure 3–7)** is converted to electrical energy to power many of the accessories on an automobile.

Electrical to Mechanical Energy In an automobile, the battery supplies electrical energy to the starting motor, and this motor converts the electrical energy to mechanical energy to crank the engine.

Thermal to Mechanical Energy The thermal energy that results from the burning of the fuel is converted to mechanical energy, which is used to move the vehicle.

Mechanical to Electrical Energy The generator is driven by the mechanical energy of the engine. The generator converts this energy to electrical energy to power the vehicle's electrical accessories and recharges the battery.

Electrical to Radiant Energy Radiant energy is light energy. Electrical energy is converted to thermal energy to heat up a filament inside a light bulb to illuminate it and release radiant energy.

Kinetic to Mechanical to Electrical Energy Hybrid vehicles have a system, called regenerative braking, that uses the energy of the moving vehicle (kinetic) to rotate a generator. The mechanical energy used to operate the generator is used to provide electrical energy to charge the batteries **(Figure 3–8)** or power the electric drive motor.

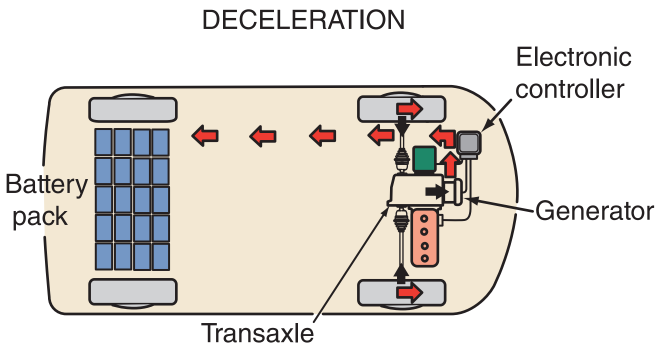


FIGURE 3-8 Regenerative braking captures some of the vehicle's kinetic energy to charge the batteries or power the electric drive motor.

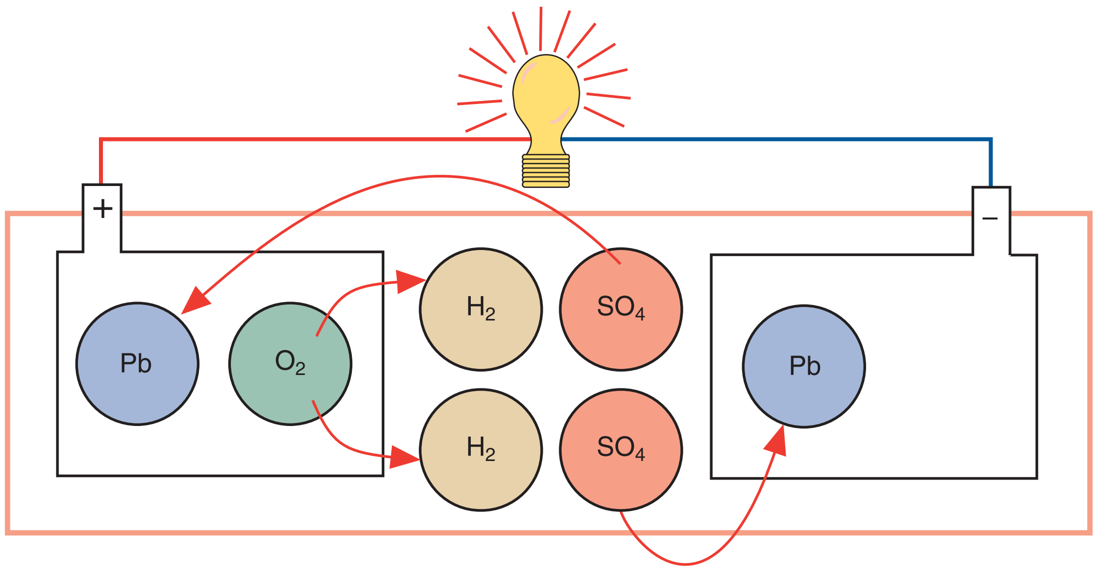


FIGURE 3-7 Chemical energy is converted to electrical energy in a battery.

Mass and Weight

Mass is the amount of matter in an object. **Weight** is a force and is measured in pounds or kilograms (1,000 grams). Gravitational force gives the mass its weight. As an example, a spacecraft can weigh 500 tons (one million pounds) here on earth where it is affected by the earth's gravitational pull. In outer space, beyond the earth's gravity and atmosphere, the spacecraft is nearly weightless but its mass remains unchanged **(Figure 3–9)**.

Automobile specifications list the weight of a vehicle primarily in two ways. **Gross weight** is the total weight of the vehicle when it is fully loaded with passengers and cargo. **Curb weight** is the weight of the vehicle when it is not loaded with passengers or cargo.

Metric Conversion To convert kilograms into pounds, simply multiply the weight in kilograms by 2.205. For example, if something weighs 5 kilograms, then $5 \times 2.205 = 11.025$ pounds. To express this answer in pounds and ounces, convert the 0.025 pound into ounces. Because there are 16 ounces in a pound, multiply 16 by 0.025 ($16 \times 0.025 =$ approximately 0.4 ounce). Therefore, 5 kilograms is equal to 11 pounds and 0.4 ounce.

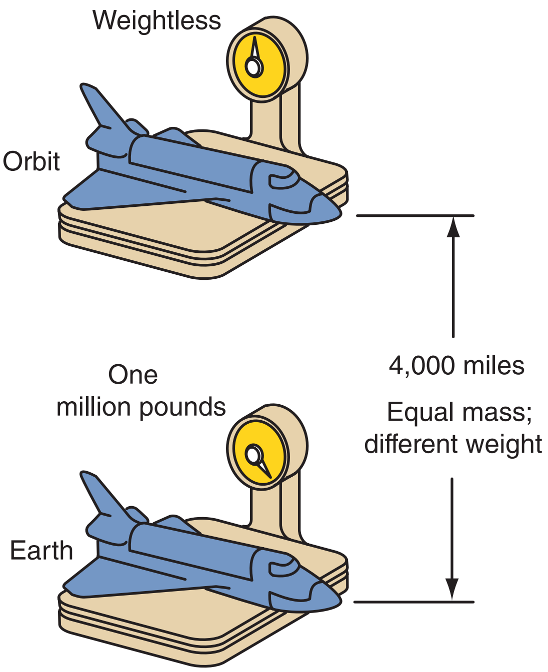


FIGURE 3–9 The difference in weight of a space shuttle on earth and in space.

Size

The size of something is related to its mass. An object's size defines how much space it occupies. Size dimensions are typically stated in terms of its length, width, and height. Length is a measurement of how long something is from one end to another. Width is a measurement of how wide something is from one side to another. Obviously height is the distance from something's bottom to its top **(Figure 3–10)**. All three of these dimensions are measured in inches, feet, yards, and miles in the English system and meters in the metric system.

Sometimes distance measurements are made with a rule that has fractional, rather than decimal, increments. Most automotive specifications are given decimally; therefore, fractions must be converted into decimals. It is also easier to add and subtract dimensions if they are expressed in decimal form rather than fractions. If you want to find the rolling circumference of a tire and the diameter of the tire is $20\frac{3}{8}$ inches, convert the fraction to decimals before going further. The distance around the tire is the circumference and is equal to the diameter multiplied by a constant called pi (π). Pi is equal to approximately 3.14; therefore, the circumference of the tire is equal to the diameter multiplied by 3.14. Convert the $20\frac{3}{8}$ inches into a whole number and a decimal. To convert the $\frac{3}{8}$ to a decimal, divide 3 by 8 ($3 \div 8 = 0.375$). Therefore, the diameter of the tire is 20.375 inches. Now multiply the diameter by π ($20.375 \times 3.14 = 63.98$). The circumference of the tire is nearly 64 inches.

Metric Conversion To convert English and metric measurements, refer to **Table 3–1**.

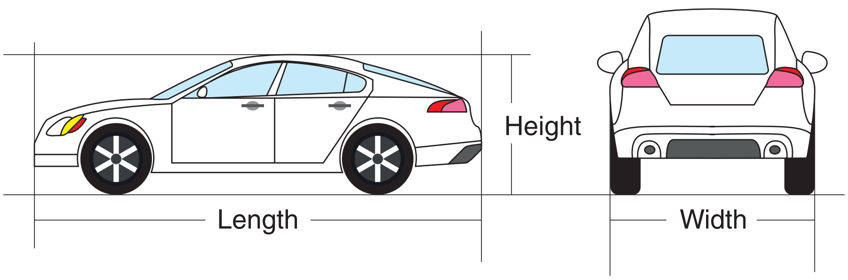


FIGURE 3–10 Common measurements used to define size.

TABLE 3-1

To Find		Multiply	×	Conversion Factors
millimeters	=	inches	×	25.40
centimeters	=	inches	×	2.540
centimeters	=	feet	×	32.81
meters	=	feet	×	0.3281
Kilometers	=	feet	×	0.0003281
Kilometers	=	miles	×	1.609
inches	=	millimeters	×	0.03937
inches	=	centimeters	×	0.3937
feet	=	centimeters	×	30.48
feet	=	meters	×	0.3048
feet	=	kilometers	×	3048.
Yards	=	meters	×	1.094
miles	=	kilometers	×	0.6214

Volume

Volume is a measurement of size and is related to mass and weight. Volume is the amount of space occupied by an object in three dimensions: length, width, and height. For example, a pound of gold and a pound of feathers both have the same weight, but the pound of feathers occupies a much larger volume. In the English system, volume is measured in cubic inches, cubic feet, cubic yards, or gallons. The measurement for volume in the metric system is cubic centimeters or liters **(Figure 3–11)**.

The volume of a container is calculated by taking an object's measured length, width, and height and multiplying them. For example, if a box has a length of 2 inches, a width of 3 inches, and a height of 4 inches ($2 \times 3 \times 4 = 24$), its volume equals 24 cubic inches. Different shapes have different formulas for calculating volume but all consider the object's three dimensions.

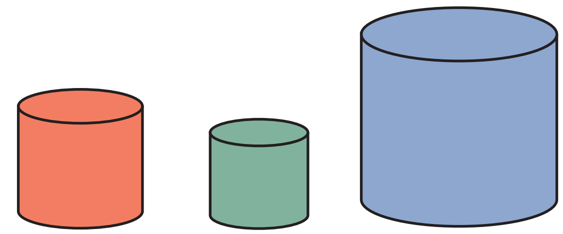


FIGURE 3–11 A comparison of metric and English units of volume.

The volume of an engine's cylinders is expressed as **displacement**. This size does *not* reflect the external (length, width, and height) of the engine. Cylinder displacement is the maximum volume of a cylinder. A piston's travel from its lowest point, called bottom dead center (BDC) to its highest point, top dead center (TDC) within the cylinder is called the stroke of the piston **(Figure 3–12)**. A cylinder's bore is the diameter of the cylinder.

Displacement is usually measured in cubic inches, cubic centimeters, or liters. The total displacement of an engine (including all cylinders) is a rough indicator of its power output. Total displacement is the sum of displacements for all cylinders in an engine. Engine cubic inch displacement (CID) may be calculated as follows:

$$CID = \pi \times R^2 \times L \times N$$

where $\pi = 3.1416$
$R =$ the radius of the cylinder or (the diameter, the bore, ÷ 2)
$L =$ length of stroke
$N =$ number of cylinders in the engine

Example: Calculate the CID of a six-cylinder engine with a 3.7 inches bore and 3.4 inches stroke.

$$CID = 3.1416 \times 1.85^2 \times 3.4 \times 6$$
$$CID = 219.66$$

Most of today's engines are listed by their metric displacement. Cubic centimeters and liters are determined by using metric measurements in the displacement formula.

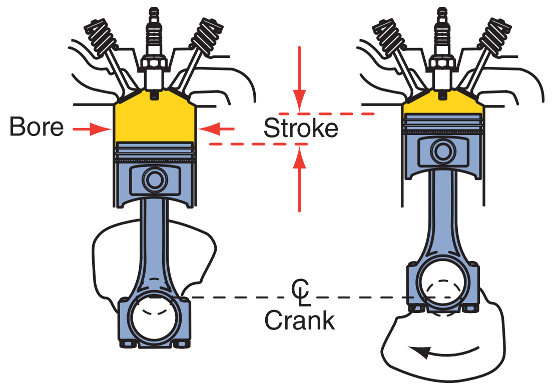


FIGURE 3–12 The bore and stroke of an engine.

Example: Calculate the metric displacement of a four-cylinder engine with a 78.9 mm stroke and a 100 mm bore. Before you use the formula to find the displacement in cubic centimeters, convert the millimeter measurements to centimeters: 78.9 mm = 7.89 cm and 100 mm = 10 cm.

Displacement = $3.1416 \times 5^2 \times 7.89 \times 4$

Displacement = 2479 cubic centimeters (cc) or approximately 2.5 liters (L)

Ratios

Often automotive features are expressed as ratios. A ratio expresses the relationship between two things. If something is twice as large as another, there is a ratio of 2:1. Sometimes ratios are used to compare the movement of an object. For example, if a 1-inch movement by something causes something else to move 2 inches, there is a travel ratio of 1:2.

An engine's **compression ratio** expresses how much the air and fuel mixture is compressed as a cylinder's piston moves from the bottom (BDC) to the top (TDC) of the cylinder. The compression ratio is defined as the ratio of the volume in the cylinder above the piston when the piston is at BDC to the volume in the cylinder at TDC **(Figure 3–13)**. The formula for calculating the compression ratio is as follows:

$$\frac{\text{volume above the piston at BDC}}{\text{volume above the piston at TDC}}$$

In many engines, the top of the piston is at the top of the cylinder block during TDC. The combustion chamber is the cavity in the cylinder head above the piston. This may be modified slightly by the shape of the top of the piston. The volume of the combustion chamber must be added to each volume in the formula in order to get an accurate calculation of compression ratio.

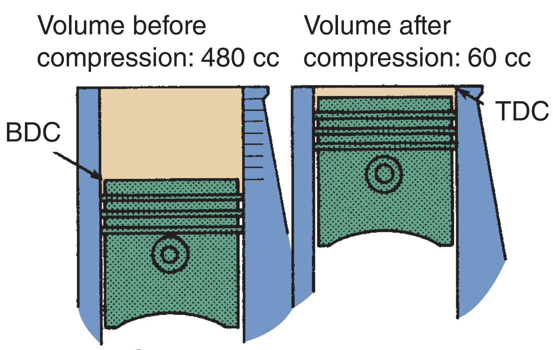


FIGURE 3–13 An engine's compression ratio indicates the amount the air and fuel mixture is compressed during the compression stroke of a piston.

Example: Calculate the compression ratio if the total piston displacement is 45 cubic inches and the combustion chamber volume is 5.5 cubic inches.

$$45 + 5.5 \div 5.5 = 9.1$$

Therefore, the compression ratio is 9.1 to 1 or 9.1:1.

Proportions

Ratios are also used to express the correct mixture for something. For example, engine coolant should typically be mixed with 50 percent coolant and 50 percent water when the cooling system is refilled **(Figure 3–14)**. This is a 1:1 ratio. This ratio allows for maximum hot and cold protection.

Consider a cooling system that has a capacity of 9.5 liters. Because most coolant is sold in gallon containers, to determine the amount of coolant that should be put in the system, first convert the liter capacity to gallons. Because 1 gallon equals 3.7854 liters, divide 9.5 liters by 3.7854 ($9.5 \div 3.7854 = 2.5097$). Therefore, the total capacity of the cooling system is a little more than 2.5 gallons. To determine how much coolant to put in the system, divide the total capacity by 2 ($2.5 \div 2 = 1.25$). Therefore, the correct mixture is 1¼ gallons of coolant mixed with 1¼ gallons of water.

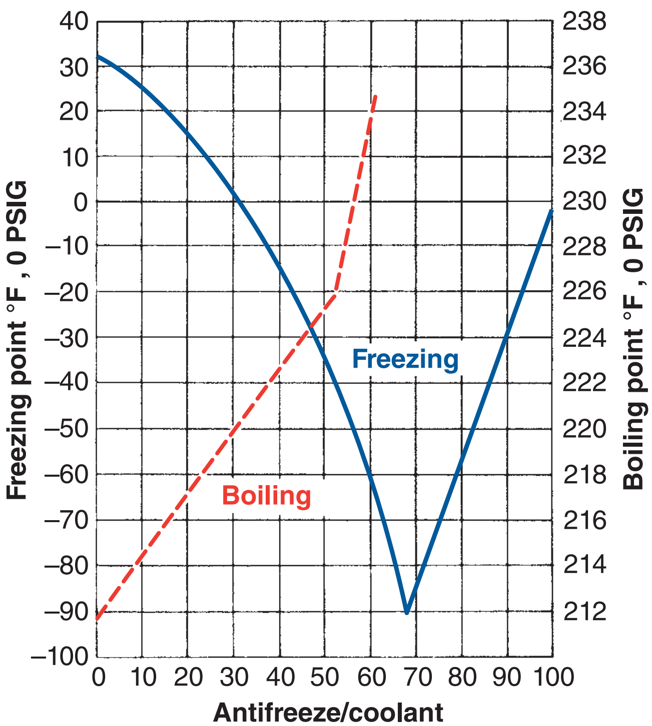


FIGURE 3–14 The relationship of the percentage of antifreeze to the freezing and boiling points of the engine's coolant.

Force

A **force** is a push or pull and can be large or small. Force can be applied by direct contact or from a distance. Gravity and electromagnetism are examples of forces that are applied from a distance. Forces can be applied from any direction and with any intensity. For example, if a pulling force is twice that of the pushing force, the object will be moved by one-half of the pulling force. When two or more forces are applied to an object, the combined force is called the resultant. The resultant is the sum of the amount and direction of the forces. For example, when a mass is suspended by two parallel lengths of wire, each wire will carry half the weight of the mass. If the attachment of the wires is moved so they are now at an angle to the mass, the wires will carry more force. They now carry the force of the mass plus the force that pulls against the other wire.

Automotive Forces

When a vehicle is sitting still, gravity exerts a downward force on the vehicle. The ground exerts an equal and opposite upward force and supports the vehicle. When the engine is running and its power is transferred to the drive wheels, the wheels exert a force against the ground in a horizontal direction. This causes the vehicle to move but it is opposed by the mass of the vehicle **(Figure 3–15)**. To move the vehicle faster, the force supplied by the wheels must increase beyond the opposing forces. As the vehicle moves faster, it pushes against the air as it travels. This becomes a growing opposing force, and the force at the drive wheels must overcome that force in order for the vehicle to increase speed. After the vehicle has achieved the desired speed, no additional force is required at the drive wheels.

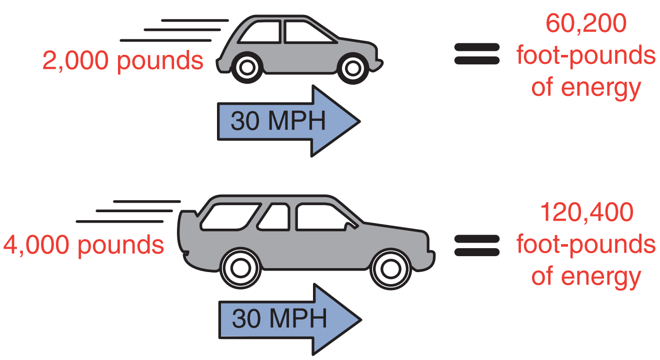


FIGURE 3–15 The amount of energy required to move a vehicle depends on its mass.

Force—Balanced and Unbalanced When the applied forces are balanced and there is no overall resultant force, the object is in **equilibrium**. An object sitting on a solid flat surface is in equilibrium. If the surface is set at a slight angle, forces will cause the object to slowly slide down the surface. If the surface is at a severe angle, forces will cause the object to quickly slide down the slope. In both cases, the surface is still supplying the force needed to support the object but the pull of gravity is greater and the resultant force causes the object to slide down at a different speed.

Turning Forces Forces can cause rotation as well as straight line motion. A force acting on an object that is free to rotate will have a turning effect, or turning force. This force is equal to the force multiplied by the distance of the force from the turning point around which it acts.

Forces on Tires and Wheels

If you roll a cone-shaped object on a smooth surface, the cone will not roll in a straight line. Rather it will move in the direction of the cone's tilt **(Figure 3–16)**. Riding a bicycle is an example of this. To turn left, it is easier to tilt the bicycle to the left. A tilted, rolling wheel tends to move in the direction of the tilt. Similarly, if a vehicle's tire and wheel are tilted, the tire and wheel will tend to move in the direction of the tilt. This is a principle considered during wheel alignment.

While riding a bicycle, your weight is projected through the bicycle's front fork to the road surface.

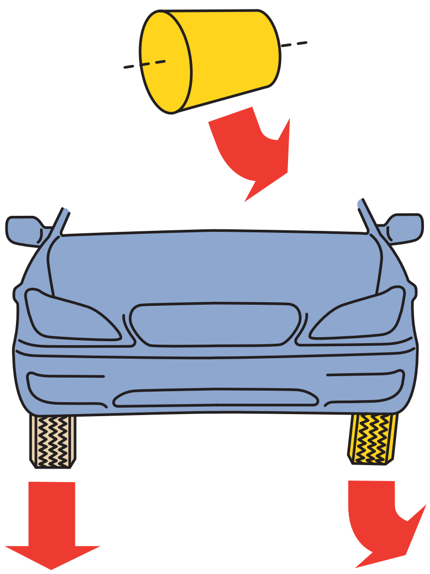


FIGURE 3–16 A tire at an angle will roll in the same way as a cone would.

The centerline of the front fork is tilted rearward in relation to the vertical centerline of the wheel. When the handle bars are turned, the tire pivots on the wheel's vertical centerline. Because the tire's pivot point is behind where your weight is projected against the surface of the road, the front wheel tends to return to the straight-ahead position after a turn. The wheel also tends to remain in the straight-ahead position as the bicycle is driven. This principle of resultant forces is the basis for precise wheel alignment.

Centrifugal/Centripetal Forces

When an object moves in a circle, its direction is continuously changing. All directional changes require a force. The forces required to maintain a circular motion are called centripetal and centrifugal forces. The forces depend on the size of the circle and the object's mass and speed.

Centripetal force tends to pull the object toward the center of the circle. **Centrifugal force** tends to push the object away from the center. The centripetal force that keeps an object whirling around on the end of a string is caused by tension in the string. If the string breaks, there is no longer string tension and the object will fly off in a straight line because of the centrifugal force on it. Gravity is the centripetal force that keeps the planets orbiting around the sun. Without this centripetal force, the earth would move in a straight line through space.

Wheel and Tire Balance

When the weight of a wheel and tire assembly is distributed equally around the center of wheel rotation, the wheel and tire has proper static balance. Being statically balanced, the wheel and tire assembly will not tend to rotate by itself, regardless of the wheel's position. If the weight is not distributed equally, the wheel and tire assembly is statically unbalanced. As the wheel and tire rotate, centrifugal force acts on this static unbalance and causes the wheel to "tramp" or "hop" **(Figure 3–17)**.

Dynamic balance exists when the weight thrown to the sides of a rotating tire and wheel assembly are equal **(Figure 3–18)**. To illustrate this, assume we have a bar with a ball attached by string to both ends of the bar. If we rotate the bar, the balls will turn with the bar and the centripetal and centrifugal forces will keep the balls in an orbit around the rotating bar. If the two balls weigh the same and are at an equal distance from the bar, the bar will rotate smoothly. However, if one of the balls is heavier, the bar will wobble as it rotates. The greater the difference in weight, the greater the wobble. The wobble can eventually destroy the mechanism used to rotate the bar.

Now if we add some weight to the end of the bar that has the lighter ball, the weights and forces can be equalized and the wobble removed. This is basically how we dynamically balance a wheel and tire assembly **(Figure 3–19)**.

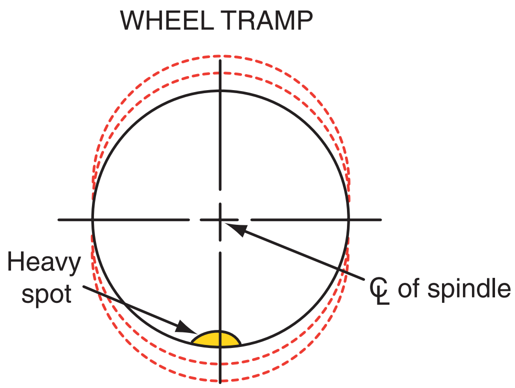


FIGURE 3–17 Wheel tramp is the result of a tire and wheel assembly being statically unbalanced.

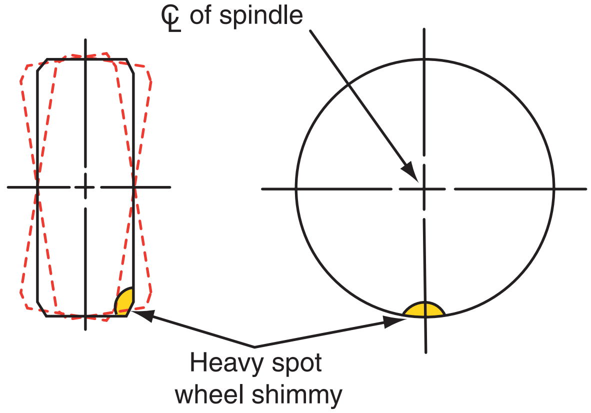


FIGURE 3–18 Dynamic imbalance causes wheel shimmy.

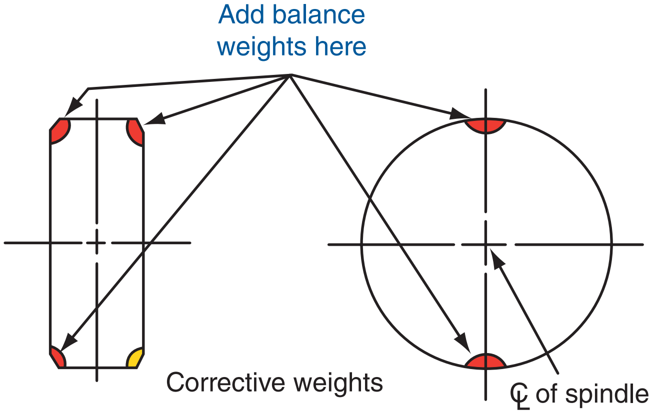


FIGURE 3–19 Adding a weight to counteract with the heavy spot of a tire and wheel assembly.

When we think of all the parts of an automobile that rotate, it is easy to see why proper balance is important. Improper balance can cause premature wear or destruction of parts.

Pressure

Pressure is a force applied against an object and is measured in units of force per unit of surface area (pounds per square inch or kilograms per square centimeter). Mathematically, pressure is equal to the applied force divided by the area over which the force acts. Consider two 10-pound weights sitting on a table; one occupies an area of 1 square inch and the other an area of 4 square inches. The pressure exerted by the first weight would be 10 pounds per 1 square inch or 10 psi. The other weight, although it weighs the same, will exert only 2.5 psi (10 pounds per 4 square inches = $10 \div 4 = 2.5$). This shows that a force acting over a large area will exert less pressure than the same force acting over a small area.

Because pressure is a force, all principles of force apply to pressure. If more than one pressure is applied to an object, the object will respond to the resultant force. Also, all matter (liquids, gases, and solids) tends to move from an area of high pressure to an area of low pressure.

Time

The word time is used to mean many things. For this discussion, time is defined as a measurement of the duration of something that has happened, is happening, or will happen. Time is measured by the increments of a clock: seconds, minutes, and hours. Often an automotive technician is concerned with how long something occurs, such as the length of time a spark plug fires to cause combustion. This time, called spark duration, is typically about 3 milliseconds (0.003 second) and is measured with a lab scope because it would be very difficult to measure that short of a time with a clock.

Technicians also monitor how many times a cycle is repeated within a period of time, such as a minute. A tachometer, which measures engine revolutions per minute, is often one of the gauges in the instrument panel.

Motion

When the forces on an object do not cancel each other out, they will change the object's speed or direction of motion, or both. The greater the object's mass, the greater the force must be to change its motion. This resistance to change is called inertia. **Inertia** is the tendency of an object at rest to remain at rest or the tendency of an object in motion to stay in motion in one direction. The inertia of an object at rest is called static inertia, whereas the inertia of an object in motion is called dynamic inertia. Inertia exists in liquids, solids, and gases. When you push and move a parked vehicle, you overcome the static inertia of the vehicle. If you catch a ball in motion, you overcome the dynamic inertia of the ball.

When a force overcomes static inertia and moves an object, the object gains momentum. **Momentum** is the product of an object's weight and speed. An object loses momentum if another force overcomes the dynamic inertia of the moving object.

Rates

Speed is the distance an object travels in a set amount of time. It is calculated by dividing the distance traveled by the time it took to travel that distance. We refer to the speed of a vehicle in miles per hour (mph) or kilometers per hour (km/h). **Velocity** is the speed of an object in a particular direction. **Acceleration** is the rate of increase in speed. Acceleration is calculated by dividing the change in speed by the time it took for that change. **Deceleration** is the reverse of acceleration; it is the rate of a decrease in speed.

Newton's Laws of Motion

How forces change an object's motion was first explained by Sir Isaac Newton in what is known as Newton's laws. Newton's first law of motion is called the law of inertia. It states that an object at rest tends to remain at rest and an object in motion tends to remain in motion, unless some force acts on it. When a car is parked on a level street, it remains stationary unless it is driven or pushed.

Newton's second law states that when a force acts on an object, the motion of the object will change. This change is equal to the size of the force divided by the object's mass. Trucks have a greater mass than cars. Because a large mass requires a larger force to produce a given acceleration, a truck needs a more powerful engine than a car.

Newton's third law says that for every action there is an equal and opposite reaction. A practical application of this occurs when the wheel strikes a bump in the road. This action drives the wheel and suspension upward with a certain force, and a specific amount of energy is stored in the spring. After

this, the spring forces the wheel and suspension downward with a force equal to the initial upward force caused by the bump.

Friction

Friction is a force that slows or prevents the motion of two objects or surfaces that touch. Friction may occur in solids, liquids, and gases. It is the joining or bonding of the atoms at each of the surfaces that causes the friction. When you attempt to pull an object across a surface, the object will not move until these bonds are overcome. Smooth surfaces produce little friction; therefore, only a small amount of force is needed to break the bonds of the atoms. Rougher surfaces produce a larger friction force because there are stronger bonds between the two surfaces **(Figure 3–20)** and a great amount of force is required.

Friction is put to good use in disc brakes **(Figure 3–21)**. The friction between the brake disc and pad slows the rotation of the wheel, reducing the vehicle's speed. In doing so, it converts the kinetic energy of the vehicle into heat.

Lubrication Friction can be reduced in two main ways: by lubrication or by the use of rollers. The presence of oil or another fluid between two surfaces keeps the surfaces apart. Because fluids (liquids and gases) flow, they allow movement between surfaces. The fluid keeps the surfaces apart, allowing them to move smoothly past one another **(Figure 3–22)**.

Rollers Rollers placed between two surfaces also keep the surfaces apart. An object placed on rollers

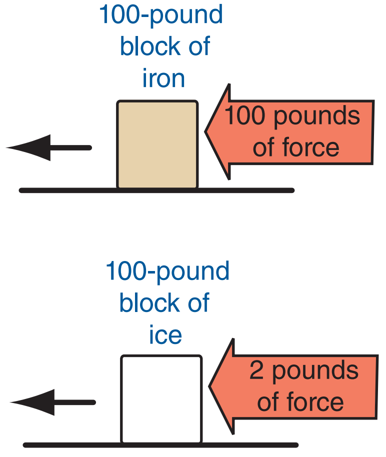


FIGURE 3–20 Sliding ice across a surface produces less friction than sliding a rougher material, such as iron, across a surface.

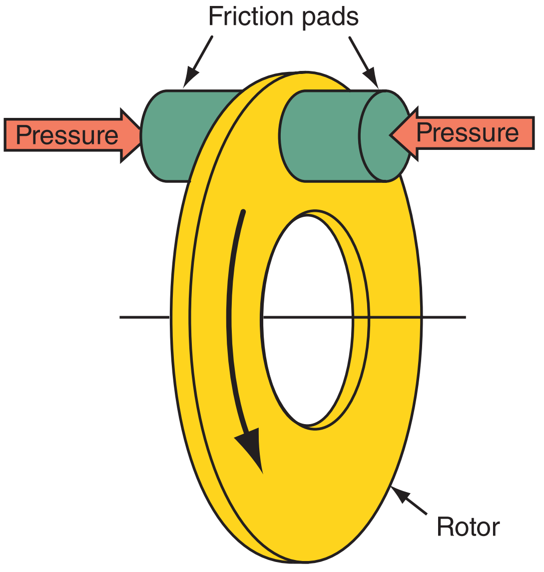


FIGURE 3–21 As pressure is applied to the friction pads, the pads attempt to stop the rotor to which the tire and wheel are attached.

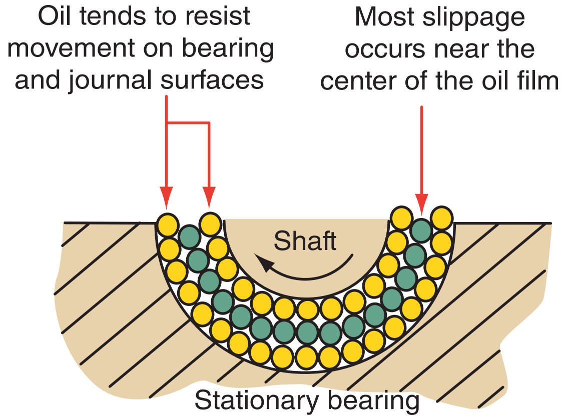


FIGURE 3–22 Oil separates the rotating shaft from the stationary bearing.

will move smoothly if pushed or pulled. Instead of sliding against one another, the surfaces produce turning forces, which cause each roller to spin. This leaves very little friction to oppose motion. Bearings are a type of roller used to reduce the friction between moving parts such as a wheel and its axle **(Figure 3–23)**. As the wheel turns on the axle, the balls in the bearing roll around inside the bearing, drastically reducing the friction between the wheel and axle.

Air Resistance

When a vehicle is driven, resistance occurs between the air and the vehicle's body. This resistance or friction opposes the momentum, or mechanical energy,

FIGURE 3–23 An assortment of tapered roller bearings and their races.

of the moving vehicle. The mechanical energy from the engine must overcome the vehicle's inertia and the friction of the air striking the vehicle. The faster an object moves, the greater the air resistance.

Body design, obviously, affects the amount of friction developed by the air striking the vehicle. The total resistance to motion caused by friction between a moving vehicle and the air is referred to as coefficient of drag (Cd). At 45 miles per hour (72 kilometers per hour), half of the engine's mechanical energy can be used to overcome air resistance. Therefore, reducing a vehicle's Cd is a very effective way to improve fuel economy. Cd may also be called aerodynamic drag.

Modern cars and trucks use passive and active aerodynamics to reduce drag and improve fuel economy. Passive items include the shape of the body and rear-view mirrors to improve the flow of air over, under, and around the vehicle. Many vehicles are using active aerodynamics, such as movable grill shutters, that open and close automatically while driving. Closing the shutters, such as during highway driving, improves aerodynamics and fuel economy.

Aerodynamics is the study of the effects of air on a moving object **(Figure 3–24)**. The basics of this science are fairly easy to understand. The larger the area facing the moving air is, the more the air will tend to hold back or resist forward motion.

Needless to say, the less air a vehicle pushes out of its way, the less power it needs to move at a given speed.

Most aerodynamic design work is done initially on a computer; the design is then checked and modified by placing the vehicle in a wind tunnel **(Figure 3–25)**. A wind tunnel is a carefully constructed facility with a large fan at one end. Inside the tunnel, the movement of air over, under, and around the vehicle is measured.

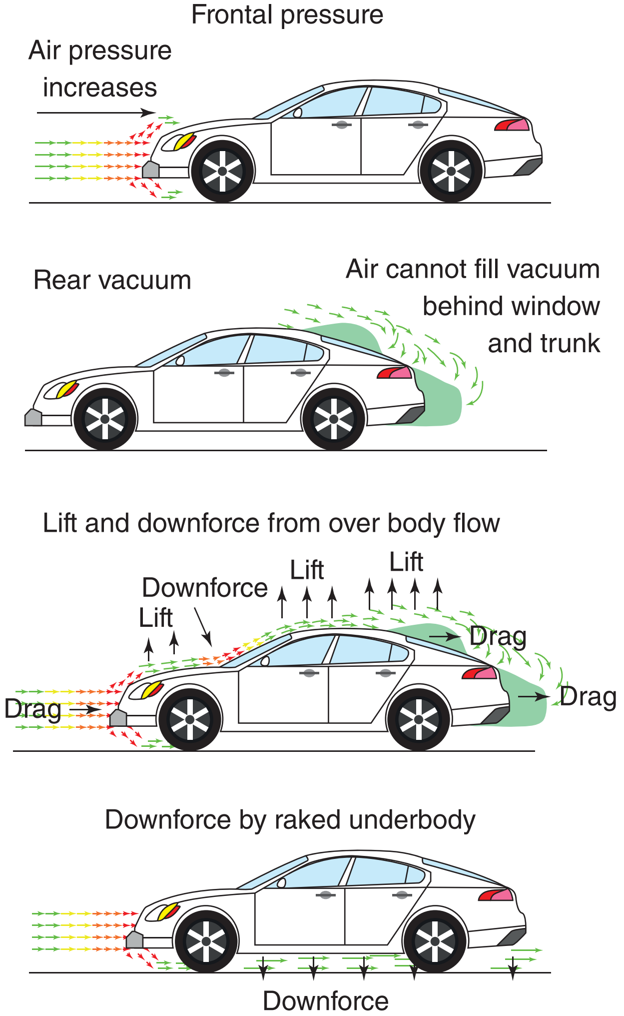


FIGURE 3–24 The various movements of air as it goes over a car.

Courtesy of Chrysler LLC.

FIGURE 3–25 This wind tunnel can generate winds as high as 150 miles per hour.

Ideally, the air moved by the vehicle will follow the contours of the vehicle. This prevents the air from doing funny things as it is pushed away. If the air that moves under the vehicle has a place to push up, the vehicle will tend to lift. This creates poor handling, a situation that can be very unsafe. Air can also be trapped under the vehicle, which increases the vehicle's air drag. If air moving over the top pushes against the vehicle, there is an increase in air drag. To help direct the air and make it usable, air dams and spoilers or wings are used.

Work

When a force moves a mass a specific distance, work is done. When work is accomplished, a mass may be lifted or pushed against a resistance or opposing force **(Figure 3–26)**. **Work** is equal to the applied force multiplied by the distance the object moved (force × distance = work) and is measured in foot-pounds **(Figure 3–27)**, watts, or Newton-meters. For example, if a force moves a 3,000-pound car 50 feet, 150,000 foot-pounds of work was done.

During work, a force acts on an object to start, stop, or change its direction. It is possible to apply a force and not move the object. For example, you may push with all your strength on a car stuck in a ditch and not move it. This means no work was done. Work is only accomplished when an object is started, stopped, or redirected by a force.

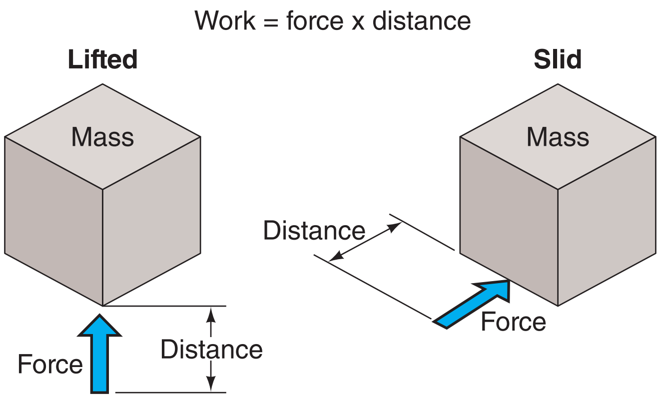


FIGURE 3–26 When work is performed, a mass is moved a certain distance.

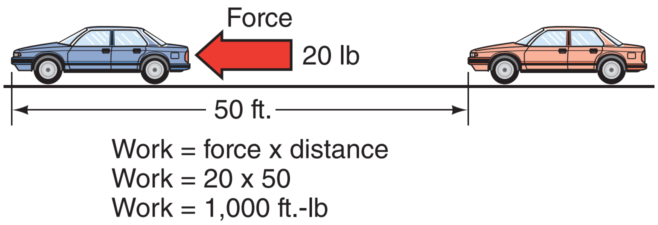


FIGURE 3–27 1,000 foot-pounds of work.

Simple Machines

A machine is any device used to transmit a force and, in doing so, changes the amount of force and/or its direction. A common example of a simple machine that does both is a valve rocker arm. One end of a rocker arm is pushed up by the action of the engine's camshaft. When this happens, the other end of the rocker arm pushes down on a valve to open it. A rocker arm is also designed to change the size of the force applied to it. Rocker arms provide more movement on the valve side or output than the input side. The difference is expressed as the rocker arm's ratio. If a rocker arm has a ratio of 1.5:1, one end of it will move 1.5 times more than the other **(Figure 3–28)**. For example, if the camshaft causes one end of the rocker arm to move ½ inch, the other end will move ¾ of an inch.

The force applied to a machine is called the effort, while the force it overcomes is called the **load**. The effort is often smaller than the load, because a small effort can overcome a heavy load if the effort is moved over a large distance. The machine is then said to give a **mechanical advantage**.

Inclined Plane The force required to drag an object up a slope **(Figure 3–29)** is less than that required to lift it vertically. However, the overall distance moved by the object is greater when pulled up the slope than if it were lifted vertically. A screw is an inclined plane wrapped around a shaft. The force that turns

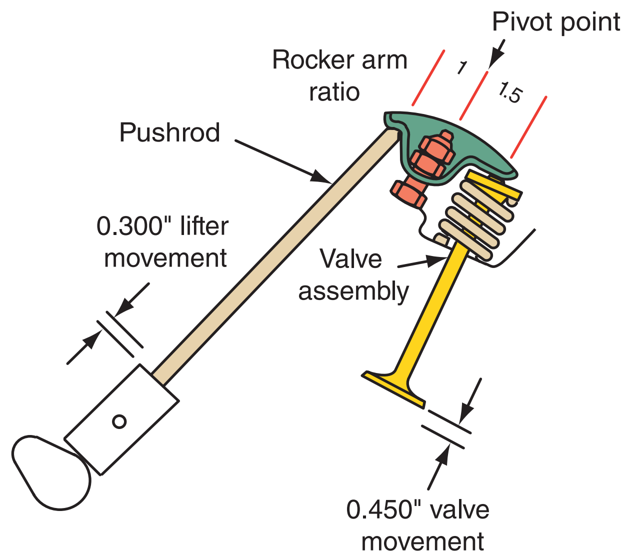


FIGURE 3–28 A rocker arm with a ratio of 1:1.5.

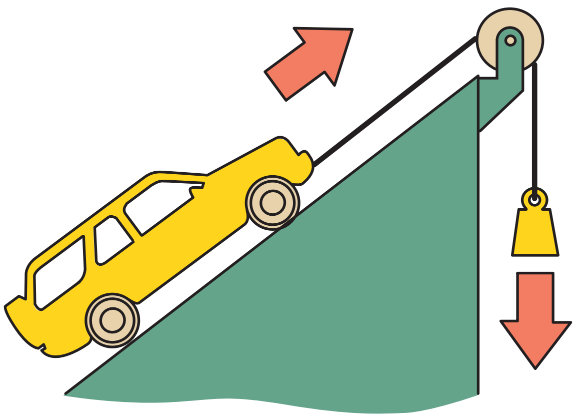


FIGURE 3–29 It takes less energy to pull a mass up an inclined plane than would be required to lift the mass vertically.

the screw is converted to a larger one, which moves a shorter distance and drives the screw inches

Pulleys A **pulley** is a wheel with a grooved rim in which a rope or belt conveys the force from another pulley to move something. A simple pulley changes the direction of a force but not its size. Also, the distance the force moves does not change. By using several pulleys connected together as in a block and tackle, the size of the force can be changed too, so that a heavy load can be lifted using a small force. With a double pulley, the required applied force to move an object can be reduced by one-half, but the distance the force must be moved is doubled. A quadruple pulley can reduce the force by four times, but the distance will be increased by four times. Pulleys of different sizes can change the required applied force as well as the speed or distance the pulley needs to travel to accomplish work **(Figure 3–30)**.

Levers A **lever** is a device made up of a bar pivoting on a fixed point called the fulcrum. A lever uses a force applied at one end to move a mass on the other end of the bar. Levers are divided into classes. In a class one lever, the fulcrum is between the effort and the load **(Figure 3–31)**. The load is larger than the effort, but it moves a smaller distance. A pair of pliers is an example of a class one lever. In a class two lever, the load is between the fulcrum and the effort. Here again, the load is greater than the effort and moves through a smaller distance **(Figure 3–32)**. A wheelbarrow is an example of class two lever. In a class three lever, the effort is between the fulcrum and the load. In this case, the load is less than the effort but it moves through a greater distance. Tweezers are an example of a class three lever.

Gears A **gear** is a toothed wheel that becomes a machine when it is meshed with another gear. The action of one gear is the same as a rotating lever and moves the other gear with it. Based on the size of the gears, the amount of force applied from one gear to

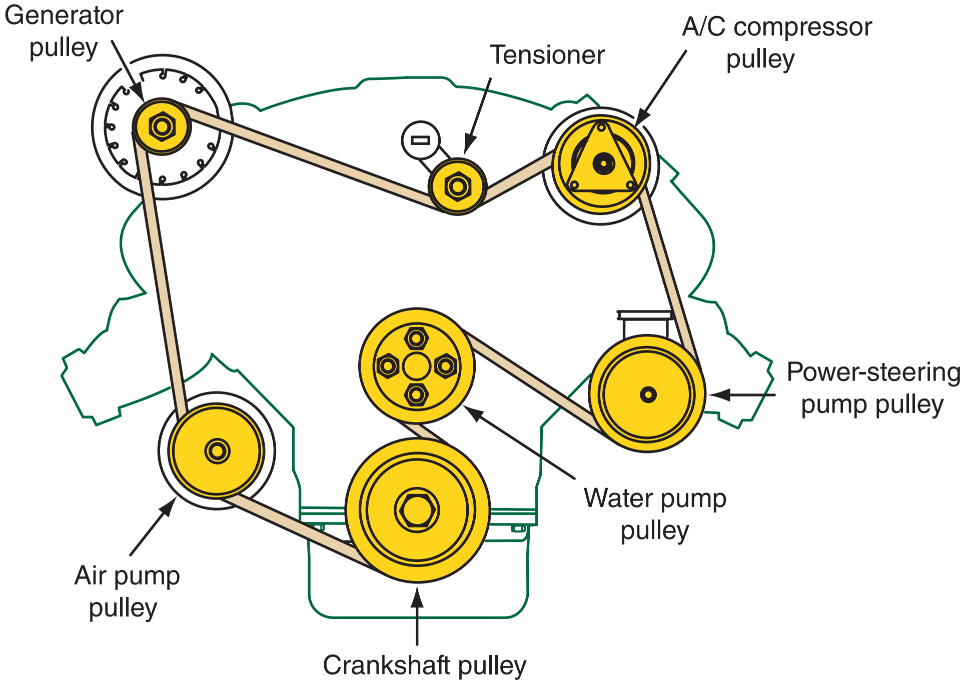


FIGURE 3–30 Accessories are driven by a common drive belt but they rotate at different speeds because of the differences in pulley size.

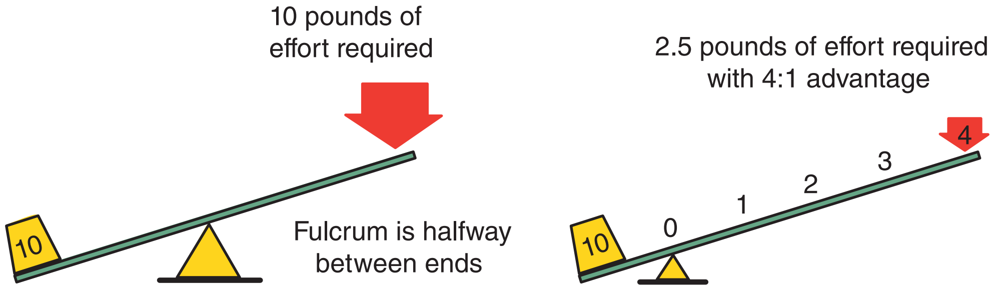


FIGURE 3–31 A mechanical advantage can be gained with a class one lever.

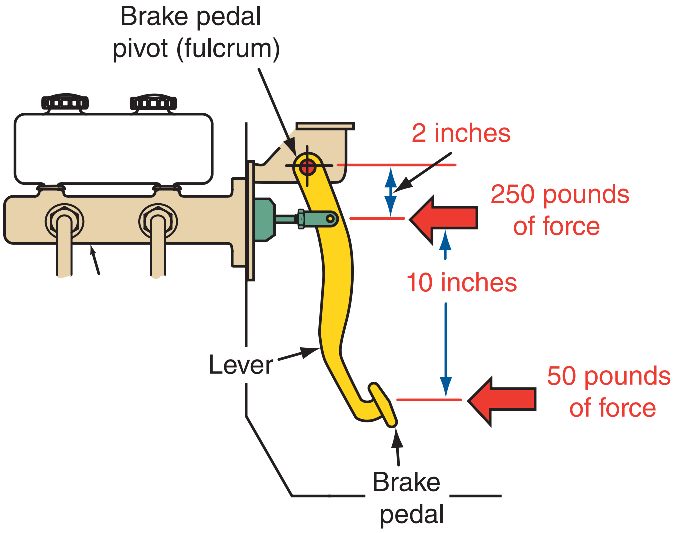


FIGURE 3–32 A brake pedal assembly is an example of a class two lever.

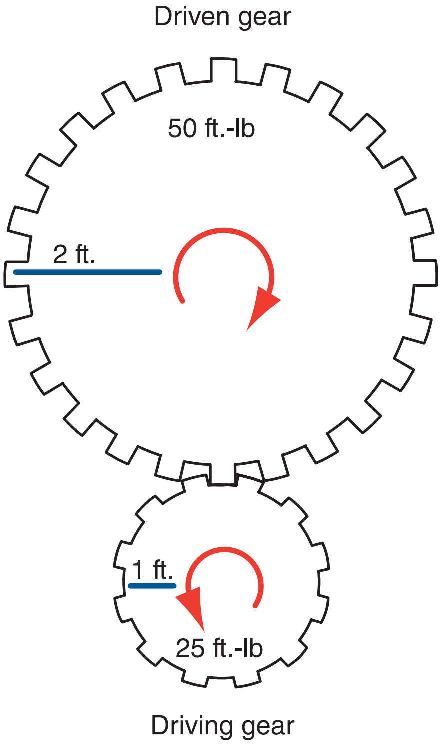


FIGURE 3–33 When a small gear drives a larger gear, the larger gear turns with more force but travels less; therefore, the amount of work stays the same.

the other can be changed. Keep in mind that this does not change the amount of work performed by the gears because the change in force is accompanied by a change in the distance of travel **(Figure 3–33)**. The relationship of force and distance is inverse. Gear ratios express the mathematical relationship (diameter and number of teeth) of one gear to another. To take advantage of the mechanical advantage offered by gears, the gears do not need to be meshed together, they can be connected by a chain.

Wheels and Axles The most obvious application of a wheel and axle is a vehicle's tires and wheels. These revolve around an axle and limit the amount of area that contacts the road. Wheels function as rollers to reduce the friction between a vehicle and the road. Basically, the larger the wheel, the less force is required to turn it. However, the wheel moves farther as it gets larger. An example of this is a steering wheel. A steering wheel that is twice the size of another will require one-half the force to turn it but will also require twice the distance to accomplish the same work.

Torque

Torque is a force that rotates or turns things and is measured by the force applied and the distance traveled. The technically correct unit of measurement for torque is pounds per foot (lb-ft.). However, it is rather common to see torque stated as foot-pounds (ft.-lb). In the metric, or SI, system, torque is stated in Newton-meters (N-m) or kilogram-meters (kg-m).

An engine creates torque and uses it to rotate the crankshaft. The combustion of fuel and air creates pressure against the top of a piston. That pressure creates a force on the piston and pushes it down. The force is transmitted from the piston to the connecting rod and from the connecting rod to the

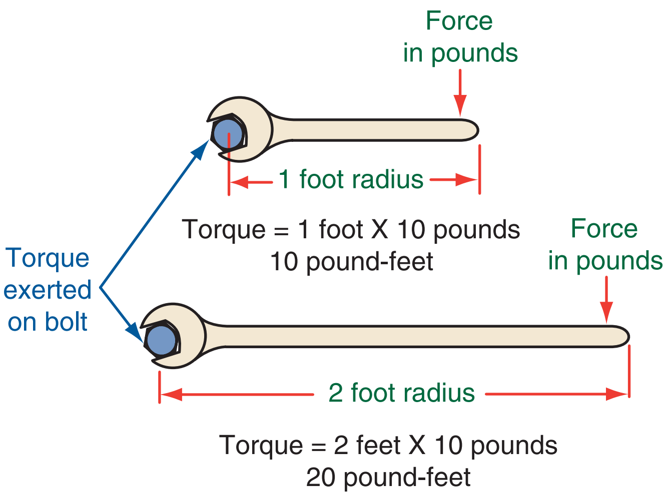


FIGURE 3–34 The amount of torque applied to a wrench is changed by the length of the wrench.

crankshaft. The engine's crankshaft rotates with a torque that is sent through the drivetrain to turn the drive wheels of the vehicle.

Torque is force times leverage, the distance from a pivot point to an applied force. Torque is generated any time a wrench is turned with force. If the wrench is a foot long, and 20 pounds of force is applied to it, 20 pounds per foot are being generated. To generate the same amount of torque while exerting only 10 pounds of force, the wrench needs to be 2 feet long **(Figure 3–34)**. To have torque, it is not necessary to have movement. When you pull a wrench to tighten a bolt, you supply torque to the bolt. If you pull on a wrench to check the torque on a bolt and the bolt torque is correct, torque is applied to the bolt but no movement occurs. If the bolt turns during torque application, work is done. If the bolt does not rotate, no work has been done.

Torque Multiplication

When gears with different numbers of teeth mesh, each rotates at a different speed and force. Torque is calculated by multiplying the force by the distance from the center of the shaft to the point where the force is exerted.

The distance from the center of a circle to its outside edge is its radius. On a gear, the radius is the distance from the center of the gear to the point on its teeth where force is applied.

If a tooth on the driving gear is pushing against a tooth on the driven gear with a force of 25 pounds and the force is applied at a distance of 1 foot (the radius of the driving gear), a torque of 25 ft.-lb is applied to the driven gear. The 25 pounds of force from the teeth of the smaller (driving) gear is applied to the teeth of the larger (driven) gear. If that same force were applied at a distance of 2 feet from the center, the torque on the shaft of the driven gear would be 50 ft.-lb **(see Figure 3–33)**. The same force is acting at twice the distance from the shaft center.

The amount of torque that can be applied from a power source is proportional to the distance from the center at which it is applied. If a fulcrum or pivot point is placed closer to the object being moved, more torque is available to move the object, but the lever must move farther than if the fulcrum were farther away from the object. The same principle is used for gears in mesh: A small gear will drive a large gear more slowly but with greater torque.

A drivetrain consisting of a driving gear with eleven teeth and a radius of 1 inch and a driven gear with forty-four teeth and a radius of 4 inches will have a torque multiplication factor of 4 and a speed reduction of ¼. Thus, the larger gear will turn with four times the torque but one-fourth the speed **(Figure 3–35)**. The radii between the teeth of a gear act as levers.

Gear ratios express the mathematical relationship of one gear to another. Gear ratios can vary by changing the diameter and number of teeth of the gears in mesh. A gear ratio also expresses the amount of torque multiplication between two gears. The ratio is obtained by dividing the diameter or number of teeth of the driven gear by the diameter or teeth of the drive gear. If the smaller driving gear had eleven teeth and the larger gear had forty-four teeth, the ratio is 4:1.

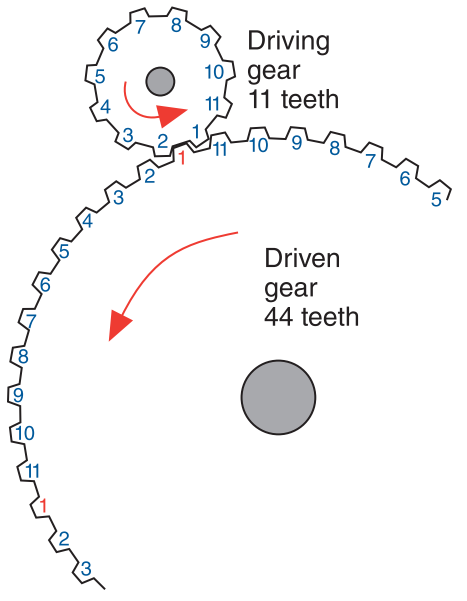


FIGURE 3–35 The driving gear must rotate four times to rotate the driven gear once.

Power

Power is a measurement of the rate, or speed, at which work is done. The metric unit for power is the watt. A watt is equal to one Newton-meter per second. Power is a unit of speed combined with a unit of force. For example, if you were pushing something with a force of 1 N and it moved at 1 meter per second, the power output would be 1 watt.

In electrical terms, 1 watt is equal to the amount of electrical power produced by a current of 1 ampere across a potential difference of 1 volt. This is expressed as Power (P) − Voltage (E) × Current (I) or $P = E \times I$.

Horsepower

Horsepower is the rate at which torque is produced. James Watt is credited with being the first person to calculate horsepower and power. He measured the amount of work a horse could do within a specific time. A horse could move 330 pounds 100 feet in 1 minute **(Figure 3–36)**. Therefore, he determined that one horse could do 33,000 ft.-lb of work in 1 minute. Thus, 1 horsepower is equal to 33,000 ft.-lb per minute, or 550 ft.-lb per second. Two horsepower could do this same amount of work in ½ minute. If you push a 3,000-pound (1,360-kilogram) car for 11 feet (3.3 meters) in ¼ minute, you produce 4 horsepower.

An engine producing 300 ft.-lb of torque at 4,000 rpm produces 228 horsepower at 4,000 rpm. This is based on the fact that horsepower is equal to torque multiplied by engine speed, and that quantity is divided by 5252 ([torque × engine speed] ÷ 5252 = horsepower). The constant, 5252, is used to convert the rpm into revolutions per second.

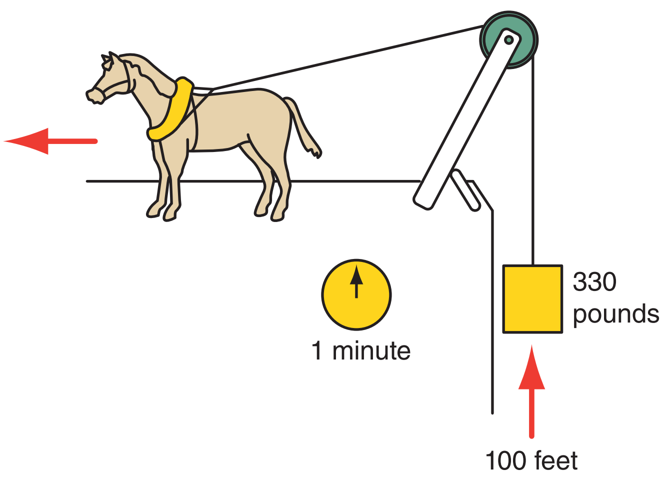


FIGURE 3–36 This is how James Watt defined one horsepower.

SHOP TALK

Manufacturers are now rating their engines' outputs in watts. One horsepower is equal to approximately 746 watts. Therefore, a 228-hp engine or motor can be rated at 170,088 watts or about 170 kW.

Gross vs Net Horsepower Engine output is measured at the flywheel. Prior to the 1972 model year, automakers rated and advertised their engines in brake horsepower (bhp), often called gross horsepower. Gross hp was measured using a stock test engine, equipped with few belt-driven accessories and sometimes fitted with exhaust headers rather than stock exhaust manifolds. Since then many manufacturers express an engine's power as net horsepower. This rating is based on a stock engine equipped with normal belt-driven accessories, emission controls, standard exhaust system, air cleaner, and common accessories. To express the true power output of an engine, a voluntary test has been established. The results of this test are reported as "SAE Certified Power".

Crankshaft vs Wheel Horsepower Crankshaft horsepower is measured at the engine's flywheel and with only the accessories required for a running engine. Wheel horsepower is measured at the vehicle's drive wheels and the engine is fitted with all of its accessories. Wheel horsepower will always be lower than crankshaft horsepower because horsepower is lost as it moves through the transmissions and drivetrain. Normally there is a power loss of 20 to 22 percent through the drivetrain.

Waves and Oscillations

An **oscillation** is the back-and-forth movement of an object between two points. When that motion travels through matter or space, it becomes a **wave**. A mass suspended by a spring, for example, is acted on by two forces: gravity and the tension of the spring. At the point of equilibrium, the resultant of these forces is zero. When the mass is given a downward push, the tension of the spring exceeds the weight of the mass. The resultant upward force accelerates the mass back up toward its original position and its momentum carries it farther upward. When the weight exceeds the spring's tension, the mass moves down again and the oscillation repeats itself until the mass is at equilibrium. As the mass

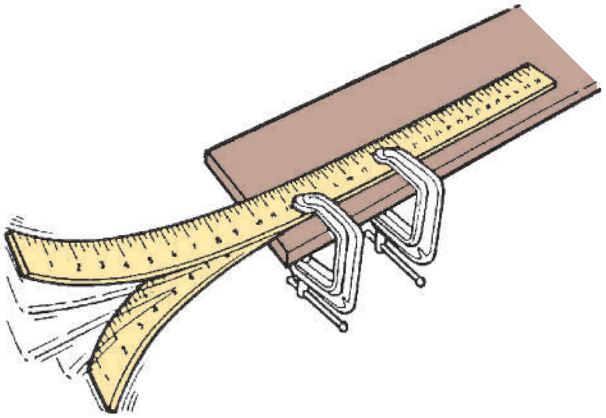


FIGURE 3–37 Vibrations happen in cycles; notice how the yardstick moves up and down in cycles.

oscillates toward the equilibrium position, the size of the oscillation decreases. As the mass oscillates, the air around it moves and becomes an air wave.

Vibrations

When an object oscillates, it vibrates **(Figure 3–37)**. To prevent the vibration of one object from causing a vibration in other objects, the oscillating mass must be isolated from other objects. This is often a difficult task. For example, all engines vibrate as they run. To reduce the transfer of engine vibrations to the rest of the vehicle, the engine is held by special mounts. The materials used in the mounts must keep the engine in place and must be elastic enough to absorb the engine's vibrations **(Figure 3–38)**. If the engine was mounted solidly, the vibrations would be felt throughout the vehicle.

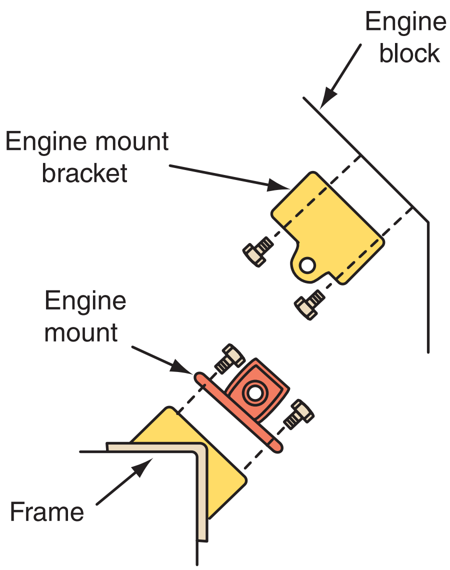


FIGURE 3–38 An engine mount holds the engine in place and isolates engine vibrations from the rest of the vehicle.

Vibration control is also important for the reliability of components. If the vibrations are not controlled, the object could shake itself to destruction. Vibration control is the best justification for always mounting parts in the way they were designed to be mounted.

Unwanted and uncontrolled vibrations typically result from one component vibrating at a different frequency than another part. When two waves or vibrations meet, they add up or interfere. This is called the principle of superposition and is common to all waves. Making unwanted vibrations tolerable can be done by canceling them with equal and opposite vibrations. This approach to vibration reduction is best illustrated by the use of balance shafts in an engine. These shafts are designed to counter the vibrations caused by the rotation of the engine's crankshaft and pistons **(Figure 3–39)**. The balance shaft spins and creates an equal but opposite vibration to cancel the vibrations of the crankshaft.

How many times the vibration occurs in 1 second is called **frequency**. Frequency **(Figure 3–40)** is most often expressed in **hertz (Hz)**. One hertz is equal to one cycle per second. The name is in honor of Heinrich Hertz, an early German investigator of radio wave transmission. The **amplitude** of a vibration is its intensity or strength **(Figure 3–41)**. The velocity of a vibration is the result of its amplitude and its frequency. All materials have a unique resonant or natural vibration frequency.

Vibrations are also classified by their order, meaning how many times per cycle the vibration occurs. For example, a tire with a bulge in the tread

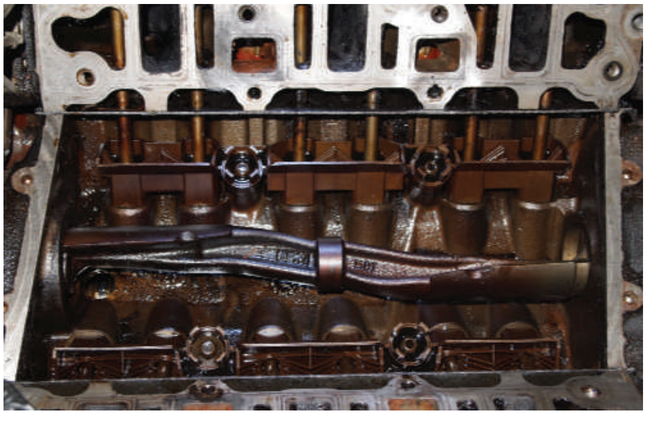


FIGURE 3–39 Balance shafts are driven by the crankshaft and work to counter crankshaft pulses and vibrations by acting with an equal force but in the opposite direction.

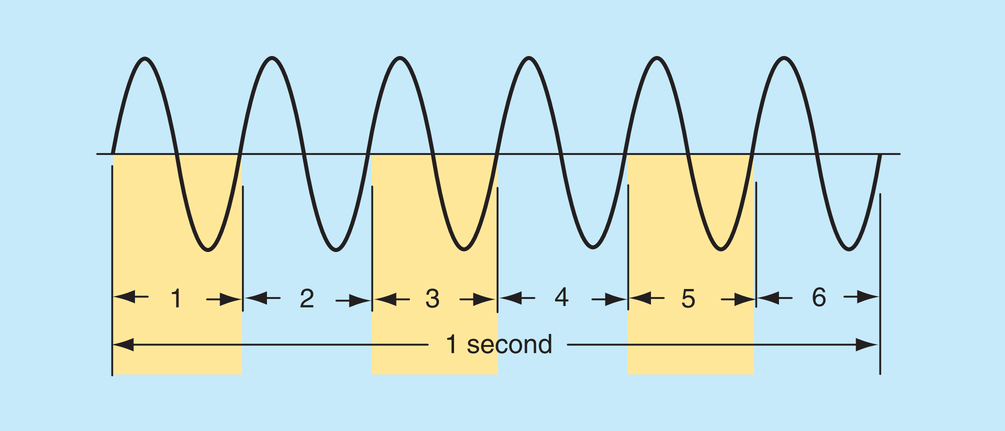


FIGURE 3–40 Frequency is a statement of how many cycles occur in a second.

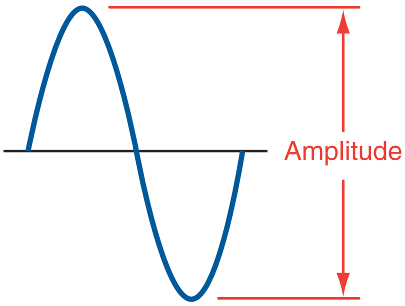


FIGURE 3–41 Amplitude is a measurement of a vibration's intensity.

will cause one bump per revolution **(Figure 3–42)**. This is called a first-order vibration. Our example tire, size P225/45/R19, has an overall diameter of 27 inches and a circumference of 84.8 inches. There are 63,360 inches of tire surface per mile, which means the tire spins about 747 times per mile or 12.5 times per second. This is the same as 12.5 Hz (747/60). Each time the bump hits the road, a vibration is sent back up the steering system to the steering wheel and can be felt by the driver. A second-order vibration takes place twice per revolution, as shown

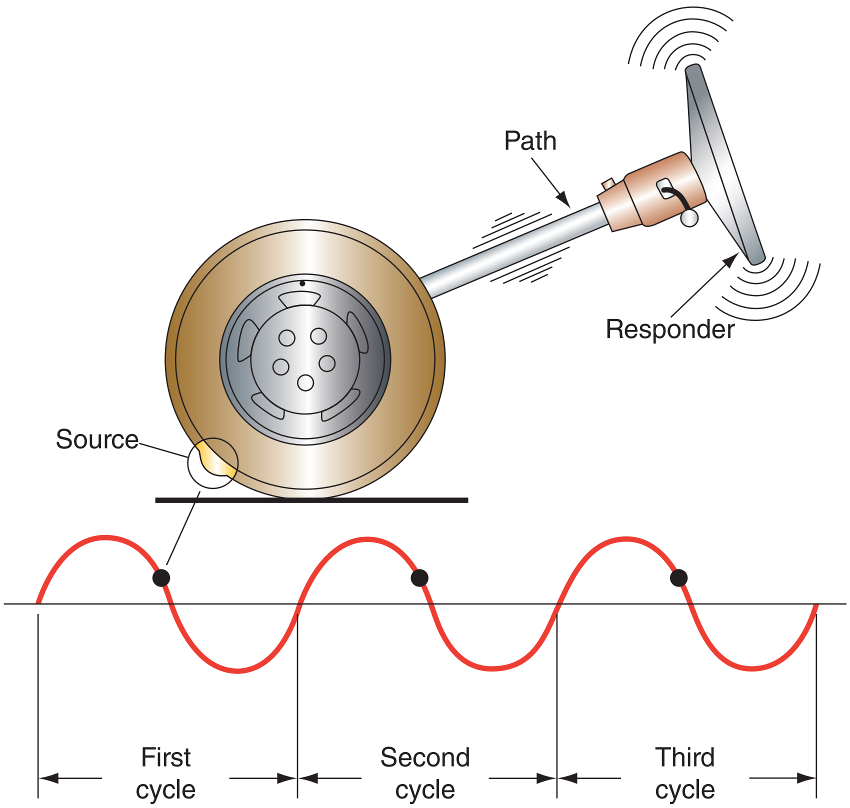


FIGURE 3–42 A bulge in the tire will cause a vibration once per revolution.

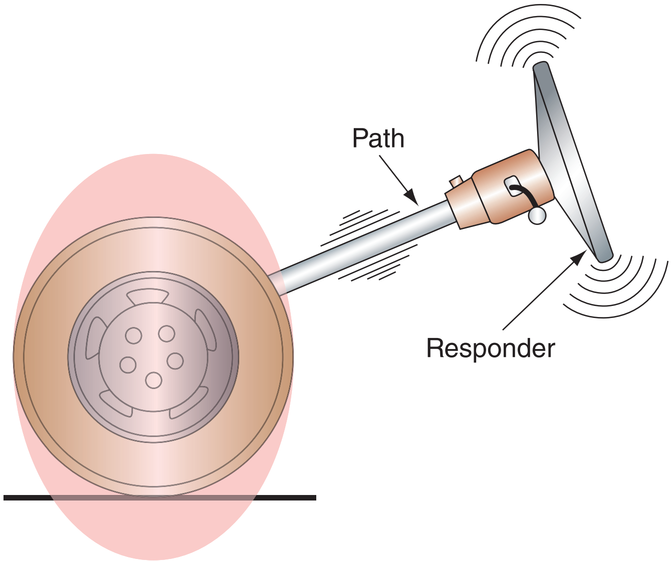


FIGURE 3-43 A tire with two bulges will vibrate twice per revolution.

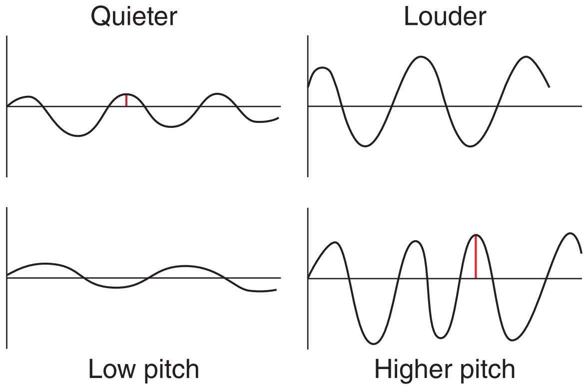


FIGURE 3-44 An example of how sound waves relate to what we hear.

in **(Figure 3–43)**. For example, suppose our tire, instead of having one bulge, has two, meaning the tire is oval shaped instead of round. As the tire travels along the road, the vibration frequency will be twice the tire's revolution frequency, causing a vibration around 25 Hz.

Sound

Vibration results in the phenomenon of sound. In air, the vibrations that cause sound are transmitted as a wave between air molecules; many other substances transmit sound in a similar way. A vibrating object causes pressure variations in the surrounding air. Areas of high and low pressure, known as compressions and rarefactions, move through the air as sound waves. Compression makes the sound waves denser, whereas rarefaction makes them less dense. The distance between each compression of a sound wave is called its **wavelength**. Sound waves with a short wavelength have a high frequency and a high-pitched sound **(Figure 3–44)**.

When the rapid variations in pressure occur between about 20 Hz and 20 kHz, sound is audible. Audible sound (as detected by the ear) results from very small rapid changes in the air pressure above and below atmospheric pressure.

Certain terms are used to describe sound:

- The pitch of a sound is based on its frequency. The greater the frequency, the higher the pitch.
- A decibel is a numerical expression of the loudness of a sound.
- Intensity is the amount of energy in a sound wave.
- An overtone is an additional tone that is heard because of the air waves of the original tone.
- Harmonics result from the presence of two or more tones at the same time.
- Resonance is produced when the natural vibration of a mass is greatly increased by vibrations at the same or nearly the same frequency of another source or mass. A cavity has certain resonant frequencies. These frequencies depend on the shape and size of the cavity and the velocity of sound within the cavity.

During diagnostics, you often need to listen to the sound of something. You will be paying attention to the type of sound and its intensity and frequency. The tone of the sound usually indicates the type of material that is causing the noise. If there is high pitch, you know that the source of the sound is something that is vibrating quickly. This means the source is less rigid than something that vibrates with a low pitch. Although pitch is dependent on the sound's frequency, the frequency itself can identify the possible sources of the sound. For example, if a sound from an engine increases with an increase in engine speed, you know that the source of the sound must be something that is moving faster as a result of the increase in engine speed.

Speakers A speaker **(Figure 3–45)** converts electrical energy into sound energy or waves. A constantly changing electrical signal is fed to the coil of a speaker, which lies within the magnetic field of a permanent magnet. The signal in the coil causes it to behave like an electromagnet, making it push against the field of the permanent magnet. The speaker cone is then pushed in and out by the coil in time with the electrical signal. As the cone moves forward, the air immediately in front of it is compressed, causing a

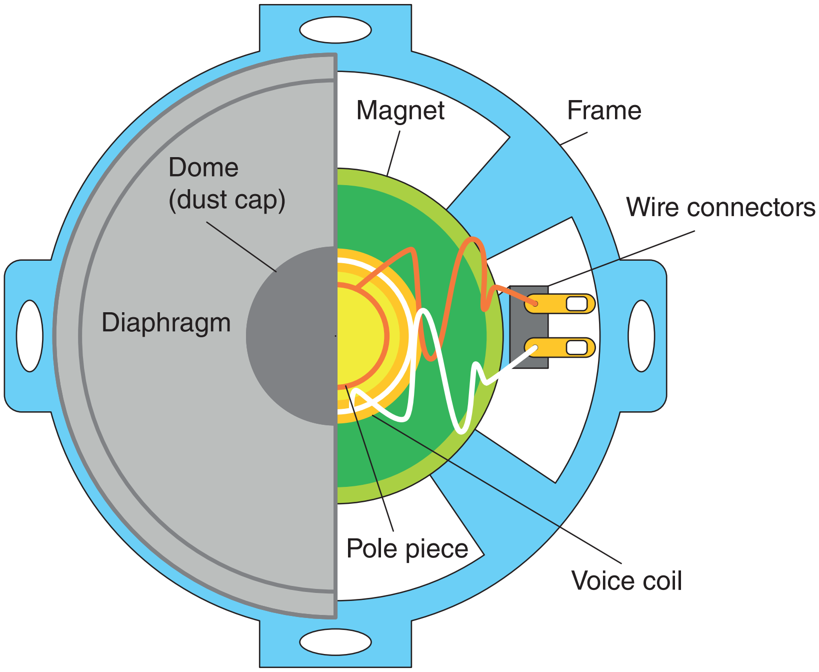


FIGURE 3-45 The construction of a speaker.

slight increase in air pressure; it then moves back past its rest position and causes a reduction in the air pressure (rarefaction). This process continues so that a wave of alternating high and low pressure is radiated away from the speaker cone at the speed of sound. These changes in air pressure are actually sound. The sound from a speaker may be amplified by the space or cavity that surrounds the speaker cone. The room or area in which the speaker sits also works to amplify the sound.

Noise

Noise is any unwanted signal or sound. It can be random or periodic. To identify the source of a noise, it is important to remember that sound or noise is a vibration and the vibration may be traveling through other components. Therefore, the source of the noise is not always where it may appear.

Three approaches can be used to prevent or reduce noise. The most effective way is to intervene to make a noisy component produce less noise. A relatively new technique of noise reduction is active noise control. This involves producing a sound that is similar to, but out of phase with, the noise. This effectively cancels the original noise. Active noise cancelling systems are becoming common equipment in modern vehicles to reduce engine, wind, and road noise. More obvious methods of noise reduction, or passive noise control, involve the use of filters, insulation, and noise barriers.

Light

Light is a form of electromagnetic radiation. In free space, it travels in a straight line at 300 million meters per second. When a beam of light meets an object, a proportion of the rays may be reflected. Some light may also be absorbed, and some transmitted. Without reflection, we would only be able to see objects that give out their own light. Light always reflects from a surface at the same angle at which it strikes. Therefore, parallel rays of light reflecting off a very flat surface will remain parallel. A beam of light reflecting from an irregular surface will scatter in all directions. Light that passes through an object is bent or refracted. The angle of refraction depends on the angle at which the light meets the object and the material it passes through. Lenses and mirrors can cause light rays to diverge or converge. When light rays converge, they can reach a point of focus.

These principles are the basis for fiber-optic lighting. With fiber optics, the light from a single lamp moves through one or more fiber cables to illuminate a point away from the source lamp. The fiber cables are designed to allow the light to travel without losing intensity and the light can be delivered to many locations at the same time.

Some vehicles use fiber optic cables for data transmission, typically on “infotainment” systems such as satellite navigation and media systems. Fiber optic transmission works by bouncing light

signals along a length of fiber optic cable. A transmitter encodes and pulses the light along the cable. A receiver then picks up and decodes the light signals.

Photo Cells

Radiation is produced in the sun's core during its nuclear reactions and is the source of most of the earth's energy. A transfer of energy, from electromagnetic radiation to electrical energy, takes place in a photovoltaic (photo) cell, or solar cell. When no light falls on it, it can supply no electricity.

Liquids

A fluid is something that does not have a definite shape; therefore, liquids and gases are fluids. A characteristic of all fluids is that they will conform to the shape of their container. A major difference between a gas and a liquid is that a gas will always fill a sealed container, whereas a liquid may not. A gas will also readily expand or compress according to the pressure exerted on it. Liquids are basically incompressible, which gives them the ability to transmit force **(Figure 3–46)**. Liquids also always seek a common level. A liquid may also change to a gas in response to temperature increases.

Liquids exert an upward resultant force, called upthrust, on objects immersed in the liquid. The upthrust is equal to the weight of the liquid displaced by the immersed object. If the upthrust on an object is greater than the weight of the object, then the object will float. Large ships float because they displace huge amounts of water, producing a large upthrust.

Laws of Hydraulics

Hydraulics is the study of liquids in motion. Liquids will predictably respond to pressures put on them. This allows hydraulics to do work. A simple hydraulic system has liquid, a pump, lines to carry the liquid, control valves, and an output device. The liquid must be available from a continuous source, such as an oil pan or sump. A pump is used to move the liquid through the system. The lines that carry the liquid may be pipes, hoses, or a network of internal bores or passages in a housing. Control valves regulate hydraulic pressure and direct the flow of the liquid. The output device is the unit that uses the pressurized liquid to do work.

Over 300 years ago a French scientist, Blaise Pascal, determined that if you had a liquid-filled container with only one opening and applied force to the liquid through that opening, the force would be evenly distributed throughout the liquid. This explains how pressurized liquid is used to operate and control systems, such as the brake system and automatic transmissions.

Pascal constructed the first known hydraulic device, which consisted of two sealed containers connected by a tube. The cylinders' pistons are sealed against the walls of each cylinder to prevent the liquid from leaking out and to prevent air from entering into the cylinder. When the piston in the first cylinder has a force applied to it, the pressure moves everywhere within the system. The force is transmitted through the connecting tube to the second cylinder. The pressurized fluid in the second cylinder exerts force on the bottom of the second piston, moving it upward and lifting the load on the top of it **(Figure 3–47)**. By using this device, Pascal found he could increase the

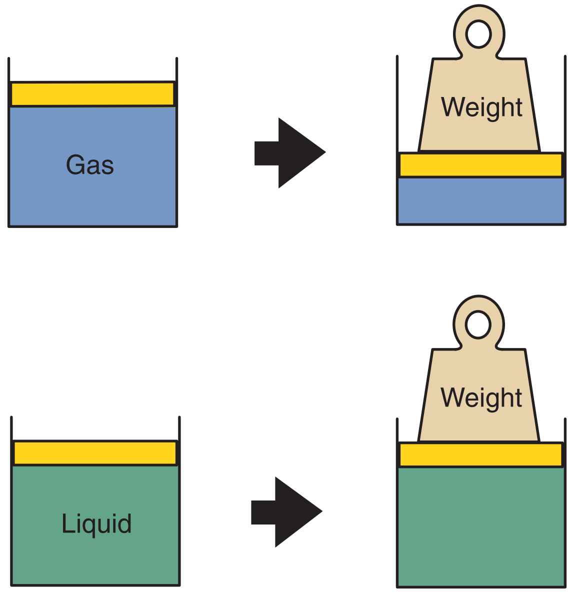


FIGURE 3–46 Gases compress, whereas liquids do not.

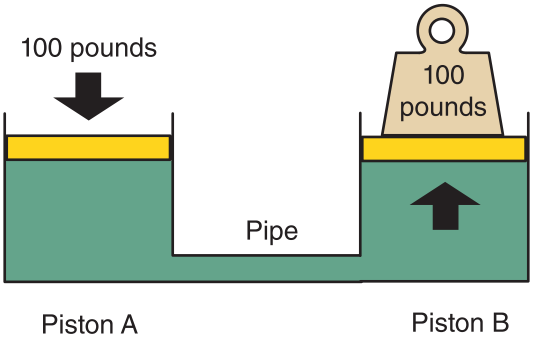


FIGURE 3–47 In a hydraulic circuit, pressure is transferred equally throughout the system.

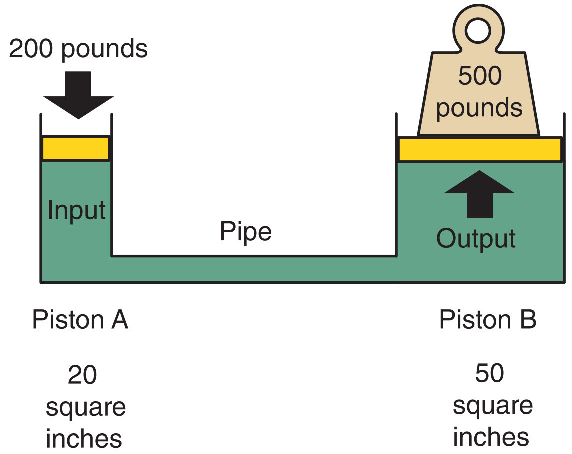


FIGURE 3–48 The force available to do work can be increased by increasing the size of the piston doing the work.

force available to do work **(Figure 3–48)**, just as could be done with levers or gears.

Pascal determined that when a pressure is applied to a liquid, it is transmitted equally in all directions and acts with equal force at every point in the container. In order to pressurize a liquid, the liquid must be in a sealed container. Any leak in the container will decrease the pressure.

Mechanical Advantage with Hydraulics

Hydraulics are used to do work in the same way as a lever or gear. These systems transmit energy and do not create more energy. If a hydraulic pump provides 100 psi, there will be 100 pounds of pressure on every square inch of the system **(Figure 3–49)**. If the system included a piston with an area of 50 square inches, each square inch receives 100 pounds of pressure. This means there will be 5,000 pounds of force applied to that piston **(Figure 3–50)**. The use of the larger piston gives the system a mechanical advantage as it increases the force available to do work. The multiplication of force through a hydraulic system is directly proportional to the difference in the piston sizes throughout the system.

By changing the size of the pistons in a hydraulic system, force is multiplied, and as a result, low amounts of pressure can be used to move heavy objects. The mechanical advantage of a hydraulic system can be increased further by the use of levers to increase the force applied to a piston.

Although the force available to do work is increased by using a larger piston in one cylinder, the total movement of the larger piston is less than

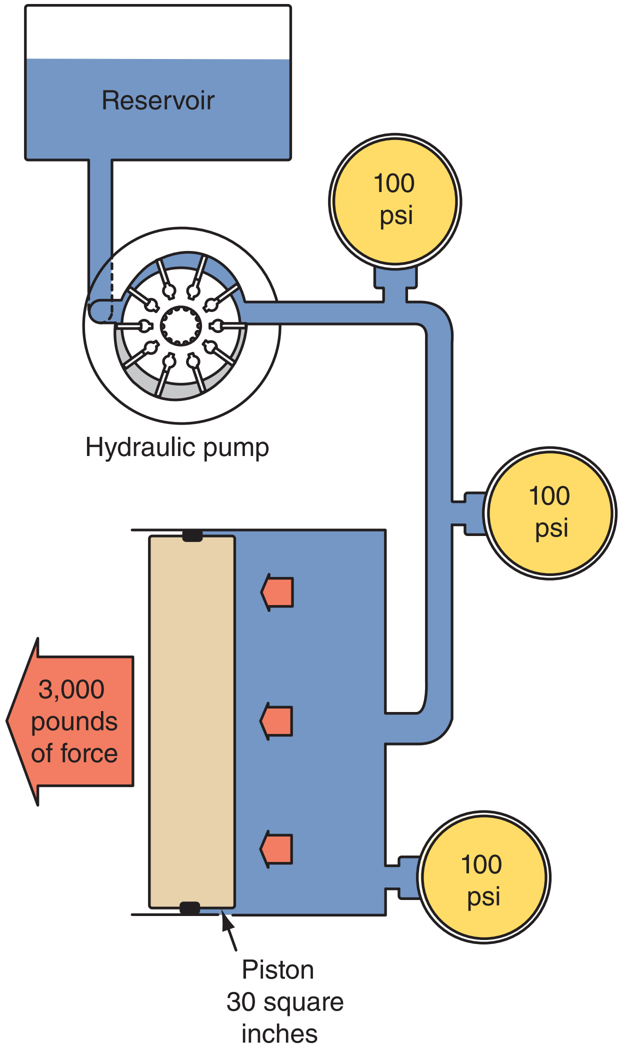


FIGURE 3–49 A pressure applied to a liquid is transmitted equally and acts with equal force at every point within the hydraulic circuit.

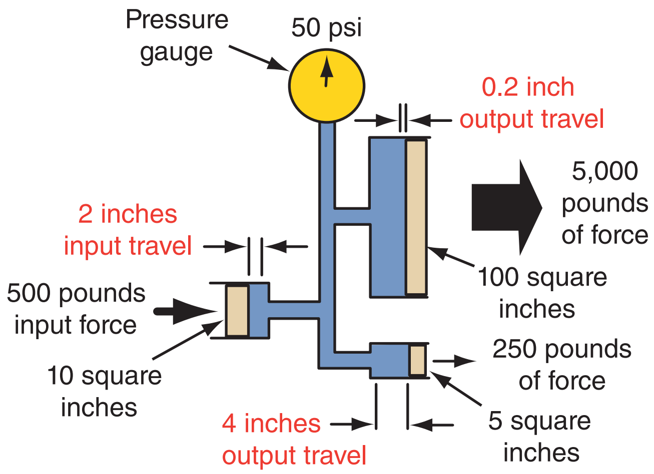


FIGURE 3–50 Hydraulic systems can provide an increase in force (mechanical advantage), but the output's travel will decrease proportionally.

that of the smaller one. A hydraulic system with two cylinders, one with a 1-inch piston and the other with a 2-inch, will double the force at the second piston. However, the total movement of the larger piston will be half the distance of the smaller one.

The use of hydraulics is most common when the size and shape of the system is of concern. In hydraulics, the force applied to one piston will transmit through the fluid and the opposite piston will have the same force on it. The distance between the two pistons in a hydraulic system does not affect the force in a static system. Therefore, the force applied to one piston can be transmitted without change to another piston located somewhere else.

A hydraulic system responds to the pressure or force applied to it. The mere presence of different-sized pistons does not always result in fluid power. Either the pressure applied to the pistons or the size of the pistons must be different to cause fluid power. If an equal amount of pressure is exerted onto the pistons in a system and the pistons are the same size, neither piston will move, and the system is balanced or is at equilibrium. The pressure in a balanced hydraulic system is called **static pressure** because there is no fluid motion.

When an unequal amount of pressure is exerted on the pistons, the piston with the least amount of pressure on it will move in response to the difference between the two pressures. Likewise, if the size of the two pistons is different and an equal amount of pressure is exerted on the pistons, the fluid will move. The pressure of the fluid while it is in motion is called **dynamic pressure**.

Gases

A **gas** is a fluid made up of independent particles—atoms or molecules—that are in constant, random motion. This means that a gas will fill any container into which it is placed. The random movement of gas particles also ensures that any two gases sharing the same container will totally mix. This is **diffusion**.

The kinetic energy of atoms and molecules increases as the temperature increases. Molecules in solids move slowly compared to those in liquids or gases. Gas molecules move quickly compared to liquid molecules. At higher temperatures, gas molecules spread out more, whereas at lower temperatures, gas molecules move closer together. The bombardment of particles against the sides of the container produces pressure.

Behavior of Gases

Three simple laws describe the predictable behavior of gases: Boyle's law, Charles' law, and the pressure (ideal gas) law. Each of these laws describes a relationship between the pressure, volume, and temperature of a gas.

Boyle's law states that the volume and pressure of a mass of gas at a fixed temperature are inversely proportional. If the pressure on a gas increases, its volume will decrease; likewise if the volume is increased, the pressure will decrease.

Charles' law states that the volume of a gas depends on its temperature. Therefore, at a constant pressure, the volume of a gas will increase or decrease in relationship to its temperature. Increasing the temperature of the gas will increase its pressure. Therefore, the pressure and temperature of a gas are directly related. If you increase one, you increase the other. This explains why cold air is denser than warm air.

Air Pressure

Because air is gaseous matter with mass and weight, it exerts pressure on the earth's surface. A 1-square-inch column of air extending from the earth's surface to the outer edge of the atmosphere weighs 14.7 psi at sea level. Therefore, atmospheric pressure is 14.7 psi at sea level **(Figure 3–51)**. **Atmospheric pressure** may be defined as the total weight of the earth's atmosphere. Pressure greater than atmospheric pressure may be measured in psi gauge (psig). Using a standard pressure gauge, air pressure is compared to

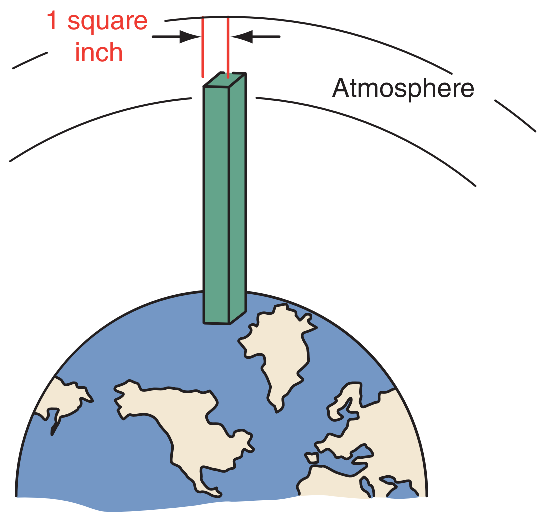


FIGURE 3-51 One square inch of air equals 14.7 pounds per square inch of pressure at sea level.

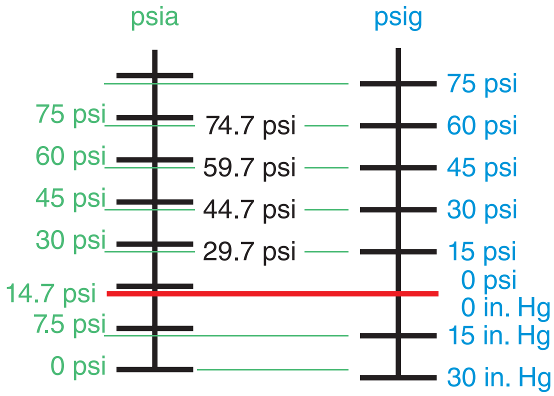


FIGURE 3-52 The relationship between psia and psig.

that of normal atmospheric pressure. When the actual pressure is 19.7 psi, the gauge will read 5 psi, showing the pressure differential **(Figure 3–52)**. The actual pressure is referred to as psi absolute (psia).

When air becomes hotter, it expands, and this hotter air is lighter compared to an equal volume of cooler air. This hotter, lighter air exerts less pressure on the earth's surface compared to cooler air. This means the weight of the atmosphere changes with weather. This change is rather slight. As the weight changes, so does the atmospheric pressure. The change in atmospheric pressure is measured with a barometer and is called **barometric pressure**. Barometric pressure at normal atmospheric pressure is 29.92 inches of mercury. A barometer is a "J"-shaped tube with mercury in it. One end of the tube is exposed to normal atmospheric pressure and the other end to current atmospheric pressure. When the current atmospheric pressure equals normal atmospheric pressure, the level of the mercury will be 29.92 inches up the tall part of the "J." When the current atmospheric pressure is lower than normal, the normal atmospheric pressure pushes the mercury down. Likewise, when current atmospheric pressure is higher than normal, it will push the mercury up the tube. The amount of mercury movement reflects the difference in the two pressures. This corresponds with a universal law that states a high pressure always moves toward a lower pressure.

Although the pressure of the atmosphere only changes slightly, the impact of these changes can be critical to the overall operation of an engine. The combustion process depends on having the correct amount of air enter the cylinders. If the calibrations for the air and the accompanying amount of fuel did not consider the changes in atmospheric pressure, the engine would most often not receive the correct mixture of air and fuel. Today's engines are equipped with a sensor to monitor barometric pressure.

To further consider the law that states a high pressure always moves to a lower pressure, look at what happens when a nail punctures an automotive tire. The high-pressure air in the tire leaks out until the pressure inside the tire is equal to the atmospheric pressure outside the tire. When the tire is repaired and inflated, air with a pressure higher than atmospheric is forced into the tire.

When you climb above sea level, atmospheric pressure decreases. The weight of a column of air is less at an elevation of 5,000 feet (1,524 meters) than it is at sea level. As altitude continues to increase, atmospheric pressure and weight continue to decrease. At an altitude of several hundred miles above sea level, the earth's atmosphere ends, and there is no pressure beyond that point **(Figure 3–53)**.

Vacuum Scientifically, **vacuum** is defined as the absence of atmospheric pressure. However, it is commonly used to refer to any pressure less than atmospheric pressure. Vacuum may also be referred to as low or negative pressure simply because it is a pressure lower than atmospheric pressure.

Vacuum could be measured in psig or psia, but inches of mercury (in. Hg) is most commonly used for this measurement **(Figure 3–54)**. Let us assume that a plastic "U" tube is partially filled with mercury, and atmospheric pressure is allowed to enter one end of the tube. If vacuum is supplied to the other end of the "U" tube, the mercury is forced downward by the atmospheric pressure. When this movement occurs, the mercury also moves upward on the side where the vacuum is supplied. For example, if the mercury moves downward 10 inches, or 25.4 centimeters (cm) where the atmospheric

Altitude in feet	Altitude in meters	Atmospheric pressure (psi)
Sea level	Sea level	14.7
18,000	5,486.3	7.35
52,926	16,131.9	1.47
101,381	30,900.9	0.147
159,013	48,467.2	0.0147
227,889	69,463.6	0.00147
283,076	96,281.6	0.000147

FIGURE 3-53 The higher the altitude, the lower the pressure of the atmosphere.

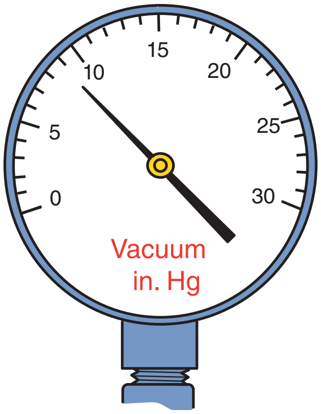


FIGURE 3–54 A vacuum gauge measures pressures below atmospheric pressure in units of inches of mercury.

pressure is supplied, and upward 10 inches (25.4 cm) where the vacuum is supplied, the mercury moved a total of 20 inches and the vacuum is rated as 20 in. Hg. The highest possible, or perfect, vacuum is approximately 29.9 in. Hg.

Heat

Heat is a form of energy. The main sources of heat are the sun, the earth, chemical reactions, electricity, friction, and nuclear energy. Heat results from the kinetic energy that is present in all matter; therefore, everything has heat. Cold objects have low kinetic energy because their atoms and molecules are moving very slowly, whereas hot objects have more kinetic energy because their atoms and molecules are moving fast.

Temperature is an indication of an object's kinetic energy. Temperature is measured with a thermometer, which has a Fahrenheit (F), Celsius (Centigrade) (C), or Kelvin (K) scale **(Figure 3–55)**. At absolute zero (–459.4 °F, –273 °C, or 0 °K), particles of matter do not vibrate, but at all other temperatures, particles have motion. The temperature of an object is a statement of how cold or hot an object is. Heat and temperature are not the same thing: Heat is the movement of kinetic energy from one object to another, whereas temperature is an indication of the amount of kinetic energy something has. Energy from something hot will always move to an object that is colder until both are at the same temperature. The greater the difference in temperature between the two objects, the faster the heat will flow from one to the other.

Heat is measured in British thermal units (Btus) and calories. One Btu is the amount of heat required to heat 1 pound of water by 1 degree Fahrenheit. One calorie is equal to the amount of heat needed to raise the temperature of 1 gram of water 1 degree Celsius.

Heat Transfer

Heat transfers between two substances that have different temperatures through convection, conduction, or radiation. **Convection** is the transfer of heat by the movement of a heated object. Convection can be easily seen by watching a pot of water on a stove. The water on the bottom of the pot is the first to be heated by the stove. As the water at the bottom becomes hotter, it expands and becomes lighter than the water at the top of the pot. This causes the heavier water to sink toward the bottom and push the warmer water up. This continues until all of the water in the pot is at the same temperature.

Conduction is the movement of heat through a material. The immense heat that results from combustion is absorbed by the engine and is used to push the pistons down. The engine's cooling system uses conduction to move the heat from the parts to help cool the engine. Because heat energy moves from something hot toward something colder, the engine's heat moves to the engine's coolant circulating within the engine. Heat can be conducted to a liquid, gas, or solid.

Radiation does not rely on another material to transfer heat. The moving atoms and molecules within an object create waves of radiant energy. These waves are typically called infrared rays. Hot objects give off more infrared rays than colder objects. Therefore, a hot object will give off infrared rays to

From	To °F	To °C	To K
°F	°F	(°F − 32)/1.8	(°F − 32) × 5/9 + 273.15
°C	(°C × 1.8) + 32	°C	°C + 273.15
K	(K − 273.15) × 9/5 + 32	K − 273.15	K

FIGURE 3–55 Conversion guidelines for °F, °C, and K.

anything around it that is colder. No movement is necessary to transfer this heat. You can feel radiation in action by simply putting your hand near something that is hot. The hot object cools as it radiates its heat energy. In an engine's cooling system, the radiator uses radiation to transfer heat from the coolant to the surrounding air.

The Effects of Temperature Change

Anytime the temperature of an object changes, a transfer of heat has occurred. The change in temperature can also cause the object to change size or its state of matter. As heat moves in and out of a mass, the movement of atoms and molecules in that mass increases or slows down. With an increase in motion, the size of the mass tends to get bigger or expand. This is commonly called thermal expansion. **Thermal contraction** takes place when a mass has heat removed from it and the atoms and molecules slow down. All gases and most liquids and solids expand when heated, with gases expanding the most. Solids, because they are not fluid, expand and contract at a much lower rate. It is important to realize that all materials do not expand and contract at the same rate. For example, an aluminum component will expand at a faster rate than the same component made of iron. This explains why aluminum cylinder heads have unique service requirements and procedures when compared to iron cylinder heads.

Thermal expansion takes place every time fuel and air are burned in an engine. The sudden temperature increase inside the cylinder causes a rapid expansion of the gases, which pushes the piston downward.

Typically when heat is added to a mass, the temperature of the mass increases. This does not always happen, however. In some cases, the additional heat causes no increase in temperature but causes the mass to change its state (solid to liquid or liquid to gas). For example, if we take an ice cube and heat it to 32 °F (0 °C), it will begin to melt **(Figure 3–56)**. As heat is added to the ice cube, the temperature of the ice cube will not increase until it becomes a liquid. The heat added to the ice cube that did not raise its temperature but caused it to melt is called **latent heat** or the heat of fusion. Each gram of ice at 0 °C requires 80 calories of heat to melt it to water at 0 °C. As more heat is added to the 0 °C water, the water's temperature will once again increase. This continues until the temperature of the water reaches 212 °F (100 °C). This is the boiling temperature of water. At this point, any additional heat applied to the water is latent heat, causing the water to change its state to that of a gas. This added heat is called the heat of evaporation.

To change the water gas back to liquid water, the same amount of heat required to change the liquid to a gas must be removed from the gas. At that point the gas condenses to a liquid. As additional heat is removed, the temperature will drop until enough heat is removed to bring its temperature back down to freezing (melting in reverse) point. At that time latent heat must be removed from the liquid before the water turns to ice again.

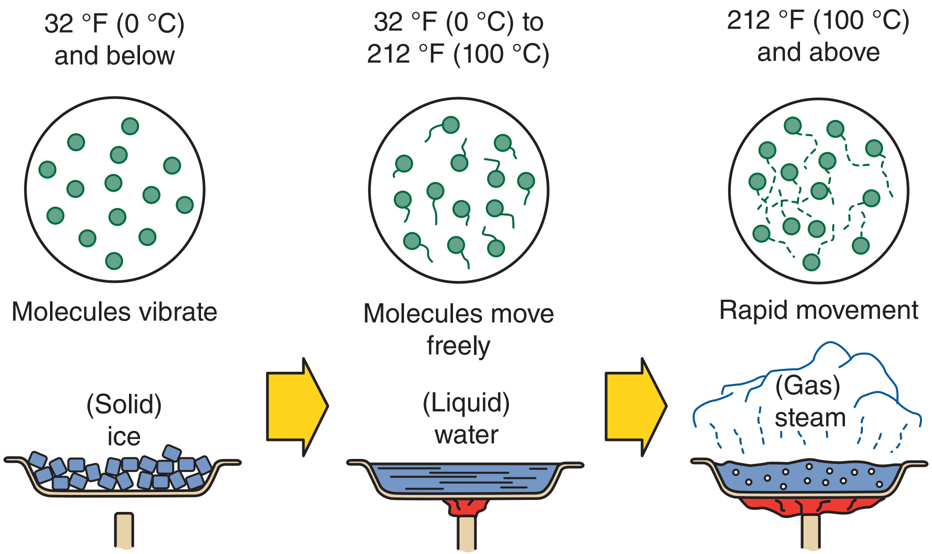


FIGURE 3–56 Water can exist in three different states of matter.

Chemical Properties

The properties of something describe or identify the characteristics of an object. Physical properties are characteristics that are readily observable, such as color, size, luster, and smell.

Chemical properties are only observable during a chemical reaction and describe how one type of matter reacts with another to form a new and different substance. Chemical properties are quite different from physical properties. A chemical property of some metals is the ability to combine with oxygen to form rust (iron and oxygen) or tarnish (silver and sulfur). Another example is hydrogen's ability to combine with oxygen to form water.

A **solution** is a mixture of two or more substances. Most solutions are liquids, but solutions of gases and solids are possible. An example of a gas solution is the air we breathe; it is composed of mostly oxygen and nitrogen. Brass is a good example of a solid solution because it is composed of copper and zinc. The liquid in a solution is called the **solvent**, and the substance added is the solute. If both are liquids, the one present in the smaller amount is usually considered the solute. Solutions can vary widely in terms of how much of the dissolved substance is actually present. A heavily diluted (much water) acid solution has very little acid and may not be noticeably acidic.

Specific Gravity

Specific gravity is the heaviness or relative density of a substance as compared to water. If something is 3.5 times as heavy as an equal volume of water, its specific gravity is 3.5. Its density is 3.5 grams per cubic centimeter, or 3.5 kilograms per liter.

Density is a statement of how much mass there is in a particular volume. Water is denser than air; therefore, there will be less air in a given container than water in that same container **(Figure 3–57)**. The density of a material changes with temperature as well **(Figure 3–58)**. This is the reason an engine runs more efficiently with cool intake air.

Substance	Density (g/cm^3)
Air	0.0013
Ice	0.92
Water	1.00
Aluminum	2.70
Steel	7.80
Gold	19.30

FIGURE 3–57 A look at the density of different substances as compared to water.

Temp (°F)	Temp (°C)	Approx. change in density (%)
200	93	–21
180	82	–16.8
160	71	–12.6
140	60	–8.4
120	49	–4.2
100	38	—
80	27	+4.2
60	16	+8.4
40	4	+12.6
20	–7	+16.8
0	–18	+21

FIGURE 3–58 The effect that temperature has on the density of air at atmospheric pressure.

Chemical Reactions

Chemical changes, or chemical reactions, result in the production of another substance, such as wood turning to carbon after it has been completely burned. A chemical reaction is always accompanied by a change in energy. This means energy is given off or taken in during the reaction. Some reactions that release energy need some energy to get the reaction started. A reaction takes place when two or more molecules interact and one of the following happens:

- A chemical change occurs.
- Single reactions occur as part of a large series of reactions.
- Ions, molecules, or pure atoms are formed.

Catalysts and Inhibitors

Reactions need a certain amount of energy to happen. A catalyst lowers the amount of energy needed to cause a reaction. A **catalyst** is any substance that affects the speed of a reaction without itself being consumed or changed. Catalysts tend to be highly specific, reacting with one substance or a small set of substances. In a car's catalytic converter, the platinum catalyst converts unburned hydrocarbons and

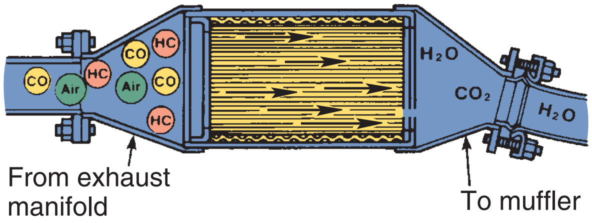


FIGURE 3–59 A basic catalytic converter that changes pollutants into chemicals that are good for the environment.

nitrogen compounds into products that are harmless to the environment **(Figure 3–59)**. Water, especially salt water, catalyzes oxidation and corrosion. An inhibitor is the opposite of a catalyst and stops or slows the rate of a reaction.

Acids/Bases

An ion is an atom or group of atoms with one or more positive or negative electric charges. Ions are formed when electrons are added to or removed from neutral molecules or other ions. Ions are what make something an acid or a base.

Acids are compounds that break into hydrogen (H^+) ions and another compound when placed in an aqueous (water) solution. They have a sour taste, are corrosive, react with some metals to produce hydrogen, react with carbonates to produce carbon dioxide, and become less acidic when combined with alkalis. Most acids are slow reacting, especially if they are weak acids. Acids also react with bases to form salts.

Alkalis (**bases**) are compounds that release hydroxide ions (OH^-) and react with H^+ ions to produce water, thus neutralizing each other. Most substances are neutral (not an acid or a base). Alkalis feel slippery and become less alkaline when they are combined with acids.

A hydroxide is any compound made up of one atom each of hydrogen and oxygen, bonded together and acting as the hydroxyl group or hydroxide anion (OH^-). An oxide is any chemical compound in which oxygen is combined with another element. Metal oxides typically react with water to form bases or with acids to form salts. Oxides of nonmetallic elements react with water to form acids or with bases to form salts.

A salt is a chemical compound formed when the hydrogen of an acid is replaced by a metal. Typically, an acid and a base react to form a salt and water.

The **pH scale** is used to measure how acidic or basic a solution is. Its name comes from the fact that pH is the absolute value of the power of the hydrogen ion concentration. The scale goes from 0 to 14. Distilled (pure) water is 7. Acids are found between 0 and 7 and bases are from 7 to 14. When the pH of a substance is low, the substance has many H^+ ions. When the pH is high, the substance has many OH^- ions. The pH value helps inform scientists, as well as technicians, of the nature, composition, or extent of reaction of substances.

The pH of something can be checked with litmus paper. Litmus is a mixture of colored organic compounds obtained from several species of lichen. Lichen is a type of plant that is actually a combination of a fungus and algae. Litmus test strips can be used to check the condition of the engine's coolant **(Figure 3–60)**. When immersed into an acid, a litmus strip will change from blue to red. Likewise when the strip is immersed in an alkali solution, it will change from red to blue.

Reduction and Oxidation

Oxidation is a chemical reaction in which a substance combines with oxygen. Rapid oxidation produces heat fast enough to cause a flame. When fuel burns, it combines with oxygen to form other

FIGURE 3–60 Litmus test strips can be used to check the condition of an engine's coolant.

compounds. This oxidation is called combustion, which produces heat and fire.

The addition of hydrogen atoms or electrons is **reduction**. Oxidation and reduction always occur simultaneously: One substance is oxidized by the other, which is reduced. During oxidation, a molecule provides electrons. During reduction, a molecule accepts electrons. Oxidation and reduction reactions are usually called redox reactions. Redox is any chemical reaction in which electrons are transferred. Batteries, also known as voltaic cells, produce an electrical current at a constant voltage through redox reactions.

An oxidizing agent is something that accepts electrons and oxidizes something else while being reduced in the process. A reducing agent is something that provides electrons and reduces something else while being oxidized.

Metallurgy

Metallurgy is the art and science of extracting metals from their ores and modifying them for a particular use. This includes the chemical, physical, and atomic properties and structures of metals and the way metals are combined to form alloys. An **alloy** is a mixture of two or more metals. Steel is an alloy of iron plus carbon and other elements.

Metals have one or more of the following properties:

- Good heat and electric conduction
- Malleability—can be hammered, pounded, or pressed into a shape without breaking
- Ductility—can be stretched, drawn, or hammered without breaking
- High light reflectivity—can make light bounce off its surface
- The capacity to form positive ions in a solution and hydroxides rather than acids when their oxides meet water

About three-quarters of the elements are metals. The most abundant metals are aluminum, iron, calcium, sodium, potassium, and magnesium.

Rust and Corrosion The rusting of iron is an example of oxidation. Unlike fire, rusting occurs so slowly that little heat is produced. Iron combines with oxygen to form rust. The rate at which this occurs depends on several factors: temperature, surface area (more iron exposed for oxygen to reach), and catalysts (speed up a reaction but do not react and change themselves).

Corrosion is the wearing away of a substance due to chemical reactions. It occurs whenever a gas or liquid chemically attacks an exposed surface. This action is accelerated by heat, acids, and salts. Some materials naturally resist corrosion; others can be protected by painting, coatings, galvanizing, or anodizing.

Galvanizing involves the coating of zinc onto iron or steel to protect it against exposure to the atmosphere. If galvanizing is properly applied, it can protect the metals for 15 to 30 years or more.

Metals can be anodized for corrosion resistance, electrical insulation, thermal control, abrasion resistance, sealing, improving paint adhesion, and decorative finishing. Anodizing is a process that electrically deposits an oxide film from an aqueous solution onto the surface of a metal, often aluminum. During the process, dyes can be added to the process to give the material a colored surface.

Hardness The hardness of something describes its resistance to scratching. **Hardening** is a process that increases the hardness of a metal, deliberately or accidentally, by hammering, rolling, carburizing, heat treating, tempering, or other processes. All of these deform the metal by compacting the atoms or molecules to make the material more dense.

Carburizing hardens the surface of steel with heat. It increases the hardness of the outer surface while leaving the core relatively soft. The combination of a hard surface and soft interior withstands very high stress. It also has a low cost and offers flexibility for manufacturing. To carburize, the steel parts are placed in a carbonaceous environment (with charcoal, coke, and carbonates or carbon dioxide, carbon monoxide, methane, or propane) at a high temperature for several hours. The carbon diffuses into the surface of the steel, altering the crystal structure of the metal. Gears, ball and roller bearings, and piston pins are often carburized.

Heat treating changes the properties of a metal by using heat. **Tempering** is the heat treating of metal alloys, particularly steel. For example, raising the temperature of hardened steel to 752 °F (400 °C) and holding it for a time before quenching it in oil decreases its hardness and brittleness and produces strong steel.

Solids under Tension

The atoms of a solid are closely packed, so solids have a greater density than most liquids and gases. The rigidity results from the strong attraction between

FIGURE 3–61 A coil spring for a suspension system.

its atoms. A force pulling on a solid moves these atoms farther apart, creating an opposing force called **tension**. If a force pushes on a solid, the atoms move closer together, creating compression. These are the principles of how springs function. Springs are used in many automotive systems, the most obvious of which are those used in suspension systems **(Figure 3–61)**.

An elastic substance is a solid that gets larger under tension, gets smaller under compression, and returns to its original size when no force is acting on it. Most solids show some elastic behavior, but there is usually a limit to the force that the material can face. When excessive force is applied, the material will not return to its original size and it will be distorted or will break. The limit depends on the material's internal structure; for example, steel has a low elastic limit and can only be extended about 1 percent of its length, whereas rubber can be extended to about 1,000 percent. Another factor involved in elasticity is the cross-sectional area of the material.

Tensile strength is the ratio of the maximum load a material can support without breaking while being stretched. It is dependent on the cross-sectional area of the material. When stresses less than the tensile strength are removed, the material returns to its original size and shape. Greater stresses form a narrow, constricted area in the material, which is easily broken. Tensile strengths are measured in units of force per unit area.

Electrochemistry

Electrochemistry is concerned with the relationship between electricity and chemical change. Many spontaneous chemical reactions release electrical energy and some of these are used in batteries and fuel cells to produce electric power. The basis for electricity is the movement of electrons from one atom to another.

Electrolysis is an electrochemical process. During this process, electric current is passed through a substance, causing a chemical change. This change causes either a gain or loss of electrons. Electrolysis normally takes place in an electrolytic cell made of separated positive and negative electrodes immersed in an electrolyte.

An **electrolyte** is a substance that conducts current as a result of the breaking down of its molecules into positive and negative ions. The most familiar electrolytes are acids, bases, and salts that ionize when dissolved in solvents such as water and alcohol. Ions drift to the electrode of the opposite charge and are the conductors of current in electrolytic cells.

Electricity and Electromagnetism

All electrical effects are caused by electric charges. There are two types of electric charges: positive and negative. These charges exert electrostatic forces on each other due to the strong attraction of electrons to protons. An electric field is the area on which these forces have an effect. Protons carry a positive charge, while electrons carry a negative charge. Atoms are normally neutral, having an equal number of protons and electrons, but an atom can gain or lose electrons. Electricity has many similarities with magnetism. For example, the lines of the electric fields between charges take the same form as the lines of magnetic force, so magnetic fields can be said to be an equivalent to electric fields. Charges of the same type repel, while charges of a different type attract **(Figure 3–62)**.

Electricity

An electric circuit is simply the path in which an electric current flows. Electrons can be moved around a circuit by electrostatic forces. A circuit usually consists of a conductive material, such as a metal, where the electrons are held very loosely to their

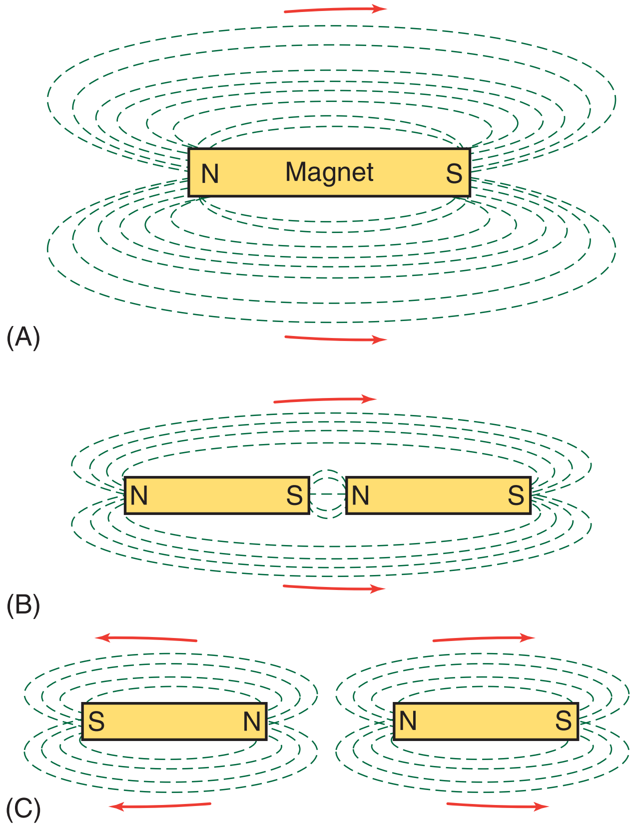


FIGURE 3-62 (A) In a magnet, lines of force emerge from the north pole and travel to the south pole before passing through the magnet back to the north pole. (B) Unlike poles attract, while (C) similar poles repel each other.

atoms, thus making electron movement possible. The strength of the electrostatic force is the voltage. The movement of the electric charge is called an electric current. The higher the voltage, the greater the current will be. But the current also depends on the thickness, length, temperature, and nature of the materials used as a conductor. Electrical resistance opposes the flow of electric current. Good conductors have low resistance, which means that a small amount of voltage will produce high current. In batteries, the dissolving of an electrode causes the freeing of electrons, resulting in their movement to another electrode and the formation of a current.

Magnets

Some materials are natural magnets; however, most magnets are produced. The materials used to make a permanent magnet are commonly called ferromagnetic materials. These are made of mostly heated iron compounds. The heat causes the atoms to shift direction, and once all of them point in the same direction, the metal becomes a magnet. This sets up two distinct poles called the north and south poles. The poles are at the ends of the magnet and there is an attraction between the two separate poles.

The lines of a magnetic field form closed lines of force from the north to the south. If another iron or steel object enters into the magnetic field, it is pulled into the magnet. If another magnet is introduced into the magnetic field, it will either move into the field or push away from it. This is the result of the natural attraction of a magnet from north to south. If the north pole of one magnet is introduced to the north pole of another, the two poles will oppose each other and will push away. If the south pole is introduced to the north pole of another, the two magnets will join together because the opposite poles are attracted to each other.

The strength of the magnetic force is uniform around the outside of the magnet. The force is strongest at the surface of the magnet and weakens with distance. If you double the distance from a magnet, the force is reduced by one-fourth.

The strength of a magnetic field is typically measured with a magnetometer and in units of Gauss (G).

Electromagnetism

Electrical current will produce magnetism that affects other objects in the same way as permanent magnets. The arrangement of force lines around a current-carrying conductor, its magnetic field, is circular. The magnetic effect of electrical current is increased by shaping the current-carrying wire into a coil **(Figure 3–63)**.

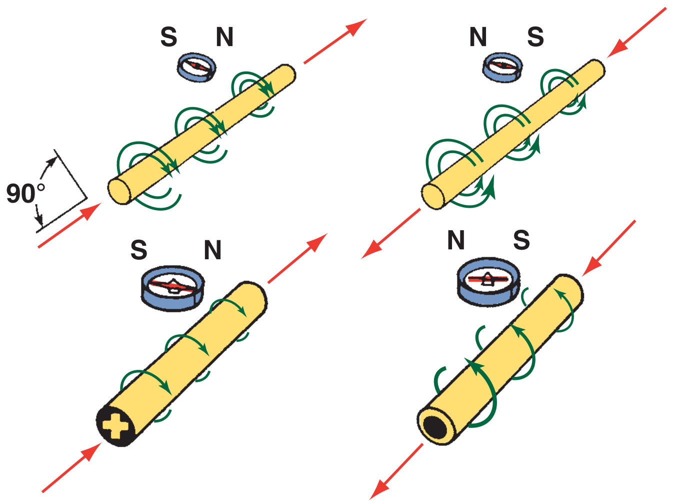


FIGURE 3-63 When current is passed through a conductor, such as a wire, magnetic lines of force are generated around the wire at right angles to the direction of the current flow.

When a coil of wire is wrapped around an iron bar, it is called an **electromagnet**. The magnetic field produced by the coil magnetizes the iron bar, strengthening the magnetic field. The strength of the magnetism produced depends on the number of windings in the coil and the amount of the current flowing in the coil.

Producing Electrical Energy

There are many ways to generate electricity. The most common is to use coils of wire and magnets in a generator. When a wire and magnet are moved relative to each other, a voltage is produced **(Figure 3–64)**. In a generator, the wire is wound into a coil and the coil rotates within the field of the magnet. The more turns in the coil and the faster the coil moves, the greater the voltage. Automotive generators are driven by the engine's crankshaft via a belt. In a generator, the kinetic energy of a spinning object is converted into electrical energy.

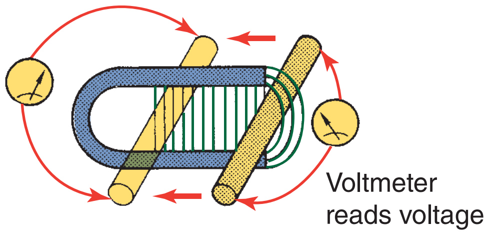


FIGURE 3–64 Moving a conductor across magnetic lines of force induces a voltage in the conductor.

A solar cell converts the energy of light directly into electrical energy, using layers of semiconductors. Electricity is produced by causing electrons to leave the atoms in a semiconductor material. Each electron leaves behind a hole or gap. Other electrons move into the hole, leaving holes in their atoms. This process continues and forms a moving chain of electrons, which is electrical current.

Radar is a detection system that uses radio waves to determine the range, altitude, direction, and/or speed of an object. It is used to detect aircraft, ships, spacecraft, guided missiles, motor vehicles, weather formations, and terrain. In an automobile, it is used in various systems including adaptive cruise control and parking assist systems. The primary components are a radar dish or antenna that transmits pulses of radio waves which bounce off anything in their path **(Figure 3–65)**. Part of these waves bounce back to the dish or antenna. A computer then analyzes the distance, direction, and approaching speed of the object.

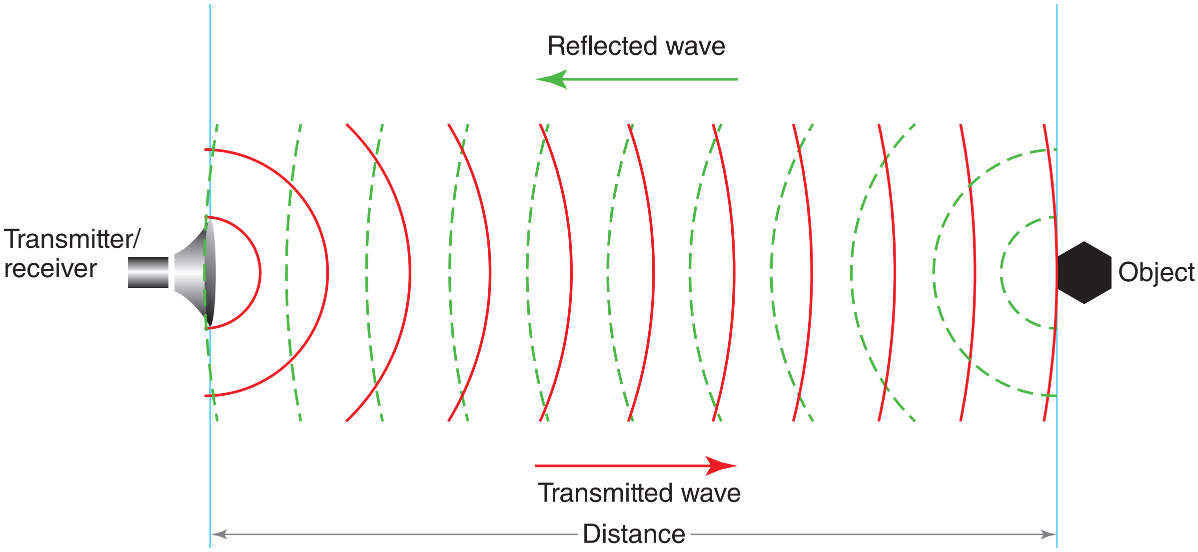


FIGURE 3–65 The basic operation of radar.

KEY TERMS

Acceleration
Acids
Aerodynamics
Alloy
Amplitude
Atmospheric pressure
Atoms
Barometric pressure
Bases
Carburizing
Catalyst
Centrifugal force
Centripetal force
Compression ratio
Conduction
Convection
Curb weight
Deceleration
Density
Diffusion
Displacement
Dynamic pressure
Electrolysis
Electrolyte
Electromagnet
Element
Engine efficiency
Equilibrium
Evaporate
Force
Frequency
Gas
Gear
Gross weight
Hardening
Heat
Heat treating
Hertz (Hz)
Horsepower
Impermeable
Inertia
Ion
Kinetic energy
Latent heat
Lever
Load
Mass
Matter
Mechanical advantage
Molecule
Momentum
Oscillation
Oxidation
Permeable
pH scale
Plasma
Potential energy
Power
Pressure
Pulley
Radiation
Reduction
Solution
Solvent
Specific gravity
Speed
Static pressure
Tempering
Tensile strength
Tension
Thermal contraction
Thermal expansion
Torque
Vacuum
Velocity
Volume
Wave
Wavelength
Weight
Work

SUMMARY

- Matter is anything that occupies space, and it exists as a gas, liquid, or solid.
- All matter is made of many tiny particles called atoms and molecules.
- When a solid dissolves in a liquid, a solution is formed. Not all solids will dissolve; rather, the liquid is either absorbed or adsorbed.
- Materials that *absorb* fluids are permeable substances. Impermeable substances *adsorb* fluids.
- Energy is the ability to do work and all matter has energy.
- The total amount of energy never changes; it can only be transferred from one form to another, not created or destroyed.
- When energy is released to do work, it is called kinetic energy. Stored energy is called potential energy.
- Energy conversion occurs when one form of energy is changed to another form.
- Mass is the amount of matter in an object. Weight is a force and is measured in pounds or kilograms. Gravitational force gives a mass its weight.
- Volume is the amount of space occupied by an object.
- The volume of an engine's cylinders determines its size, expressed as displacement.
- The compression ratio of an engine is the ratio of the volume in the cylinder above the piston when the piston is at the bottom of its travel to the cylinder's volume above the piston when the piston is at its uppermost position.
- A force is a push or pull, which can be large or small, and can be applied to something by direct contact or from a distance.
- When an object moves in a circle, its direction is continuously changing and all changes in direction require a force. The forces required to maintain circular motion are called centripetal and centrifugal forces.
- Pressure is a force applied against an object and is measured in units of force per unit of surface area (pounds per square inch or kilograms per square centimeter).
- The greater the mass of an object, the greater the force needed to change its motion.

- When a force overcomes static inertia and moves an object, the object gains momentum. Momentum is the product of an object's weight times its speed.
- Speed is the distance an object travels in a set amount of time. Velocity is the speed of an object in a particular direction. Acceleration is the rate of speed increase. Deceleration is the reverse of acceleration, because it is the rate of the decrease in speed.
- Newton's laws of motion are: (1) an object at rest tends to remain at rest and an object in motion tends to remain in motion; (2) when a force acts on an object, the motion of the object will change; and (3) for every action there is an equal and opposite reaction.
- Friction is a force that slows or prevents motion of two moving objects that touch.
- Friction can be reduced in two main ways: by lubrication or by the use of rollers.
- Aerodynamics is the study of the effects of air on a moving object.
- When a force moves a certain mass a specific distance, work is done.
- A machine is any device used to transmit a force and, in doing so, changes the amount of force and/or its direction. Examples of simple machines are inclined planes, pulleys, levers, gears, and wheels and axles.
- Torque is a force that tends to rotate or turn things and is measured by the force applied and the distance traveled.
- Gear ratios express the mathematical relationship of one gear to another.
- Power is a measurement of the rate at which work is done and is measured in watts.
- Horsepower is the rate at which torque is produced.
- An oscillation is any single swing of an object back and forth between the extremes of its travel. When that motion travels through matter or space, it becomes a wave.
- How many times the vibration occurs in 1 second is called frequency and is commonly expressed in hertz (Hz), which is equal to one cycle per second. The *amplitude* of a vibration is its intensity or strength.
- Noise is any unwanted signal or sound and can be random or periodic.
- Light is a form of electromagnetic radiation. It travels in a straight line at 300 million meters per second.
- A gas will always fill a sealed container, whereas a liquid may not. A gas will also readily expand or compress according to the pressure exerted on it. Liquids are basically incompressible, which gives them the ability to transmit force.
- Hydraulics is the study of liquids in motion.
- Pascal constructed the first known hydraulic device and established what is known as Pascal's law of hydraulics.
- The pressure inside the hydraulic system is called static pressure because there is no fluid motion. The pressure of the fluid while it is in motion is called dynamic pressure.
- Boyle's law states that the volume and pressure of gas at a fixed temperature is inversely proportional.
- The pressure law states that the pressure exerted by a gas increases as the temperature of the gas is increased.
- Charles' law states that the volume of a mass of gas depends on its temperature.
- Atmospheric pressure is the total weight of the earth's atmosphere. Pressure greater than atmospheric pressure may be measured in psi gauge (psig); actual pressure is measured in psi absolute (psia).
- Scientifically, vacuum is defined as the absence of atmospheric pressure. However, it is commonly used to refer to any pressure less than atmospheric pressure.
- Heat is a form of energy caused by the movement of atoms and molecules and is measured in British thermal units (Btus) and calories.
- Temperature is an indication of an object's kinetic energy and is measured with a thermometer.
- Convection is the transfer of heat by the movement of a heated object.
- Conduction is the movement of heat through a material.
- Through radiation, heat is transferred from one object to another.
- As heat moves in and out of a mass, the size of the mass tends to change.
- Sometimes additional heat causes no increase in temperature but causes the mass to change its state; this heat is called latent heat.

- The liquid in a solution is called the solvent, and the substance added is the solute.
- Specific gravity is the heaviness or density of a substance compared to that of water.
- A catalyst is a substance that affects a chemical reaction without being consumed or changed.
- An ion is an atom or group of atoms with one or more positive or negative electric charges. Ions are formed when electrons are added to or removed from neutral molecules or other ions. Ions are what make something an acid or a base.
- The pH scale is used to measure how acidic or basic a solution is.
- Oxidation is a chemical reaction in which a substance combines with oxygen. The addition of hydrogen atoms or electrons is called reduction.
- Hardening is a process that increases the hardness of a metal by hammering, rolling, carburizing, heat treating, tempering, or other processes.
- An elastic substance is a solid that gets larger under tension, smaller under compression, and returns to its original size when no force is acting on it.
- Tensile strength represents the maximum load a material can support without breaking when being stretched and is dependent on the cross-sectional area of the material.
- Electrolysis is an electrochemical process in which electric current is passed through a substance, causing a chemical change.
- An electrolyte is a substance or compound that conducts electric current as a result of the breaking down of its molecules into positively and negatively charged ions.
- Any electrical current will produce magnetism. When a coil of wire is wrapped around an iron bar, it is called an electromagnet.
- The most common way to produce electricity is to use coils of wire and magnets in a generator.

REVIEW QUESTIONS

Short Answer

1. Describe Newton's first law of motion and give an application of this law in automotive theory.
2. In what four states does matter exist? Cite examples of each.
3. Explain Newton's second law of motion and give an example of how this law is used in automotive theory.
4. Describe five different forms of energy conversions in an automobile.
5. Describe four different types of energy conversion.
6. Explain why a rotating, tilted wheel moves in the direction of the tilt.
7. Why are gases and liquids considered fluids?
8. Describe how out-of-balance forces can affect the automobile.
9. Describe the effect of pressure on an enclosed volume of a gas.
10. Explain why elastic mounts are used to connect the engine to the frame.
11. Name three types of simple machines.

Fill in the Blanks

1. The nucleus of an atom contains ___ and ___. Work is calculated by multiplying ___ by ___.
2. Energy may be defined as the ability to do ___.
3. When one object is moved over another object, the resistance to motion is called ___.
4. Weight is the measurement of the earth's ___ on an object.
5. Torque is a force that does work with a ___ action.
6. Vacuum is defined as the absence of ___.

Multiple Choice

1. Which of the following is the correct formula used to calculate engine displacement?
   a. Displacement = $\pi \times R^2 \times L \times N$
   b. Displacement = $\pi^2 \times R \times L \times N$
   c. Displacement = $\pi \times D \times L \times N$
   d. Displacement = $\pi \times D \times L^2 \times N$
2. While discussing different types of energy: Technician A says that when energy is released to do work, it is called potential energy. Technician B says that stored energy is referred to as kinetic energy. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

3. While discussing friction in matter: Technician A says that friction creates heat. Technician B says that friction only occurs with solids and is not present with liquids and gases. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. While discussing mass and weight: Technician A says that mass is the measurement of an object's inertia. Technician B says that mass and weight may be measured in cubic inches. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. When applying the principles of work and force, ___.
   a. work is accomplished when force is applied to an object that does not move
   b. in the metric system the measurement for work is cubic centimeters
   c. no work is accomplished when an object is stopped by mechanical force
   d. if a 50-pound object is moved 10 feet, 500 ft.-lb of work are produced
6. All these statements about energy and energy conversion are true, *except* ___.
   a. thermal energy may be defined as light energy
   b. chemical to thermal energy conversion occurs when gasoline burns
   c. mechanical energy is defined as the ability to do work
   d. mechanical to electrical energy conversion occurs when the engine drives the generator
7. Which of the following is *not* a true statement about heat transfer?
   a. Whenever the temperature of something changes, a transfer of heat has occurred.
   b. Conduction is the transfer of heat by infrared rays.
   c. Light bulbs are examples of heat transfer by radiation.
   d. Convection occurs when a hot object moves to an area with less heat.

CHAPTER 4

AUTOMOTIVE SYSTEMS

OBJECTIVES

- Explain the major events that have influenced the development of the automobile in the recent past.
- Explain the difference between unitized vehicles and body-over-frame vehicles.
- List the basic systems that make up an automobile and name their major components and functions.

Historical Background

The automobile has changed quite a bit since the first horseless carriage went down an American street. In 1896, both Henry Ford and Ransom Eli Olds test drove their first gasoline-powered vehicles. Prior to this time, other individuals were making their own automobiles. Most were powered by electricity or steam. The year 1896 marks the beginning of the automotive industry, not because of what Ford or Olds did, but because of the Duryea Brothers, who, by 1896, had made thirteen cars in the first factory that made cars for customers. The introduction of the Ford Model T was a turning point in the auto industry because it was the first car to be built on an assembly line and was very affordable **(Figure 4–1)**.

In the beginning, the automobile looked like the horse-drawn carriage it was designed to replace. In 1919, 90 percent of the cars had carriage like open bodies. These early cars had rear-mounted engines and very tall tires. They were designed to move people down dirt roads.

FIGURE 4–1 Model T Ford.

FIGURE 4–2 A look at the past!

The automobile changed when the roads became paved, more people owned cars, manufacturers tried to sell more cars, concerns for safety and the environment grew, and new technologies were developed **(Figure 4–2)**. All of these changes resulted in automobiles that are more practical, more affordable, safer, more comfortable, more dependable, and faster. Although many improvements have been made to the original design, the basics of the automobile have changed very little:

- Nearly all of today's cars still use gasoline engines to drive two or more wheels.
- A steering system is used to control the direction of the car.
- A brake system is used to slow down and stop the car.
- A suspension system is used to absorb road shocks and help the driver maintain control on bumpy roads.
- The major systems are mounted on steel frames and the frame is covered with body panels.
- The body panels give the car its shape and protect those inside from the weather and dirt.
- The body panels also offer some protection for the passengers if the automobile is in an accident.

Although these basics have changed little in the past 100 years, the design of the systems has greatly changed. The entire automobile is almost technologically unrecognizable compared to Ford's and Olds's early models. New technologies have changed the slow, unreliable, user-hostile vehicles of the early 1900s into vehicles that can travel at very high speeds, operate trouble-free for many thousands of miles, and provide comforts that even the very rich had not dreamed of in 1896.

Social and political pressures have had a great influence on automobile design for the past 40-plus years. In 1965, laws were passed that limited the amount of harmful gases emitted by an automobile. Although this had little immediate effect on the industry, the automobile manufacturers were forced to focus on the future. They needed to build cleaner-burning engines. In the following years, stricter emissions laws were passed and manufacturers were required to develop new emission control systems.

World events in the 1970s continued to shape the development of the automobile. An oil embargo by Arab nations in 1973 caused the price of gasoline to quickly increase to four times its normal price. This event caused most Americans to realize that the supply of gasoline and other nonrenewable resources was limited. Car buyers wanted cars that were not only kind to the environment but that also used less fuel.

The **Corporate Average Fuel Economy (CAFE)** standards were set in 1975. These required automakers to build more fuel-efficient vehicles. Under the CAFE standards, different models from each manufacturer are tested for the number of miles they can be driven on a gallon of gas. The fuel efficiencies of these vehicles are averaged together to arrive at a corporate average. The CAFE standards have increased many times since it was established. A manufacturer that does not meet CAFE standards for a given model year faces heavy fines. The current proposed CAFE standards will increase fuel economy to 54.5 mpg between the years 2022 and 2025.

While trying to produce more fuel-efficient vehicles, manufacturers replaced large eight-cylinder engines with four-cylinder and other small engines. Basic engine systems like carburetors and ignition breaker points were replaced by electronic fuel injection and electronic ignition systems.

By the mid-1980s, all automobiles were equipped with some type of electronic control system. These systems did, and still do, monitor the engine's operation and provide increased power outputs while minimizing fuel consumption and emissions. Electronic sensors are used to monitor the engine and many other systems. Computerized engine control systems control air and fuel delivery, ignition timing, emission systems operation, and a host of other related operations. The result is a clean-burning, fuel-efficient, and powerful engine **(Figure 4–3)**.

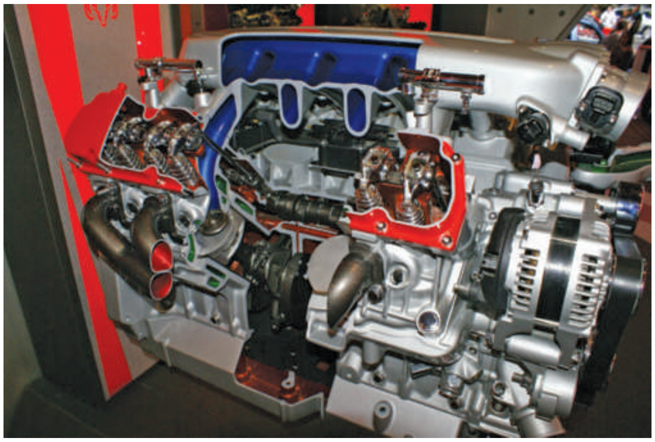


FIGURE 4-3 A cutaway of a late-model V-10 gasoline engine.

Design Evolution

Not too long ago, nearly every car and truck was built with body-over-frame construction, rear-wheel drive, and symmetrical designs. Today, most vehicles do not have a separate frame; instead, the frame and body are built as a single unit, called a unibody. Most large pickup trucks and SUVs still use body-over-frame construction.

Another major influence to design was the switch from rear-wheel drive to front-wheel drive. Making this switch accomplished many things, the most notable being improved traction at the drive wheels, increased interior space, shortened hood lines, and a created very compact driveline. Because of the weight and loads that pickup trucks are designed to move, most remain rear-wheel drive.

Perhaps the most obvious design change through the years has been body styles. Body styles have changed to respond to the other design considerations and to trends of the day. For example, in the 1950s America had a strange preoccupation with the unknown, outer space, which led to cars that had rocket-like fins. Since then fins have disappeared and body styles have become more rounded to reduce air drag.

Body-Over-Frame Construction

In body-over-frame construction, the frame is the vehicle's foundation. The body and all major parts of the vehicle are attached to the frame. The frame must be strong enough to keep the rest of the vehicle in alignment should a collision occur.

The frame is an independent, separate component. The body is generally bolted to the frame **(Figure 4–4)**, but large, specially designed rubber

FIGURE 4-4 In body-over-frame construction, the frame is the vehicle's foundation.

mounts are placed between the frame and body to reduce noise and vibration from entering the passenger compartment. Quite often two layers of rubber are used in these pads to provide a smoother ride. The frame rails are made of stamped steel, which are welded together. Some frames are made by a **hydroforming** process, which uses high-pressure water, rather than heat, to shape the steel into the desired shape.

Unitized Construction

A **unibody (Figure 4–5)** is a stressed hull structure in which each of the body parts supplies structural support and strength to the entire vehicle. Unibody vehicles tend to be tightly constructed because the major parts are all welded together. This helps protect the occupants during a collision. However, it causes damage patterns that differ from those of body-over-frame vehicles. Rather than localized damage, the stiffer sections used in unibody design tend to transmit and distribute impact energy throughout more of the vehicle.

Nearly all unibodies are constructed from steel. However, some newer cars, and SUVs, use aluminum instead. An aluminum car body and frame can weigh up to 40 percent less than an identical body made of steel. Most front-wheel-drive unibody vehicles have a cradle or partial frame that is used to support the powertrain and suspension for the front wheels.

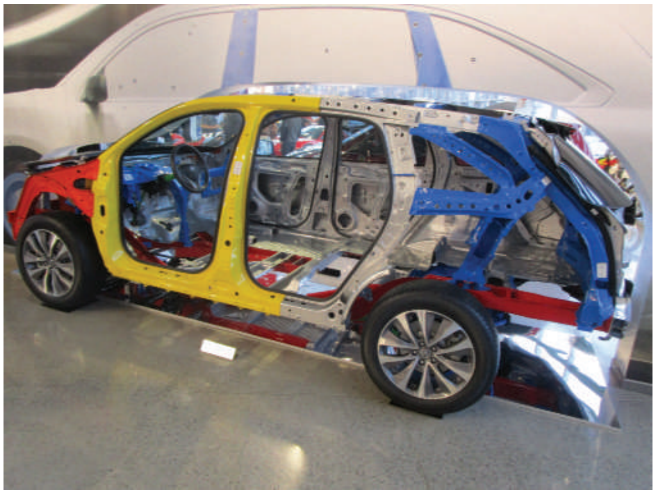


FIGURE 4–5 The structure of a unibody car. The different colors represent the different materials used to construct the unit.

Vehicle Construction

Modern vehicles are required to meet fuel economy and safety standards, as well as incorporate new technology that consumers expect. To satisfy these demands, manufacturers are using new materials and construction methods to build their vehicles. This includes light weight high-strength steels, carbon fiber components, and using adhesives in place of rivets or welding.

Body Shapes

Various methods of classifying vehicles exist. Vehicles may be classified by engine type, body/frame construction, fuel type, type of drive, or the classifications most common to consumers, which are body shape, seat arrangement, and number of doors. Ten basic body shapes are used today:

FIGURE 4–6 This Honda Accord is an example of a typical late-model sedan.

FIGURE 4–7 This Mustang Boss 302 is a coupe.

FIGURE 4–8 This BMW is a German sports car.

- *Sedan.* A vehicle with front and back seats that accommodates four to six persons is classified as either a two-or four-door sedan **(Figure 4–6)**. Often, a two-door sedan is called a coupe **(Figure 4–7)**.
- *Convertibles.* Convertibles have vinyl roofs that can be raised or lowered. A few late-model convertibles feature a folding metal roof that tucks away in the trunk when it is down. Some convertibles have both front and rear seats. Those without rear seats are commonly referred to as sports cars **(Figure 4–8)**.
- *Liftback or hatchback.* The distinguishing feature of this vehicle is its rear luggage compartment, which is an extension of the passenger compartment. Access to the luggage compartment is gained through an upward opening hatch-type door **(Figure 4–9)**. This design car can be a three- or a five-door model. The third or fifth door is the rear hatch.
- *Station wagon.* A station wagon is characterized by its roof, which extends straight back, allowing a spacious interior luggage compartment in the rear **(Figure 4–10)**. The rear door, which can be

FIGURE 4–9 This four-door Ford Focus is a hatchback. Its rear luggage compartment is an extension of the passenger compartment.

FIGURE 4–10 This Subaru is an example of a late-model station wagon.

opened in various ways depending on the model, provides access to the luggage compartment. Station wagons typically have four doors and can have space for up to nine passengers.

- *Pickups.* Pickup trucks have an open cargo area behind the passenger compartment. There are many varieties available today: there are compact, medium-sized, full-sized, and heavy-duty pickups. They also can have two-, three-, or four-door models. Some have extended cab areas with seats behind the front seats **(Figure 4–11)**. They are available in two-wheel drive, four-wheel drive (4 × 4), or all-wheel drive.
- *Vans.* The van body design has a tall roof and a totally enclosed large cargo or passenger area. Vans can seat from two to twelve passengers, depending on size and design. Basically, there are two sizes of vans: mini- and full-size. The most common are mini-vans **(Figure 4–12)**.

FIGURE 4–11 This Ram with an extended cab is a popular pickup truck.

FIGURE 4–12 This Honda is an excellent example of a minivan. Full-size vans are also available.

- *Sport utility vehicles (SUVs).* SUVs are best described as multipurpose vehicles that can carry a wide range of passengers, depending on their size and design. A good majority of SUVs have four-wheel drive, although some do not. Most small SUVs are based on an automobile platform and take on many different looks and features **(Figure 4–13)**. Mid-size SUVs are larger and typically offer more features and comfort. There are

FIGURE 4–13 This Subaru is an example of a small SUV.

FIGURE 4–14 This Range Rover is a large SUV.

many large SUVs available **(Figure 4–14)**. These vehicles can seat up to nine adults and tow up to 6 tons.

- *Crossover vehicles.* These automobiles look like an SUV but are built lighter and offer fuel efficiency. They are actually a combination of a station wagon and an SUV. They have SUV features but are not quite the same size. The basic construction of a crossover vehicle leads to a less truck-like ride than a normal SUV **(Figure 4–15)**. They also are not designed to tow heavy loads or for off-the-road use.
- *Hybrid vehicles.* There are many hybrid vehicles available today. Each of these incorporate different technologies to achieve low emissions and excellent fuel mileage. The Chevrolet Volt is a series hybrid and is referred to as an extended range electric vehicle **(Figure 4–16)**.
- *Electric vehicles.* As time passes, more manufacturers are introducing pure electric vehicles. One of the first to be available is the Nissan Leaf **(Figure 4–17)**.

FIGURE 4–15 This Nissan Rogue is a crossover vehicle.

FIGURE 4–16 The Chevrolet Volt is referred to as an extended range electric vehicle.

FIGURE 4–17 A Nissan Leaf.

The Basic Engine

The engine provides the power to drive the wheels of the vehicle. All automobile engines, both gasoline and diesel, are classified as internal combustion engines because the combustion or burning that provides the power to move the vehicle takes place inside the engine. **Combustion** is the burning of an air and fuel mixture. As a result of combustion, large amounts of pressure are generated in the engine. This pressure or energy is used to power the car. The engine must be built strong enough to hold the pressure and temperatures formed by combustion.

Diesel engines have been around a long time and are mostly found in big heavy-duty trucks. However, they are also used in some pickup trucks and are becoming more common in automobiles due to their fuel economy. **(Figure 4–18)**. Although the construction of gasoline and diesel engines is similar, their operation is quite different. Diesel engines achieve better fuel economy than gasoline engines of the

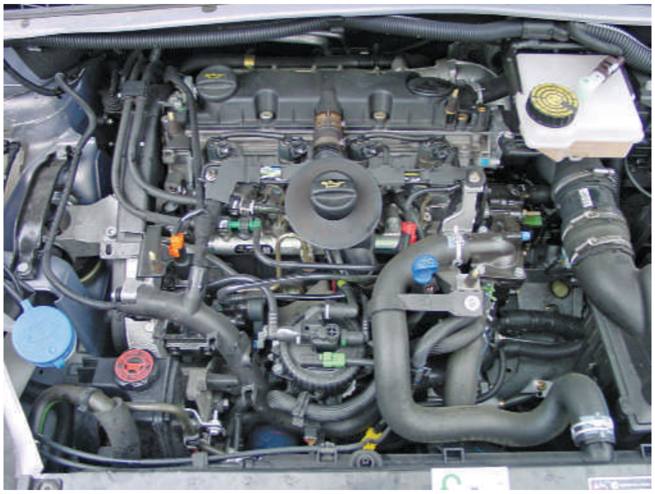


FIGURE 4–18 A four-cylinder automotive diesel engine.

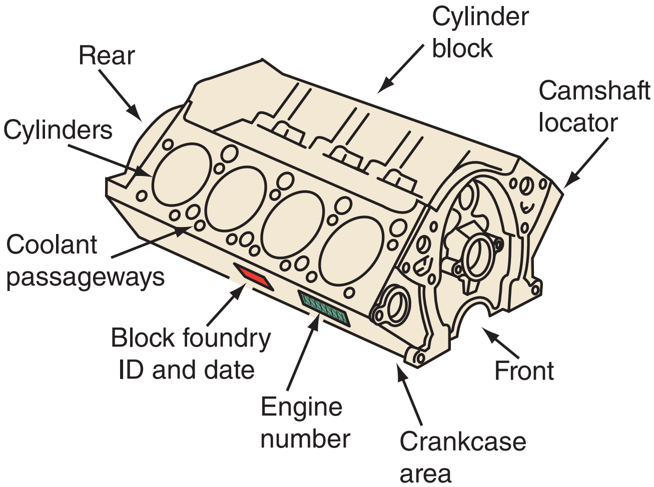


FIGURE 4–19 An engine block for a V8 engine.

same size. With new technologies and the cleaner fuels, their emissions levels can be comparable to the best of gasoline engines.

A gasoline engine relies on a mixture of fuel and air that is ignited by a spark to produce power. A diesel engine also uses fuel and air, but it does not need a spark to cause ignition. A diesel engine is often called a compression ignition engine. This is because its intake air is tightly compressed, which greatly raises its temperature. The fuel is then injected into the compressed air. The heat of the compressed air ignites the fuel and combustion takes place. The following sections cover the basic parts and the major systems of a gasoline engine.

Cylinder Block

The biggest part of the engine is the **cylinder block**, which is also called an **engine block (Figure 4–19)**. The cylinder block is a large casting of metal (cast iron or aluminum) that is drilled with holes to allow for the passage of lubricants and coolant within the block and provide spaces for movement of mechanical parts. The block contains the cylinders, which are round passageways fitted with pistons. The block houses or holds the major mechanical parts of the engine.

Cylinder Head

The **cylinder head** fits on top of the cylinder block to close off and seal the top of the cylinders **(Figure 4–20)**. The **combustion chamber** is an area into which the air-fuel mixture is compressed and burned. The cylinder head contains all or most of the combustion chamber. The cylinder head also

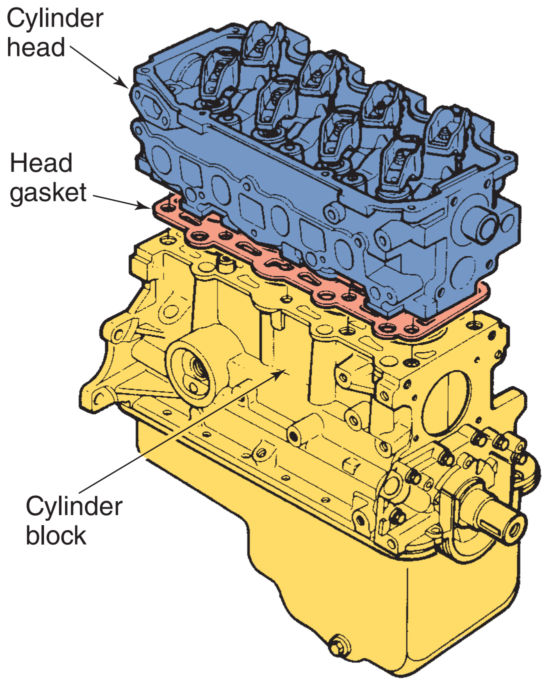


FIGURE 4–20 The two major units of an engine, the cylinder block and the cylinder head, are sealed together with a gasket and are bolted together.

contains **ports**, which are passageways through which the air-fuel mixture enters and burned gases exit the cylinder. A cylinder head can be made of cast iron or aluminum.

Piston

The burning of air and fuel takes place between the cylinder head and the top of the piston. The **piston** is a can-shaped part closely fitted inside the cylinder **(Figure 4–21)**. In a four-stroke cycle engine, the

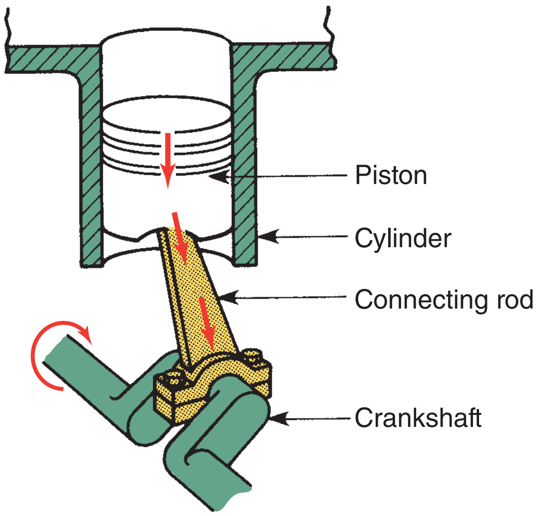


FIGURE 4-21 The engine's pistons fit tightly in the cylinders and are connected to the engine's crankshaft with connecting rods.

piston moves through four different movements or strokes to complete one cycle. These four are the intake, compression, power, and exhaust strokes. On the intake stroke, the piston moves downward, and a charge of air-fuel mixture is introduced into the cylinder. As the piston travels upward, the air-fuel mixture is compressed in preparation for burning. Just before the piston reaches the top of the cylinder, ignition occurs and combustion starts. The pressure of expanding gases forces the piston downward on its power stroke. When it reciprocates, or moves upward again, the piston is on the exhaust stroke. During the exhaust stroke, the piston pushes the burned gases out of the cylinder.

Connecting Rods and Crankshaft

The reciprocating motion of the pistons must be converted to rotary motion before it can drive the wheels of a vehicle. This conversion is achieved by linking the piston to a **crankshaft** with a **connecting rod**. As the piston is pushed down on the power stroke, the connecting rod pushes on the crankshaft, causing it to rotate. The end of the crankshaft is connected to the transmission to continue the power flow through the drivetrain and to the wheels.

Valve Train

A **valve train** is a series of parts used to open and close the intake and exhaust ports. A valve is a movable part that opens and closes a passageway. A camshaft controls the movement of the valves **(Figure 4–22)**, causing them to open and close at the proper time. Springs are used to help close the valves.

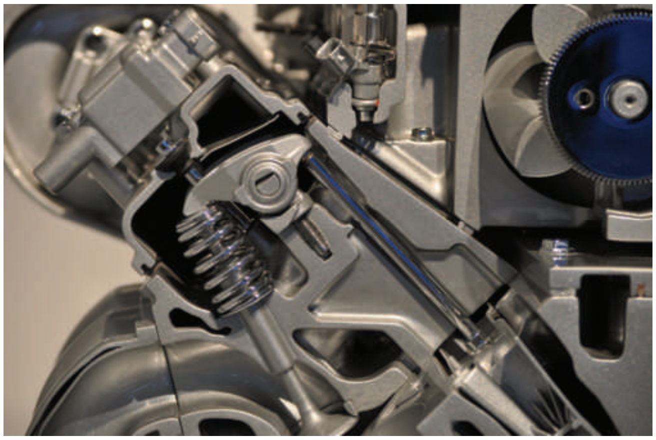


FIGURE 4-22 The valve train for one cylinder of an overhead valve engine.

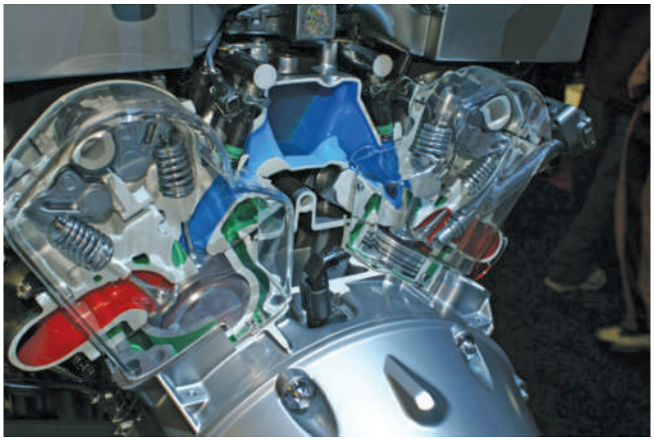


FIGURE 4-23 The blue manifold is the intake manifold and the red manifold is for the exhaust.

Manifolds

A **manifold** is a ductwork assembly used to direct the flow of gases to or from the combustion chambers. Two separate manifolds are attached to the cylinder head **(Figure 4–23)**. The intake manifold delivers a mixture of air and fuel to the intake ports. The **exhaust manifold** mounts over the exhaust ports and carries exhaust gases away from the cylinders.

Engine Systems

The following sections present a brief explanation of the systems that help an engine run and keep running.

Lubrication System

The moving parts of an engine need constant lubrication. Lubrication limits the amount of wear and reduces the amount of friction in the engine.

Motor or engine oil is the fluid used to lubricate the engine. Several quarts of oil are stored in an oil pan bolted to the bottom of the engine block. The oil pan is also called the crankcase or oil sump. When the engine is running, an oil pump draws oil from the pan and forces it through oil galleries. These galleries are small passageways that direct the oil to the moving parts of the engine.

Oil from the pan passes through an oil filter before moving through the engine **(Figure 4–24)**. The filter removes dirt and metal particles from the oil. Premature wear and damage to parts can result from dirt in the oil. Regular replacement of the oil filter and oil is an important step in a preventive maintenance program.

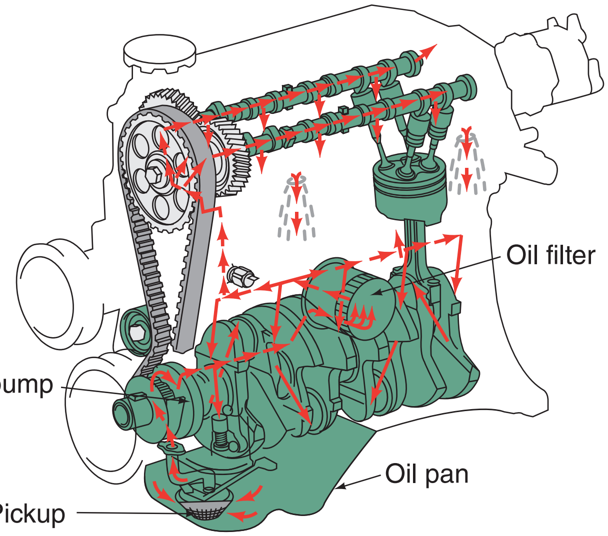


FIGURE 4–24 Oil flow in a typical engine's lubrication system.

Cooling System

The combustion of the air-fuel mixture produces large amounts of heat in the engine. This heat must not be allowed to buildup and must be reduced. The heat can damage and warp engine parts. To prevent this, engines have a cooling system **(Figure 4–25)**.

The most common way to cool an engine is to circulate a liquid coolant through passages in the engine block and cylinder head. An engine can also be cooled by passing air over and around the engine, however few air-cooled engines are found in automobiles today.

A typical cooling system relies on a **water pump**, which circulates the coolant through the system. The pump is driven by the engine or an electric motor.

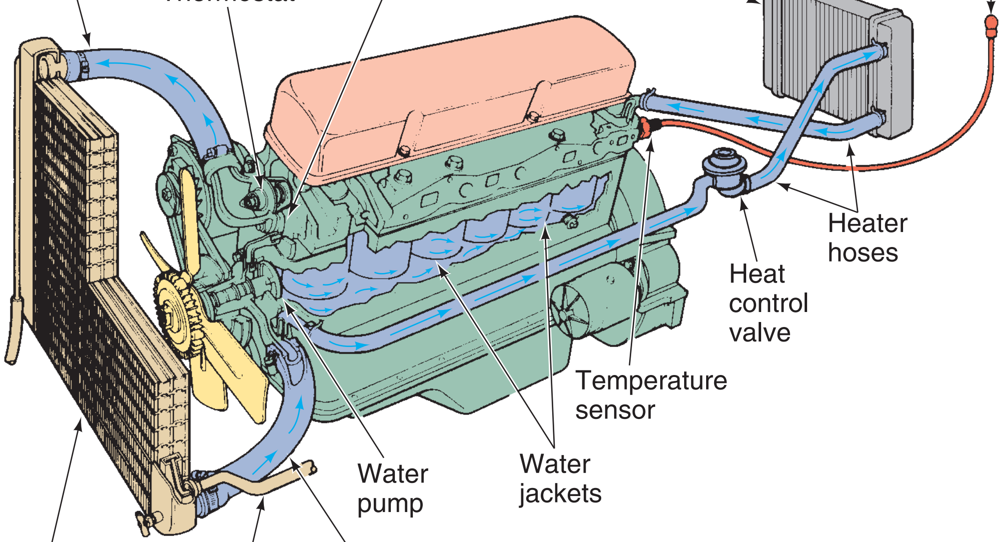


FIGURE 4–25 A typical engine cooling system.

The coolant is a mixture of water and antifreeze. The coolant is pushed through passages, called **water jackets**, in the cylinder block and head to remove heat from the area around the cylinders. The heat picked up by the coolant is sent to the **radiator**. The radiator transfers the coolant's heat to the outside air as the coolant flows through its tubes. To help remove the heat from the coolant, a cooling fan is used to pull cool outside air through the fins of the radiator.

To raise the boiling point of the coolant, the cooling system is pressurized. To maintain this pressure, a radiator or **pressure cap** is fitted to the radiator. A **thermostat** is used to block off circulation in the system until a preset temperature is reached. This allows the engine to warm up faster. The thermostat also keeps the engine temperature at a predetermined level. Because parts of the cooling system are located in various spots under the vehicle's hood, hoses are used to connect these parts and keep the system sealed.

Fuel and Air System

The fuel and air system is designed to supply the correct amount of fuel mixed with the correct amount of air to the cylinders of the engine. This system also:

- Stores the fuel for later use
- Delivers fuel to a device that will control the amount of fuel going to the engine
- Collects and cleans the outside air
- Delivers outside air to the individual cylinders
- Changes the fuel and air ratios to meet the needs of the engine during different operating conditions

The fuel system is made up of different parts. A fuel tank stores the liquid gasoline. Fuel lines carry the liquid from the tank to the other parts of the system. A pump moves the gasoline from the tank through the lines. A filter removes dirt or other particles from the fuel. A fuel pressure regulator keeps the pressure below a specified level. An air filter cleans the outside air before it is delivered to the cylinders. Fuel injectors mix fuel with the air for delivery to the cylinders or directly to the cylinders. An intake manifold directs the air to each of the cylinders **(Figure 4–26)**.

Emission Control System

Today's engines have been engineered to emit very low amounts of certain pollutants. The pollutants that have been drastically reduced are **hydrocarbons (HC)**, **carbon monoxide (CO)**, and **oxides of nitrogen (NO_x)**. The Environmental Protection Agency establishes emissions standards that limit the amount of these pollutants a vehicle can emit.

FIGURE 4–26 The intake system for a twin-turbocharged BMW engine.

To meet these standards, many changes have been made to the engine itself. There also have been systems developed and added to the engines to reduce the pollutants they emit. A list of the most common pollution control devices follows:

- ***Positive crankcase ventilation (PCV)*** *system.* This system reduces HC emissions by drawing fuel and oil vapors from the crankcase and sends them into the intake manifold where they are delivered to and burned in the cylinders. This system prevents the pressurized vapors from escaping the engine and entering into the atmosphere.
- *Evaporative emission control system.* This system reduces HC emissions by drawing fuel vapors from the fuel system and releases them into the intake air to be burned. This system stops these vapors from leaking into the atmosphere.
- ***Exhaust gas recirculation (EGR)*** *system.* This system introduces exhaust gases into the intake air to reduce the temperatures reached during combustion. This reduces the chances of forming NO_x during combustion.
- *Catalytic converter.* Located in the exhaust system, it allows for the burning or converting of HC, CO, and NO_x into harmless substances, such as water.
- *Air injection system.* This system reduces HC emissions by introducing fresh air into the exhaust stream to cause minor combustion of the HC in

the engine's exhaust. Most newer engines do not need this system to achieve acceptable emissions levels.

Diesel Emission Controls

Many of the systems used on gasoline engines are also used on diesel engines to reduce their emissions. In the past, emissions have always been an obstacle to having diesel cars. Today, that problem is rapidly disappearing. Many new diesel vehicles have an assortment of traps and filters to clean the exhaust before it leaves the tailpipe; others use selective catalytic reduction (SCR) systems. SCR is a process in which a reductant is injected into the exhaust stream and then absorbed onto a catalyst. A reductant removes oxygen from a substance and combines the oxygen to another substance and forms another compound. In this case, oxygen is separated from the NO_x and is combined with hydrogen to form water.

Exhaust System

During the exhaust stroke, the engine's pistons push the burned air-fuel mixture, or exhaust, out of the cylinder and into the exhaust manifold. From the manifold, the gases travel through the exhaust system until they are expelled into the atmosphere **(Figure 4–27)**. The exhaust system is designed to direct toxic exhaust fumes away from the passenger compartment, to quiet the sound of the exhaust pulses, and to burn or catalyze pollutants in the exhaust.

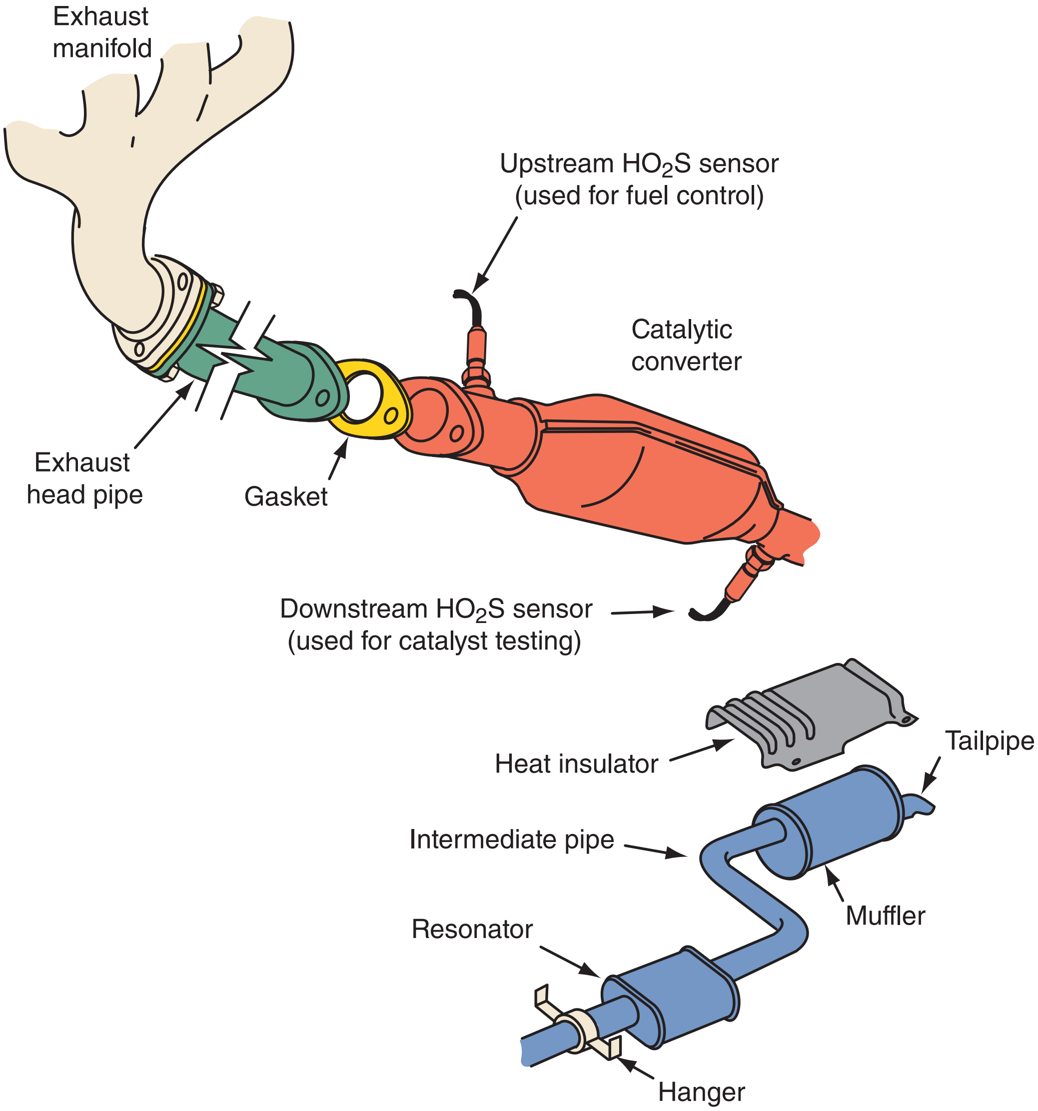


FIGURE 4–27 A typical exhaust system on a late-model car.

Electrical and Electronic Systems

Automobiles have many circuits that carry electrical current from the battery to individual components. An automotive electrical system includes such major subsystems as the ignition, starting, charging, lighting, and other electrical systems.

Ignition System

After the air-fuel mixture is delivered to a cylinder and compressed by the piston, it must be ignited. A gasoline engine uses an electrical spark to ignite the mixture. Generating this spark is the role of the ignition system.

The **ignition coil** generates the electricity that creates this spark **(Figure 4–28)**. The coil transforms the low voltage of the battery into a burst of 30,000 to 100,000 volts. This burst is what ignites the mixture. The mixture must be ignited at the proper time, although the exact time varies with engine design. Ignition must occur at a point before the piston has completed its compression stroke.

In most engines, the motion of the piston and the rotation of the crankshaft are monitored by a **crankshaft position sensor**. The sensor electronically tracks the position of the crankshaft and relays that information to a control module. Based on input from the crankshaft position sensor, an electronic engine control computer turns battery current to the coil on and off at the precise time so that a voltage surge arrives at the cylinder at the right time.

This voltage surge must be distributed to the correct cylinder because only one cylinder is fired at a time. In earlier systems, this was the job of the distributor. A **distributor** is driven by the camshaft. It transfers the high-voltage surges from the coil to spark plug wires in the correct firing order. The spark plug wires then deliver the high voltage to the spark plugs, which are screwed into the cylinder head. The voltage jumps across a gap between two electrodes at the end of each **spark plug** and causes a spark. This spark ignites the air-fuel mixture.

Today's ignition systems do not use a distributor. Instead, these systems have several ignition coils—one for each spark plug or pair of spark plugs. When a coil is activated by the control module, high voltage is sent through a spark plug circuit. The control module has total control of the timing and distribution of the spark-producing voltage to the various cylinders.

Starting and Charging Systems

The starting system is responsible for starting the engine **(Figure 4–29)**. When the ignition key is turned to the start position or the START button is pressed, a small amount of current flows from the battery to a **solenoid** or relay. This activates the solenoid or relay and closes another electrical circuit that allows full battery voltage to reach the starter motor. The starter then engages in the engine's flywheel, which is attached the engine's crankshaft, and spins it. As the crankshaft turns, the pistons move through their strokes. At the correct time for each cylinder, the ignition system provides the spark to ignite the air-fuel mixture. If good combustion takes place, the engine will now rotate on its own without the need of the starter motor. The ignition key is now allowed to return to the "on" position. From this point on, the engine will continue to run until the ignition key is turned off.

The power to operate the starter circuit comes from the battery. While the starter is rotating the

FIGURE 4–28 An ignition module and coil assembly for four cylinders.

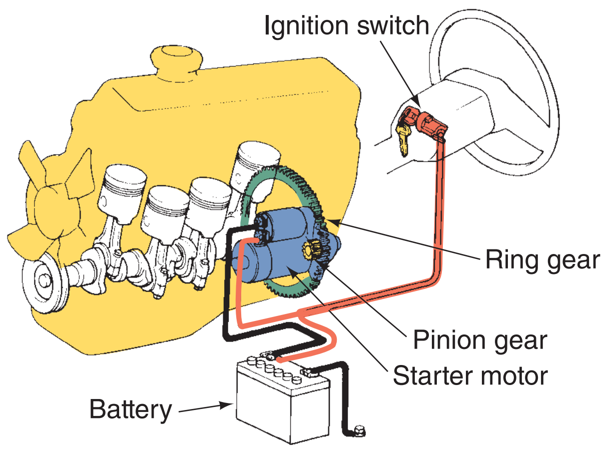


FIGURE 4–29 A typical starting system.

crankshaft, it uses a lot of electricity. This tends to lower the amount of power in the battery. Therefore, a system is needed to recharge the battery so that engine starts can be made in the future.

The charging system is designed to recharge and maintain the battery's state of charge. It also provides electrical power for the ignition system, air conditioner, heater, lights, radio, and all electrical accessories when the engine is running.

The charging system includes an AC generator (alternator), voltage regulator, indicator light, and the necessary wiring. Rotated by the engine's crankshaft through a drive belt, the AC generator **(Figure 4–30)** converts mechanical energy into electrical energy. The AC is converted into direct current (DC) within the alternator. When the output or electrical current from the charging system flows back to the battery, the battery is being charged. When the current flows out of the battery, the battery is said to be discharging.

Image courtesy of Robert Bosch GmbH.

FIGURE 4-30 The major components of a late-model AC generator.

Electronic Engine Controls

Nearly all vehicles have an electronic engine control system. This system is comprised of many electronic and electromechanical parts. It is designed to continuously monitor the engine and to make adjustments that will allow the engine to run more efficiently. Electronic engine control systems dramatically improve fuel mileage, engine performance, and driveability and greatly reduce exhaust emissions.

Electronic control systems have three main types of components: input sensors, a computer, and output devices **(Figure 4–31)**, all of these are connected

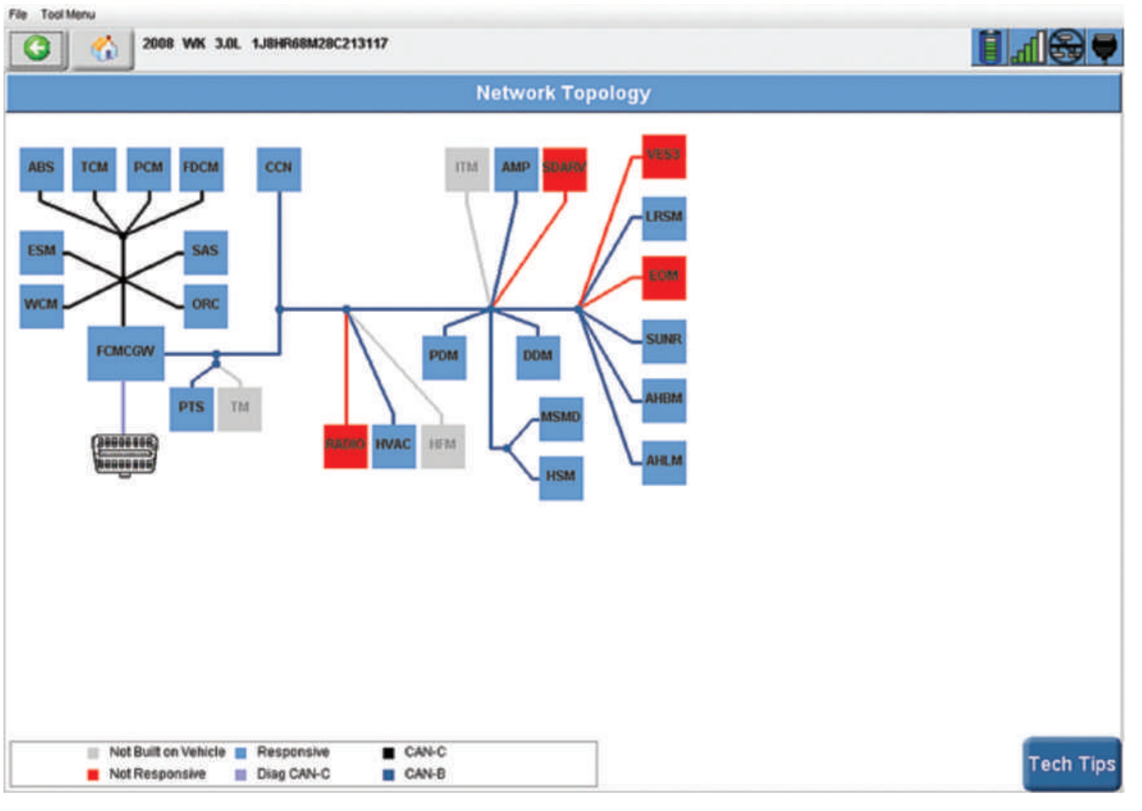


FIGURE 4-31 Late-model electronic engine control systems have many processors that are connected through networks.

by a network circuit. The computer analyzes data from the input sensors. Then, based on the inputs and the instructions held in its memory, the computer directs the output devices to make the necessary changes in the operation of some systems.

As an added advantage, an electronic control system is very flexible. Because it uses computers, it can be programmed to meet a variety of engine combinations or calibrations. Critical quantities that determine an engine's performance can be changed easily by changing data that is stored in the computer's memory.

On-Board Diagnostics

Today's engine control systems are on-board diagnostic (OBD II) second-generation systems. These systems were developed to ensure proper emission control system operation for the vehicle's lifetime by monitoring emission-related components for deterioration and malfunction. The OBD system consists of engine and transmission control modules and their sensors and actuators along with the diagnostic software.

The computer **(Figure 4–32)** can detect system problems even before the driver notices a driveability problem because many problems that affect emissions can be electrical or even chemical in nature.

When the OBD system determines that a problem exists, a corresponding "diagnostic trouble code" is stored in the computer's memory. The computer also illuminates a yellow dashboard light indicating "check engine" or "service engine soon" or displays an engine symbol. This light informs the driver of the need for service, not of the need to stop the vehicle.

FIGURE 4–32 A typical automotive computer.

A blinking or flashing dashboard lamp indicates a rather severe level of engine misfire. When this occurs, the driver should reduce engine speed and load and have the vehicle serviced as soon as possible. After the problem has been fixed, the dashboard lamp will be turned off.

Heating and Air-Conditioning Systems

Heating and air-conditioning systems do little for the operation of a vehicle; they merely provide comfort for the vehicle's passengers. The heating system basically adds heat to the vehicle's interior, whereas air conditioning removes heat. To do this, the systems rely on many parts to put basic theories to work.

Heating Systems

To meet federal safety standards, all vehicles must be equipped with passenger compartment heating and windshield defrosting systems. The main components of an automotive heating system are the heater core, the heater control valve, the blower motor and the fan, and the heater and defroster ducts. The heating system works with the engine's cooling system and converts the heat from the coolant circulating inside the engine to hot air, which is blown into the passenger compartment. A heater hose transfers hot coolant from the engine to the heater control valve and then to the heater core inlet. As the coolant circulates through the core, heat is transferred from the coolant to the tubes and fins of the core. Air blown through the core by the blower motor and fan then picks up the heat from the surfaces of the core and transfers it into the passenger compartment. After giving up its heat, the coolant is then pumped out through the heater core outlet, where it is returned to the engine's cooling system to be heated again.

Transferring heated air from the heater core to the passenger compartment is the job of the heater and defroster ducts. The ducts are typically part of a large plastic shell that connects to the necessary inside and outside vents. Contained inside the duct are also the doors required to direct air to the floor, dash, and/or windshield.

Air-Conditioning Systems

In an automotive air-conditioning (A/C) system, heat is removed from the passenger compartment and moved to the outside of the vehicle. The substance used to remove heat is called the **refrigerant**. To understand how a refrigerant is used to cool the interior of a vehicle, the effects of pressure and temperature on it must be first understood. If the pressure of the refrigerant is high, so is its temperature. Likewise if the pressure is low, so is its temperature. Therefore, changing its pressure can change the refrigerant's temperature.

To absorb heat, the temperature and pressure of the refrigerant are kept low. To get rid of the heat, the temperature and pressure are high. As the refrigerant absorbs heat, it evaporates or changes from a liquid to a vapor. As it dissipates heat, it condenses and changes from a vapor to a liquid. These two changes of state occur continuously as the refrigerant circulates through the system.

An A/C system is a closed, pressurized system. It consists of a compressor, condenser, receiver/dryer or accumulator, expansion valve or orifice tube, and an evaporator. The best way to understand the purpose of the components is to divide the system into two sides: the high side and the low side. High side refers to the side of the system that is under high pressure and high temperature. Low side refers to the low-pressure, low-temperature side **(Figure 4–33)**.

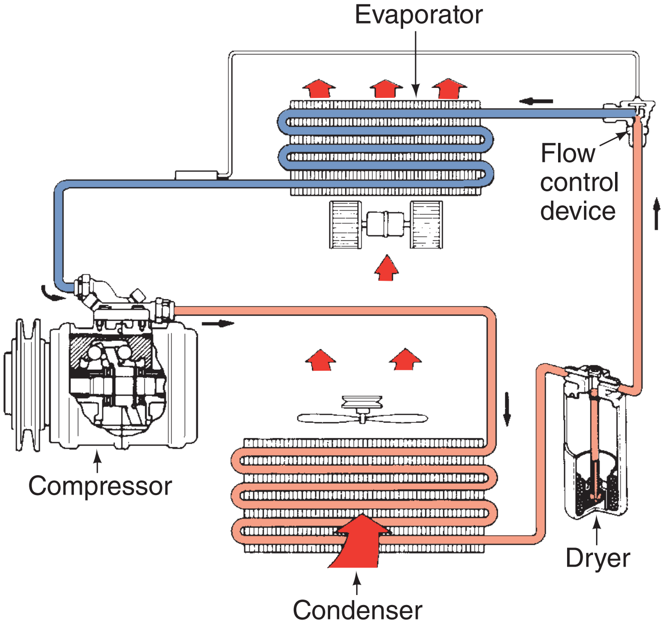


FIGURE 4–33 A simple look at an air-conditioning system. The blue signifies low pressure and the red is high pressure.

Compressor The **compressor** separates the high and low sides of the system. Its primary purpose is to draw the low-pressure and low-temperature vapor from the evaporator and compress this vapor into high-temperature, high-pressure vapor. The compressor also circulates or pumps the refrigerant through the system. The compressor is normally driven by the engine's crankshaft via a drive belt.

Compressors are equipped with an electromagnetic clutch as part of the compressor pulley assembly. The clutch is designed to engage the pulley to the compressor shaft when the clutch coil is energized. When the clutch is not engaged, the compressor shaft does not rotate, and the pulley freewheels. The clutch provides a way for turning the compressor on or off.

Condenser The **condenser** consists of coiled tubing mounted in a series of thin cooling fins to provide maximum heat transfer in a minimum amount of space. The condenser is normally mounted just in front of the vehicle's radiator. It receives the full flow of ram air from the movement of the vehicle or airflow from the radiator fan when the vehicle is standing still.

The condenser condenses or liquefies the high-pressure, high-temperature vapor coming from the compressor. To do this, it must give up its heat. Very hot, high-pressure refrigerant vapor enters the inlet at the top of the condenser, and as the hot vapor passes down through the condenser coils, heat moves from the refrigerant into the cooler air that flows across the coils and fins. This loss of heat causes the refrigerant to change from a high-pressure hot vapor to a high-pressure warm liquid. The high-pressure warm liquid flows from the bottom of the condenser to the receiver/dryer or to the refrigerant metering device if an accumulator is used.

Receiver/Dryer The **receiver/dryer** is a storage tank for the liquid refrigerant from the condenser. The refrigerant flows into the receiver tank, which contains a bag of desiccant (moisture-absorbing material). The desiccant absorbs unwanted water and moisture in the refrigerant.

Accumulator Most late-model systems have an accumulator rather than a receiver/dryer. The accumulator is connected into the low side at the outlet of the evaporator. The accumulator contains a desiccant and is designed to store excess refrigerant. If liquid refrigerant flows out of the evaporator, it will be collected by and stored in the accumulator. The

main purpose of an accumulator is to prevent liquid from entering the compressor.

Thermostatic Expansion Valve/Orifice Tube The refrigerant flow to the evaporator must be controlled to obtain maximum cooling while ensuring complete evaporation of the liquid refrigerant within the evaporator. This is the job of a **thermostatic expansion valve (TEV or TXV)** or a fixed orifice tube. The TEV is mounted at the inlet to the evaporator and separates the high-pressure side of the system from the low-pressure side. The TEV regulates the refrigerant flow to the evaporator by balancing the inlet flow to the outlet temperature.

Like the TEV, the **orifice tube** is the dividing point between the high- and low-pressure sides of the system. However, its metering or flow rate control does not depend on comparing evaporator pressure and temperature. It is a fixed orifice. The flow rate is determined by pressure difference across the orifice and by the additional cooling of the refrigerant in the bottom of the condenser after it has changed from vapor to liquid.

Evaporator The **evaporator** is made up of tubes that are mounted in a series of thin cooling fins. The evaporator is usually located beneath the dashboard or instrument panel.

The low-pressure, low-temperature liquid refrigerant from the TEV or orifice tube enters the evaporator as a spray. The heat at the evaporator causes the refrigerant to boil and change into a vapor. The transfer of heat from the evaporator to the refrigerant causes the evaporator to get cold. Because hot air always moves toward cold air, the hot air from inside the vehicle moves across the evaporator. As the process of heat loss from the air to the evaporator core surface is taking place, any moisture in the air condenses on the outside of the evaporator core and is drained off as water. This dehumidification of air adds to passenger comfort.

Refrigerant Lines There are three major refrigerant lines. Suction lines are located between the outlet side of the evaporator and the inlet side or suction side of the compressor. They carry the low-pressure, low-temperature vapor to the compressor. The discharge or high-pressure line connects the compressor to the condenser. The liquid lines connect the condenser to the receiver/dryer and the receiver/dryer to the inlet side of the expansion valve. Through these lines, the refrigerant travels in its path from a gas state (compressor outlet) to a liquid state (condenser outlet) and then to the inlet side of the expansion valve, where it vaporizes at the evaporator.

Drivetrain

The **drivetrain** is made up of all components that transfer power from the engine to the driving wheels of the vehicle. The exact components used in a vehicle's drivetrain depend on whether the vehicle is equipped with rear-wheel drive, front-wheel drive, or four-wheel drive.

Today, most cars and mini-vans are front-wheel drive (FWD). Some larger luxury and performance cars are rear-wheel drive (RWD). Most pickup trucks and large SUVs are also RWD vehicles. Power flow in a RWD vehicle passes through the **clutch** or **torque converter**, manual or automatic transmission, and the driveline (drive shaft assembly). Then it goes through the rear differential, the rear-driving axles, and onto the rear wheels.

Power flow through the drivetrain of FWD vehicles passes through the clutch or torque converter, manual or automatic transmission, then moves through a front differential, the driving axles, and onto the front wheels.

Four-wheel-drive (4WD) or all-wheel-drive (AWD) vehicles combine features of both rear- and front-wheel-drive systems so that power can be delivered to all wheels either on a permanent or on-demand basis. Typically if a truck, pickup or large SUV, has 4WD, the system is based on a RWD and a front drive axle is added. When a car has AWD or 4WD, the drivetrain is a modified FWD system. Modifications include a rear drive axle and an assembly that transfers some of the power to the rear axle.

Transmissions and Transaxles

A transmission is found in RWD vehicles. Transaxles are used in FWD vehicles. Both provide various drive gears that allow the vehicle to move forward and in reverse. The primary difference between a transmission and a transaxle is a transaxle unit also contains the final drive gears. The final drive gears for a RWD vehicle are contained in a separate axle housing. Transmissions and transaxles can either be manually shifted or shifted automatically.

Clutch

A clutch is used with manual transmissions/transaxles. It mechanically connects the engine's flywheel to the transmission/transaxle input shaft **(Figure 4–34)**. This is accomplished by a special friction disc that is splined to the input shaft of the transmission. When the clutch is engaged, the friction disc contacts the flywheel and transfers engine power to the input shaft.

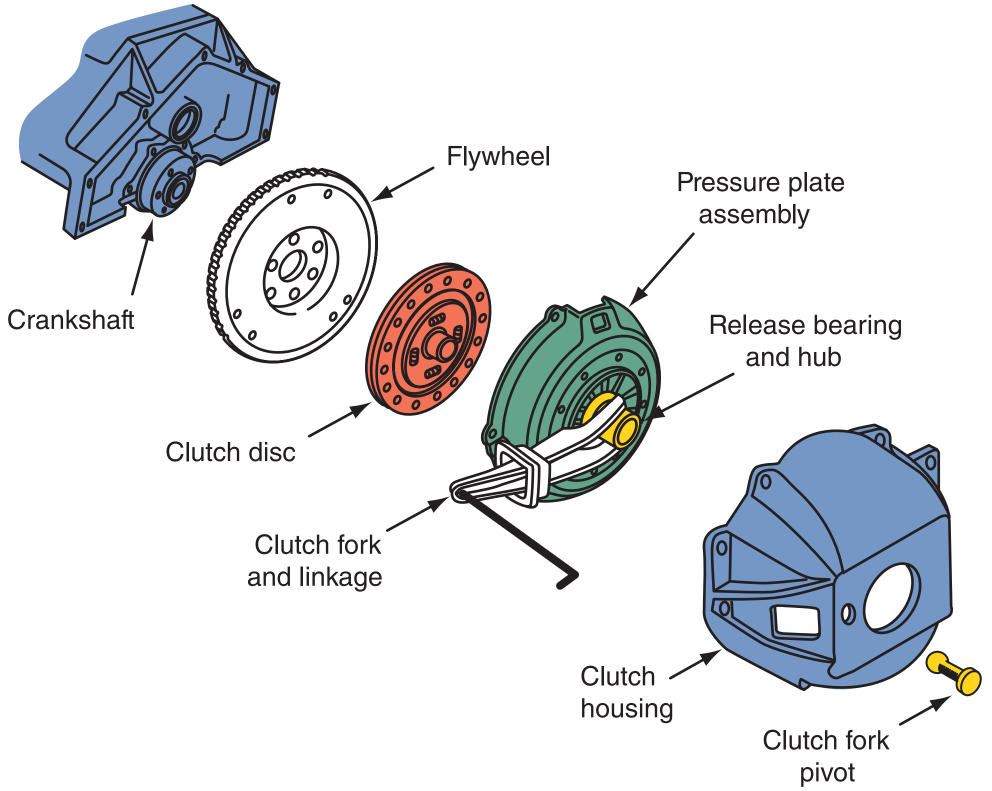


FIGURE 4-34 The major components of a clutch assembly for a manual transmission.

When stopping, starting, and shifting from one gear to the next, the clutch is disengaged by pushing down on the clutch pedal. This moves the clutch disc away from the flywheel, stopping power flow to the transmission. The driver can then shift gears without damaging the transmission or transaxle. Releasing the clutch pedal reengages the clutch and allows power to flow from the engine to the transmission.

Manual Transmission

A manual or standard transmission is one in which the driver manually selects the gear of choice. Proper gear selection allows for good driveability and requires some driver education.

Whenever two or three gears have their teeth meshed together, a gearset is formed. The movement of one gear in the set will cause the others to move. If any of the gears in the set are a different size than the others, the gears will move at different speeds. The size ratio of a gearset is called the **gear ratio** of that gearset.

A manual transmission houses a number of individual gearsets, which produce different gear ratios **(Figure 4–35)**. The driver selects the desired operating gear or gear ratio. A typical manual transmission has five or six forward gear ratios, neutral, and reverse.

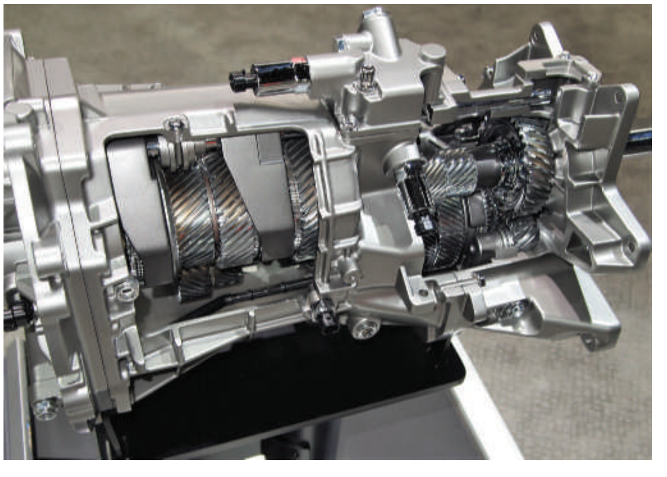


FIGURE 4-35 An inside view of a typical manual transmission.

Automatic Transmission

An automatic transmission does not need a clutch pedal and shifts through the forward gears without the control of the driver. Instead of a clutch, a torque converter is used to transfer power from the engine's flywheel to the transmission input shaft. The torque converter allows for transfer of power at all engine speeds **(Figure 4–36)**.

Shifting in an automatic transmission is controlled by a hydraulic and/or electronic control system. In a

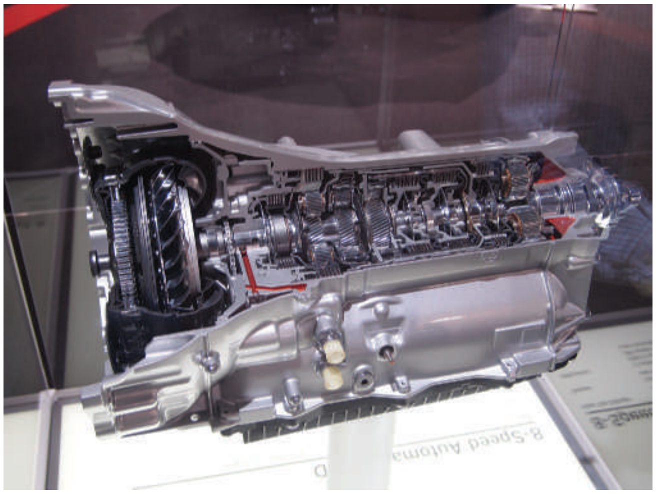


FIGURE 4–36 A cutaway of an eight-speed automatic transmission shown with the torque converter in the housing.

hydraulic system, an intricate network of valves and other components use hydraulic pressure to control the operation of planetary gearsets. These gearsets provide the four to ten forward speeds, neutral, park, and reverse gears. Newer electronic shifting systems use electric solenoids to control shifting mechanisms. Electronic shifting is precise and can be varied to suit certain operating conditions. All late model automatic transmission-equipped vehicles have electronic shifting.

Dual Clutch (Shaft) Transmissions

One of the latest trends to save fuel and reduce emissions is the use of dual clutch or shaft transmissions **(Figure 4–37)**. These transmissions are a combination of automatic and manual transmissions. Shifts can be made on demand or automatically.

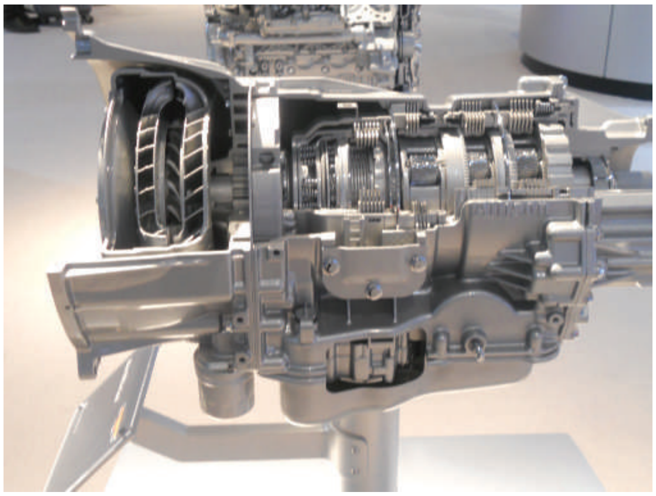


FIGURE 4–37 A cutaway of a dual clutch transmission.

Continuously Variable Transmissions (CVTs)

Continuously variable transmissions are a type of automatic transmission but instead of using sets of gears to change speeds, two variable diameter pulleys and a metal belt are used. By changing the diameter of the input and output pulleys, the CVT can keep the engine speed within its most efficient range of operation, improving fuel economy.

Driveline

Drivelines are used on RWD vehicles and 4WD vehicles. They connect the output shaft of the transmission to the final gears in the rear axle housing. They are also used to connect the output shaft to the front and rear drive axles on a 4WD vehicle.

A driveline consists of a hollow drive or propeller shaft that is connected to the transmission and drive axle by universal joints (U-joints). These U-joints allow the drive shaft to move with the movement of the rear suspension, preventing damage to the shaft.

Differential

On RWD vehicles, the drive shaft turns perpendicular to the forward motion of the vehicle. The differential gearing in the rear axle housing is designed to turn the direction of the power so that it can be used to drive the wheels of the vehicle. The power flows into the **differential**, where it changes direction, then flows to the rear axles and wheels **(Figure 4–38)**.

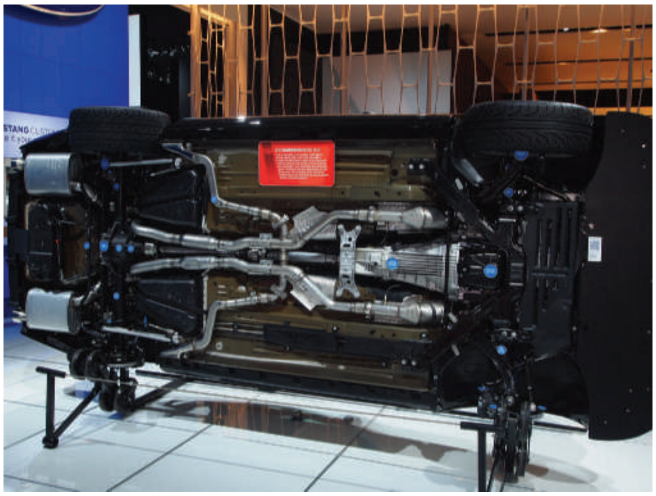


FIGURE 4–38 The driveline connects the output from the transmission to the differential unit and drive axles.

The gearing in the differential also multiplies the torque it receives from the drive shaft by providing a final gear reduction. Also, it divides the torque between the left and right driving axles and wheels so that a differential wheel speed is possible. This means one wheel can turn faster than the other when going around turns.

Driving Axles

Driving axles are solid steel shafts that transfer the torque from the differential to the driving wheels. A separate axle shaft is used for each driving wheel. In a RWD vehicle, the driving axles are enclosed in an axle housing that protects and supports these parts. Some rear drive axle units are mounted to an independent suspension and the drive axle assembly is similar to that of a FWD vehicle.

Each drive axle is connected to the side gears in the differential. The inner ends of the axles are splined to fit into the side gears. As the side gears are turned, the axles to which they are splined turn at the same speed.

The drive wheels are attached to the outer ends of the axles. The outer end of each axle has a flange mounted to it. A **flange** is a rim for attaching one part to another part. The flange, fitted with studs, at the end of an axle holds the wheel in place. **Studs** are threaded shafts, resembling bolts without heads. One end of the stud is screwed or pressed into the flange. The wheel fits over the studs, and a nut, called the lug nut, is tightened over the open end of the stud. This holds the wheel in place.

The differential carrier supports the inner end of each axle. A bearing inside the axle housing supports the outer end of the axle shaft. This bearing, called the axle bearing, allows the axle to rotate smoothly inside the axle housing.

Transaxle

A **transaxle** is used on FWD vehicles. It is made up of a transmission and differential housed in a single unit **(Figure 4–39)**. The gearsets in the transaxle provide the required gear ratios and direct the power flow into the differential. The differential gearing provides the final gear reduction and splits the power flow between the left and right drive axles.

The drive axles extend from the sides of the transaxle. The outer ends of the axles are fitted to the hubs of the drive wheels. **Constant velocity (CV) joints** mounted on each end of the drive axles allow for changes in length and angle without affecting the power flow to the wheels.

FIGURE 4–39 A cutaway of an automatic transaxle.

Four-Wheel-Drive System

4WD or AWD vehicles combine the features of RWD transmissions and FWD transaxles. Additional **transfer case** gearing splits the power flow between a differential driving the front wheels and a rear differential that drives the rear wheels. This transfer case can be a housing bolted directly to the transmission/transaxle, or it can be a separate housing mounted somewhere in the driveline. Most RWD-based 4WD vehicles have a drive shaft connecting the output of the transmission to the rear axle and another connecting the output of the transfer case to the front drive axle. Typically, AWD cars have a center differential, which splits the torque between the front and rear drive axles.

Running Gear

The **running gear** of a vehicle includes the wheels and tires and the suspension, steering, and brake systems.

Suspension System

The suspension system **(Figure 4–40)** is normally comprised of such components as the springs, shock absorbers, MacPherson struts, torsion bars, axles, and connecting linkages. These are designed to support the body and frame, the engine, and the drivelines. Without these systems, the comfort and ease of driving the vehicle would be reduced.

Springs or **torsion bars** are used to support the axles of the vehicle. The two types of springs commonly used are the coil spring and the leaf spring. Torsion bars are long spring steel rods. One end of

FIGURE 4-40 A strut assembly of a typical suspension system.

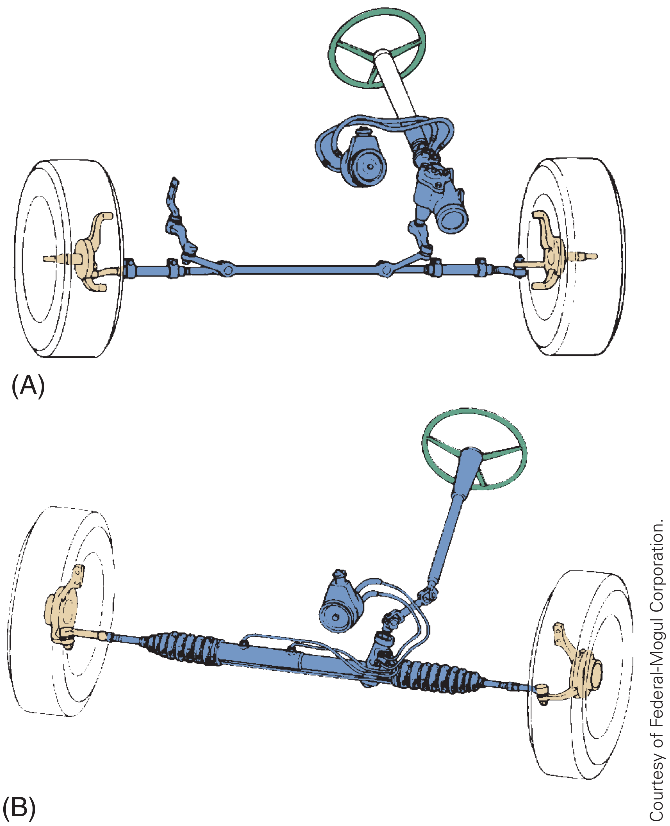


FIGURE 4-41 (A) A parallelogram-type steering system. (B) A rack and pinion steering system.

the rod is connected to the frame, whereas the other end is connected to the movable parts of the axles. As the axles move up and down, the rod twists and acts as a spring.

Shock absorbers dampen the upward and downward movement of the springs. This is necessary to limit the car's reaction to a bump in the road.

Steering System

The steering system allows the driver to control the direction of the vehicle. It includes the steering wheel, steering gear, steering shaft, and steering linkage.

Two basic types of steering systems are used today: the **rack-and-pinion** and **recirculating ball** systems **(Figure 4–41)**. The rack-and-pinion system is commonly used in passenger cars. The recirculating ball system is found only on larger heavy-duty pickup trucks and SUVs.

Steering gears provide a gear reduction to make changing the direction of the wheels easier. On most vehicles, the steering gear is also power assisted to ease the effort of turning the wheels. In a power-assisted system, a pump provides hydraulic fluid under pressure to the steering gear. Pressurized fluid is directed to one side or the other of the steering gear to make it easier to turn the wheels. Electric motors are often used in late-model vehicles to provide power-assisted steering.

Some vehicles are equipped with speed-sensitive power-steering systems. These change the amount of power assist according to vehicle speed. Power assist is the greatest when the vehicle is moving slowly and decreases as speed increases.

Brakes

Obviously, the brake system is used to slow down and stop a vehicle **(Figure 4–42)**. Brakes, located at each wheel, use friction to slow and stop a vehicle.

The brakes are activated when the driver presses down on the brake pedal. The brake pedal is connected to a plunger in a **master cylinder**, which is filled with hydraulic fluid. As pressure is put on the brake pedal, a force is applied to the hydraulic fluid

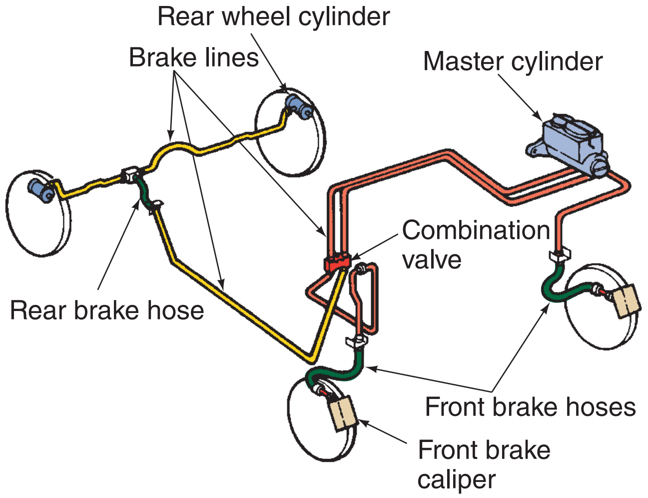


FIGURE 4–42 A typical hydraulic brake system with disc brakes at the front and rear wheels.

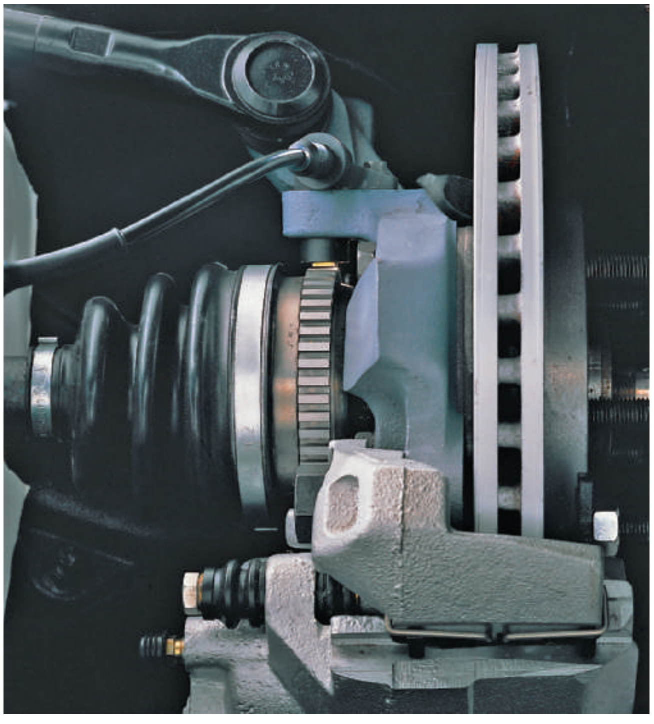
FIGURE 4–44 An alloy wheel with high-performance brakes and tires.

in the master cylinder. This force is increased by the master cylinder and transferred through brake hoses and lines to the four brake assemblies.

Two types of brakes are used—**disc brakes** and drum brakes. Many vehicles use a combination of the two types: disc brakes at the front wheels **(Figure 4–43)** and drum brakes at the rear wheels; others have disc brakes at all wheels.

Most vehicles have power-assisted brakes. Many vehicles use a vacuum **brake booster** to increase the pressure applied to the plunger in the master cylinder. Others use hydraulic pressure from the power-steering pump to increase the pressure on the brake fluid. Both of these systems lessen the amount of pressure that must be applied to the brake pedal and increase the responsiveness of the brake system.

All late-model vehicles have an **antilock brake system (ABS)**. The purpose of ABS is to prevent skidding during hard braking to give the driver control of the vehicle during hard stops.



Chrysler LLC.

FIGURE 4–43 A disc brake unit with a wheel-speed sensor for ABS.

Wheels and Tires

The only contact a vehicle has with the road is through its tires and wheels. Tires are filled with air and made of rubber and other materials to give them strength. Wheels are made of metal and are bolted to the axles or spindles **(Figure 4–44)**. Wheels hold the tires in place. Wheels and tires come in many different sizes. Their sizes must be matched to one another and to the vehicle.

Hybrid Vehicles

A **hybrid electric vehicle (HEV)** uses one or more electric motors and an engine to propel the vehicle **(Figure 4–45)**. Depending on the design of the system, the engine may move the vehicle by itself, assist the electric motor while it is moving the vehicle, or it may drive a generator to charge the vehicle's batteries. The electric motor may power the vehicle by itself or assist the engine while it is propelling the vehicle. Many hybrids rely exclusively on the electric motor(s) during slow speed operation, the engine at higher speeds,

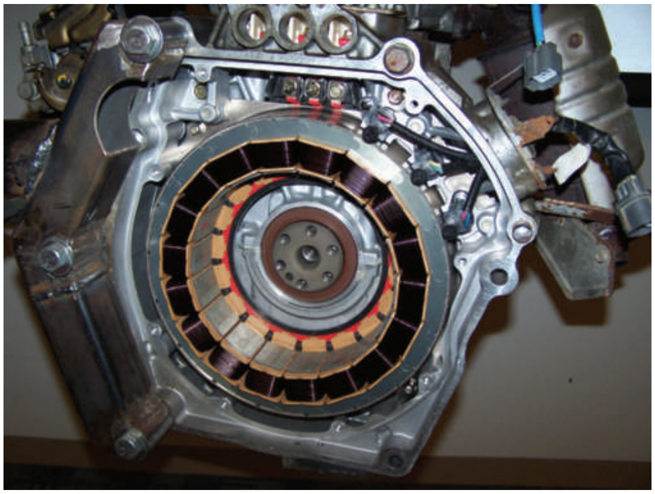


FIGURE 4-45 The electric motor in this hybrid arrangement fits between the engine and the transmission.

and both during some driving conditions. Complex electronic controls monitor the operation of the vehicle. Based on the operating conditions, electronics control the engine, electric motor, and generator.

A hybrid's electric motor is powered by high-voltage batteries, which are recharged by a generator driven by the engine and through regenerative braking. **Regenerative braking** is the process by which a vehicle's kinetic energy can be captured while it is decelerating and braking. The electric drive motors become generators driven by the vehicle's wheels. This generator takes the kinetic energy, or the energy of the moving vehicle, and changes it into energy that charges the batteries. The magnetic forces inside the generator cause the drive wheels to slow down. A conventional brake system brings the vehicle to a safe stop.

The engines used in hybrids are specially designed for the vehicle and electric assist. They operate more efficiently, resulting in very good fuel economy and very low tailpipe emissions. HEVs can provide the same performance, if not better, as a comparable vehicle equipped with a larger engine.

There are primarily two types of hybrids: the parallel and the series designs. A parallel HEV uses either the electric motor or the gas engine to propel the vehicle, or both. The engine in a true series HEV is used only to drive the generator that keeps the batteries charged. The vehicle is powered only by the electric motor(s). Most current HEVs are considered as having a series/parallel configuration because they have the features of both designs.

Recently some true series hybrids have been released. These are commonly called range extending hybrids because they are capable of driving farther before recharging the batteries than a pure electric vehicle.

Although most current hybrids are focused on fuel economy, the same ideas can be used to create high-performance vehicles. Hybrid technology is also influencing off-the-road performance. By using individual motors at the front and rear drive axles, additional power can be applied to certain drive wheels when needed.

Electric Vehicles Because of the current fuel economy and emission regulations set by the government, auto manufacturers are introducing a variety of battery-operated electric vehicles. In the first half of 2017, about 48,000 electric vehicles were sold in the United States. Sales are expected to increase as more models of electric vehicles become available.

Alternative Fuels

There are several ways to reduce fuel consumption, other than using electric drive. Much research has and is being conducted on the use of alternative fuels in internal combustion engines. By using alternative fuels, we not only reduce our reliance on oil but we reduce emissions and the effects an automobile's exhaust has on global warming. Common alternative fuels are:

- Propane, also referred to as liquefied petroleum gas (LPG)
- Methyl alcohol, normally called Methanol
- Ethyl alcohol, also referred to as Ethanol
- Compressed natural gas (CNG)

KEY TERMS

Antilock brake system (ABS)
Brake booster
Carbon monoxide (CO)
Clutch
Combustion
Combustion chamber
Compressor
Condenser
Connecting rod
Constant velocity (CV) joint
Corporate Average Fuel Economy (CAFE)
Crankshaft
Crankshaft position sensor
Cylinder block

Cylinder head
Differential
Disc brakes
Distributor
Drivetrain
Engine block
Evaporator
Exhaust gas recirculation (EGR)
Exhaust manifold
Flange
Gear ratio
Hybrid electric vehicle (HEV)
Hydrocarbons (HC)
Hydroforming
Ignition coil
Manifold
Master cylinder
Orifice tube
Oxides of nitrogen (NO_x)
Piston
Port
Positive crankcase ventilation (PCV)
Pressure cap
Rack and pinion
Radiator
Receiver/dryer
Recirculating ball
Refrigerant
Regenerative braking
Running gear
Shock absorber
Solenoid
Spark plug
Spring
Steering gear
Stud
Thermostat
Thermostatic expansion valve (TEV or TXV)
Torque converter
Torsion bar
Transaxle
Transfer case
Unibody
Valve train
Water jacket
Water pump

SUMMARY

- Dramatic changes to the automobile have occurred over the last 40 years, including the addition of emission control systems, more fuel-efficient and cleaner-burning engines, and lighter body weight.
- In addition to being lighter than body-over-frame vehicles, unibodies offer better occupant protection by distributing impact forces throughout the vehicle.
- Today's computerized engine control systems regulate such things as air and fuel delivery, ignition timing, and emissions. The result is an increase in overall efficiency.
- All automotive engines are classified as internal combustion, because the burning of the fuel and air occurs inside the engine. Diesel engines share the same major parts as gasoline engines, but they do not use a spark to ignite the air-fuel mixture.
- The cooling system maintains proper engine temperatures.
- The lubrication system distributes motor oil throughout the engine. This system also has an oil filter to remove dirt and other foreign matter from the oil.
- The fuel system is responsible not only for fuel storage and delivery, but also for atomizing and mixing it with the air in the correct proportion.
- The exhaust system has three primary purposes: to channel toxic exhaust away from the passenger compartment, to quiet the exhaust pulses, and to burn the emissions in the exhaust.
- The electrical system of an automobile includes the ignition, starting, charging, and lighting systems. Electronic engine controls regulate these systems very accurately through the use of computers.
- Modern automatic transmissions use a computer to match the demand for acceleration with engine speed, wheel speed, and load conditions. It then chooses the proper gear ratio and, if necessary, initiates a gear change.
- The running gear is critical to controlling the vehicle. It consists of the suspension system, braking system, steering system, and wheels and tires.
- Hybrid electric vehicles have an internal combustion engine and an electrical motor that are used to propel the vehicle together or separately.

REVIEW QUESTIONS

Short Answer

1. Under the CAFE standards, for what are vehicles tested?
2. Explain the four strokes of the internal combustion engine.
3. In addition to the battery, what does the charging system include?
4. What is meant by the term *regenerative braking*?

Multiple Choice

1. Which of the following is *not* a common emission control system?
   a. EGR
   b. PCV
   c. EVAP
   d. Air injection
2. Automatic transmissions use a ___ instead of a clutch to transfer power from the flywheel to the transmission's input shaft.
   a. differential
   b. U-joint
   c. torque converter
   d. constant velocity joint
3. Which of the following is *not* one of the strokes of a four-cycle engine?
   a. Compression
   b. Exhaust
   c. Intake
   d. Ignition
4. Technician A says that the PCV system is designed to limit CO emissions. Technician B says that catalytic converters reduce HC emissions at the tailpipe. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Which is not a common automotive fuel?
   a. Gasoline
   b. Diesel
   c. Hydrogen
   d. Ethanol
6. What does the valve train do?
   a. It delivers fuel to a device that controls the amount of fuel going to the engine.
   b. It houses the major parts of the engine.
   c. It converts reciprocating motion to rotary motion.
   d. It opens and closes the intake and exhaust ports of each cylinder.
7. Technician A says that liquid cooling an engine helps to maintain a consistent operating temperature. Technician B says that oil is circulated through the cooling system to remove heat from the engine's parts. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. An engine will not start and no spark is found at the spark plugs when the engine is turned over by the starter. Technician A says that the problem is probably the battery. Technician B says that the ignition system is most likely at fault. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. Which emission control system introduces exhaust gases into the intake air to reduce the formation of NO_x in the combustion chamber?
   a. EVAP
   b. EGR
   c. Air injection
   d. PCV
10. Technician A says that many vehicles use an AC generator as the charging unit. Technician B says that all vehicles use an alternator as the charging unit. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
11. Technician A says that a transaxle delivers torque to the front and the rear drive axles. Technician B says that a transaxle is most commonly found in 4WD pickups and SUVs. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
12. Which of the following is *not* part of the running gear?
    a. Differential
    b. Steering
    c. Suspension
    d. Brakes

13. Which of the following statements about unibody construction is *not* true?
    a. A unibody is a stressed hull structure in which each of the body parts supplies structural support and strength to the entire vehicle.
    b. Unibody vehicles tend to be tightly constructed because the major parts are all welded together.
    c. All unibodies are constructed from steel.
    d. Most front-wheel-drive unibody vehicles have a cradle or partial frame.
14. Which type of transmission uses pulleys to change engine speed?
    a. Dual-clutch
    b. Manual
    c. Continuously variable
    d. Automatic
15. Which of the following components are used to dampen the upward and downward movement of a vehicle's springs?
    a. Torsion bars
    b. Shock absorbers
    c. Constant velocity joints
    d. Connecting linkages
16. What two major engine components work together to change the reciprocating motion of the pistons into a rotary motion?
    a. Crankshaft and connecting rod
    b. Camshaft and crankshaft
    c. Camshaft and connecting rod
    d. Crankshaft and valve train
17. Technician A says that an air-conditioning system removes heat from inside the engine. Technician B says that the heating system removes heat from the inside of the vehicle. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
18. The boiling point of the coolant in an engine's cooling system is raised by the ___.
    a. thermostat
    b. pressure cap
    c. radiator
    d. water pump
19. While discussing the operation of air-conditioning systems: Technician A says that in order for the refrigerant to release heat, it must be at a low temperature and pressure. Technician B says that in order for the refrigerant to absorb heat, it must be at a high temperature and pressure. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
20. While discussing HEVs: Technician A says that in a series hybrid, the engine is only used to power a generator to recharge the batteries. Technician B says that in a parallel hybrid, the engine and/or the battery can supply the power to move the vehicle. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
21. Which of the following is *not* accomplished by the fuel and air system of a gasoline engine?
    a. Stores the fuel for later use
    b. Collects and cleans the outside air
    c. Delivers fuel to a device that will control the amount of fuel going to the engine
    d. Keeps the fuel and air ratio constant regardless of the conditions under which the engine is operating

HAND TOOLS AND SHOP EQUIPMENT

CHAPTER 5

OBJECTIVES

- List the basic units of measure and apply them to the two measuring systems.
- Describe the different types of fasteners used in the automotive industry.
- List the various mechanical measuring tools used in the automotive shop.
- Describe the proper procedure for measuring with a micrometer.
- List some of the common hand tools used in auto repair.
- List the common types of shop equipment and state their purpose.
- Describe the use of common pneumatic, electrical, and hydraulic power tools.
- Describe the different sources for service information that are available to technicians.

Repairing the modern automobile requires the use of various tools. Many of these tools are common hand and power tools used every day by a technician. Other tools are very specialized and are only for specific repairs on specific systems and/or vehicles. This chapter presents some of the more commonly used hand and power tools with which every technician must be familiar. Because units of measurement play such an important part in tool selection and in diagnosing automotive problems, this chapter begins with a presentation of measuring systems. Prior to the discussion on tools, there is a discussion on another topic that relates very much to tools: measuring systems and fasteners.

Measuring Systems

Two systems of weights and measures exist side-by-side in the United States—the Imperial or U.S. customary (US) system and the international or metric system.

The basic unit of linear measurement in the US system is the inch. The basic unit of linear measurement in the metric system is the meter. The meter is easily broken down into smaller units, such as the centimeter ($^{1}/_{100}$ meter) and millimeter ($^{1}/_{1,000}$ meter).

All units of measurement in the metric system are related to each other by a factor of 10. Every metric unit can be multiplied or divided by the factor of 10 to get larger units (multiples) or smaller units (submultiples).

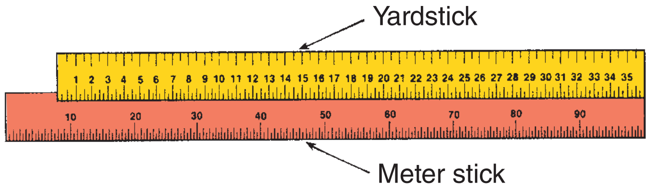


FIGURE 5–1 A meter stick has 1,000 increments known as millimeters and is slightly longer than a yardstick.

This makes the metric system much easier to use, with less chance of math errors than when using the US system **(Figure 5–1).**

The United States passed the Metric Conversion Act in 1975 in an attempt to get American industry and the general public to use the metric system, as the rest of the world does. While the general public has been slow to drop the customary measuring system of inches, gallons, and pounds, many industries, led by the automotive industry, have now adopted the metric system for the most part.

Nearly all vehicles are now built to metric standards. Technicians must be able to measure and work with both systems. The following are some common equivalents in the two systems:

Linear Measurements

1 meter (m) = 1000 mm = 39.37 inches (in.)

1 centimeter (cm) = 10 mm = 0.3937 inch

1 millimeter (mm) = 0.03937 inch

1 inch = 2.54 centimeters

1 inch = 25.4 millimeters

1 mile = 1.6093 kilometers

Linear Comparisons

1 meter is slightly longer than a yard.

1 cm is about the diameter of a thick pencil or pen.

1 mm is about the thickness of a dime. A penny is just over 19 mm in diameter, making it useful for comparing nut and bolt head sizes.

A standard USB Type A connector is about 12 mm wide.

Square Measurements

1 square inch = 6.452 square centimeters

1 square centimeter = 0.155 square inch

Volume Measurements

1 cubic inch = 16.387 cubic centimeters

1,000 cubic centimeters = 1 liter (L)

1 liter (L) = 61.02 cubic inches

1 gallon = 3.7854 liters

Weight Measurements

1 ounce = 28.3495 grams

1 pound = 453.59 grams

1,000 grams = 1 kilogram

1 kilogram = 2.2046 pounds

Temperature Measurements

1 °Fahrenheit (°F) = $\frac{9}{5}$ °C + 32°

1 °Celsius (°C) = $\frac{5}{9}$ (°F − 32°)

Pressure Measurements

1 pound per square inch (psi) = 0.07031 kilogram (kg) per square centimeter

1 kilogram per square centimeter = 14.22334 pounds per square inch

1 bar = 14.504 pounds per square inch

1 pound per square inch = 0.06895 bar

1 atmosphere = 14.7 pounds per square inch

Torque Measurements

10 foot-pounds (ft.-lb) = 13.558 Newton-meters (N-m)

1 N-m = 0.7375 ft.-lb

1 ft.-lb = 0.138 m kg

1 cm kg = 7.233 ft.-lb

10 cm kg = 0.98 N-m

Fasteners

Fasteners are used to secure or hold different parts together or to mount a component. Many types and sizes of fasteners are used. Each fastener is designed for a specific purpose and condition. The most commonly used is the threaded fastener. Threaded fasteners include bolts, nuts, screws, and similar items that allow for easy removal and installation of parts **(Figure 5–2)**.

The threads can be cut or rolled into the fastener. Rolled threads are 30 percent stronger than cut threads. They also offer better fatigue resistance because there are no sharp notches to create stress points. There are four classifications for the threads of US fasteners: Unified National Coarse (UNC), Unified National Fine (UNF), Unified National Extrafine (UNEF), and Unified National Pipe Thread (UNPT or NPT). Metric fasteners are also available in fine and coarse threads.

NPT is the standard thread design for joining pipes and fittings. There are two basic designs: tapered and straight cut threads. Straight cut pipe thread is used to join pipes but it does not provide a good seal at the joining point. Tapered pipe threads

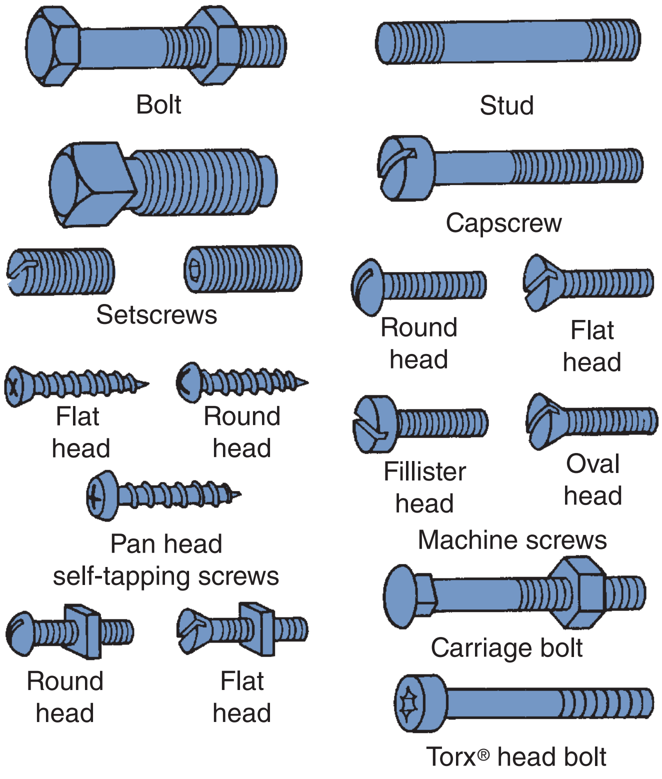


FIGURE 5–2 Common automotive threaded fasteners.

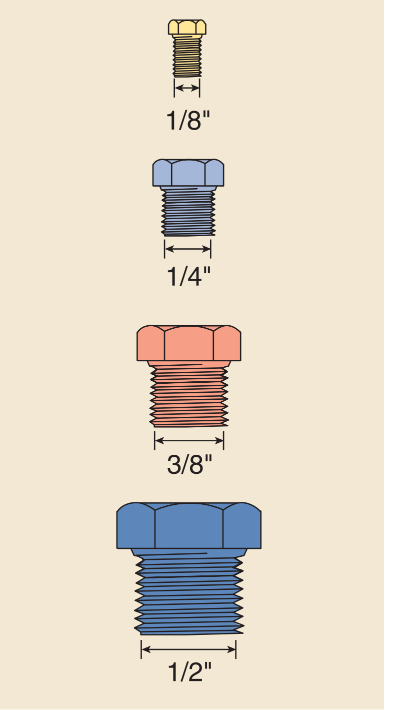


FIGURE 5–3 Various sizes of pipe fittings used with lines and hoses.

provide a good seal because the internal and external threads compress against each other as the joint is tightened. Most often a sealant is used on pipe threads to provide a better seal. Pipe threads are commonly used at the ends of hoses and lines that carry a liquid or gas **(Figure 5–3)**.

Coarse (UNC) threads are used for general-purpose work, especially where rapid assembly and disassembly are required. Fine threads (UNF) are used where greater holding force is necessary. They are also used where greater vibration resistance is desired.

Bolts

Bolts have a head on one end and threads on the other. They are identified by their head size, shank (shoulder) diameter, thread pitch, length **(Figure 5–4)**, and grade. The threads of a bolt travel from below the shank to the end of the bolt.

The **bolt head** is used to loosen and tighten the bolt; a socket or wrench fits over the head and is used to screw the bolt in or out. The size of the bolt head varies with the bolt's diameter and is available in US and metric wrench sizes. Many confuse the size of the head with the size of the bolt. The size of a bolt is the diameter of its shank. **Table 5–1** lists the most common bolt head sizes.

Bolt diameter is the measurement across the diameter of the threaded area or **bolt shank**. The

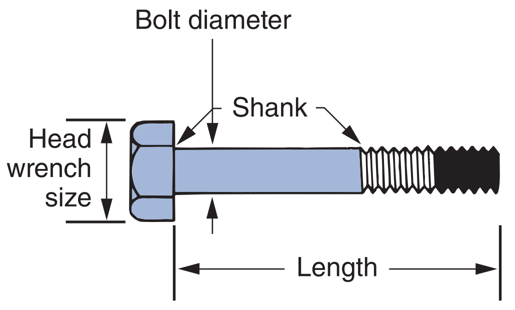


FIGURE 5–4 Basic terminology for bolt identification.

length of a bolt is measured from the bottom surface of the head to the end of the threads.

The **thread pitch** of a bolt in the US system is the number of threads that are in 1 inch of the threaded length and is expressed in number of threads per inch. A UNF bolt with a 3/8-inch diameter is marked as a 3/8 $\times$ 24 bolt. It has 24 threads per inch. Likewise a 3/8-inch UNC bolt with 16 threads per inch is called a 3/8 $\times$ 16 bolt.

The distance, in millimeters, between two adjacent threads determines the thread pitch in the metric system. This distance will vary between 1.0 and 2.0 and depends on the diameter of the bolt. The lower the number, the closer the threads are placed and the finer the threads are.

The bolt's tensile strength, or grade, is the amount of stress or stretch it is able to withstand before it breaks. The material that the bolt is made of and the

TABLE 5-1 STANDARD BOLT HEAD SIZES

Common English (U.S. Customary) Head Sizes	Common Metric Head Sizes
Wrench Size (inches)	Wrench Size (millimeters) (rough equivalency)
5/16	8
3/8	10
7/16	12
1/2	13
9/16	14
5/8	16
11/16	17
3/4	19
13/16	21
7/8	22
15/16	24
1	26
1 1/16	27
1 1/8	30
1 1/4	32
1 5/16	34
1 3/8	35

diameter of the bolt determine its grade. In the US system, the tensile strength of a bolt is identified by the number of radial lines (**grade marks**) on the bolt's head. More lines mean higher tensile strength

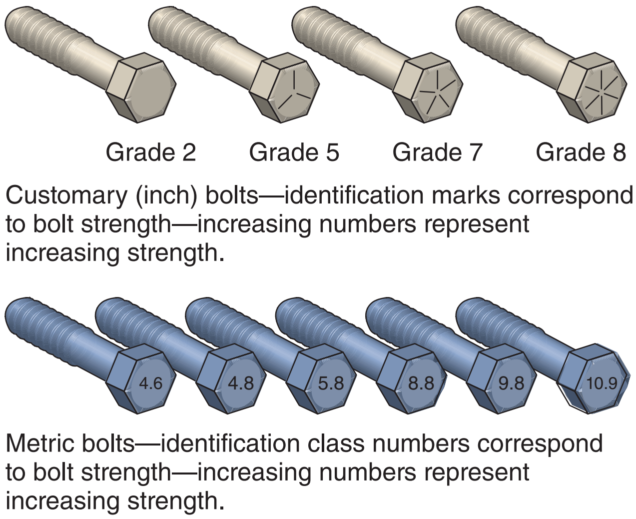


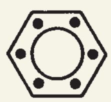
FIGURE 5-5 Bolt grade markings.

(Figure 5–5). Count the number of lines and add 2 to determine the grade of a bolt.

On metric bolts, a property class number on the bolt head identifies its grade. The property class is expressed with two numbers. The first represents the tensile strength of the bolt. The higher the number, the greater the tensile strength. The second is a percentage rating of the bolt's yield strength. This denotes how much stress the bolt can take before it is not able to return to its original shape. For example, a 10.9 bolt has a tensile strength of 1,000 MPa (145,000 psi) and a yield strength of 900 MPa (90 percent of 1,000). A 10.9 metric bolt is similar in strength to a grade 8 bolt.

Nuts are graded to match their respective bolts **(Table 5–2)**; a grade 8 nut must be used with a grade

TABLE 5-2 STANDARD NUT STRENGTH MARKINGS

Inch System		Metric System	
Grade	Identification	Class	Identification
Hex Nut Grade 5	 3 Dots	Hex Nut Property Class 9	 Arabic 9
Hex Nut Grade 8	 6 Dots	Hex Nut Property Class 10	 Arabic 10
Increasing dots represent increasing strength.		Can also have blue finish or paint dab on hex flat. Increasing numbers represent increasing strength.	

SHOP TALK

Bolt heads can pop off because of fillet damage. The **fillet** is the slightly curved area where the shank flows into the bolt head **(Figure 5–6)**. Scratches in this area introduce stress to the bolt head, causing failure. Replace all bolts that are damaged.

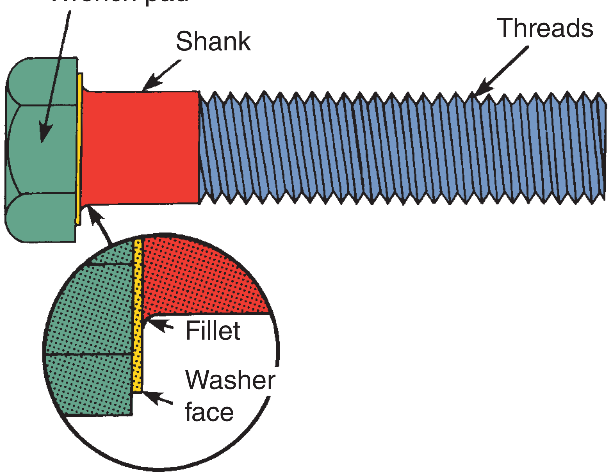


FIGURE 5–6 Bolt fillet detail.

8 bolt. If a grade 5 nut is used, a grade 5 connection would result.

Tightening Bolts Any fastener is near worthless if it is not as tight as it should be. When a bolt is properly tightened, it will be "spring loaded" against the part it is holding. This spring effect is caused by the stretch of the bolt. Normally a properly tightened bolt is stretched to 70 percent of its elastic limit. The elastic limit of a bolt is that point of stretch from which the bolt will not return to its original shape when it is loosened. Not only will an overtightened or stretched bolt not have sufficient clamping force, it also will have distorted threads. The stretched threads will make it more difficult to screw and unscrew the bolt or a nut on the bolt **(Figure 5–7)**.

Fatigue breaks are the most common causes of bolt failure. A bolt becomes fatigued when it is able to move in its bore due to being undertightened.

Washers

Many different types of washers are used with fasteners. Flat washers are used to spread the load of tightening a nut or bolt. This stops the bolt head or nut from digging into the surface as it is tightened. Always place flat washers with their rounded, punched side against the bolt head. Soft flat washers, called compression washers, are also used to spread the load of tightening and help seal one component to another. Copper washers are often used with oil pan bolts to help seal the pan to the engine block. Grade 8 and other critical applications require the use of fully hardened flat washers. These will not dish out when tightened like soft washers do.

Lock washers are used to lock the head of a bolt or nut to the workpiece to keep them from coming loose and to prevent damage to softer metal parts.

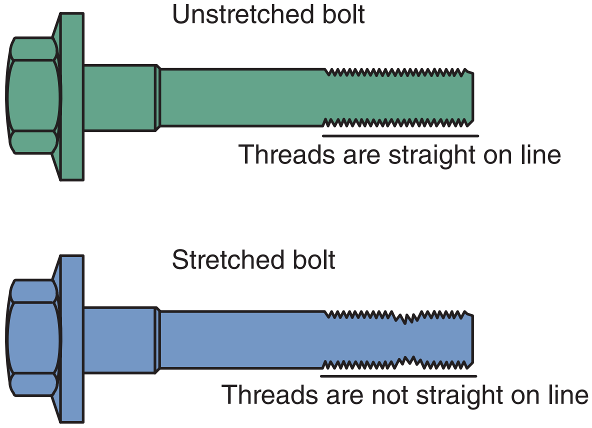


FIGURE 5–7 A comparison of a stretched and an unstretched bolt.

Other Common Fasteners

The use of other fastener designs depends on the purpose of the fastener. Some of the more commonly used fasteners are described here.

Nuts Nuts are used with other threaded fasteners. Many different designs of nuts are found on today's cars **(Figure 5–8)**. The most common one is the hex nut, which is used with studs and bolts and tightened with a wrench.

Locknuts are often used in places where vibration may tend to loosen a nut. Locking nuts are standard nuts with nylon inserted into a section of the threads. The nylon cushions the vibrations.

Studs Studs are rods with threads on both ends. Most often, the threads on one end are coarse while the threads on the other end are fine. One end of the stud is screwed into a threaded bore. A bore in the part that will be mounted by the stud is fit over the stud and held in place with a nut that is screwed

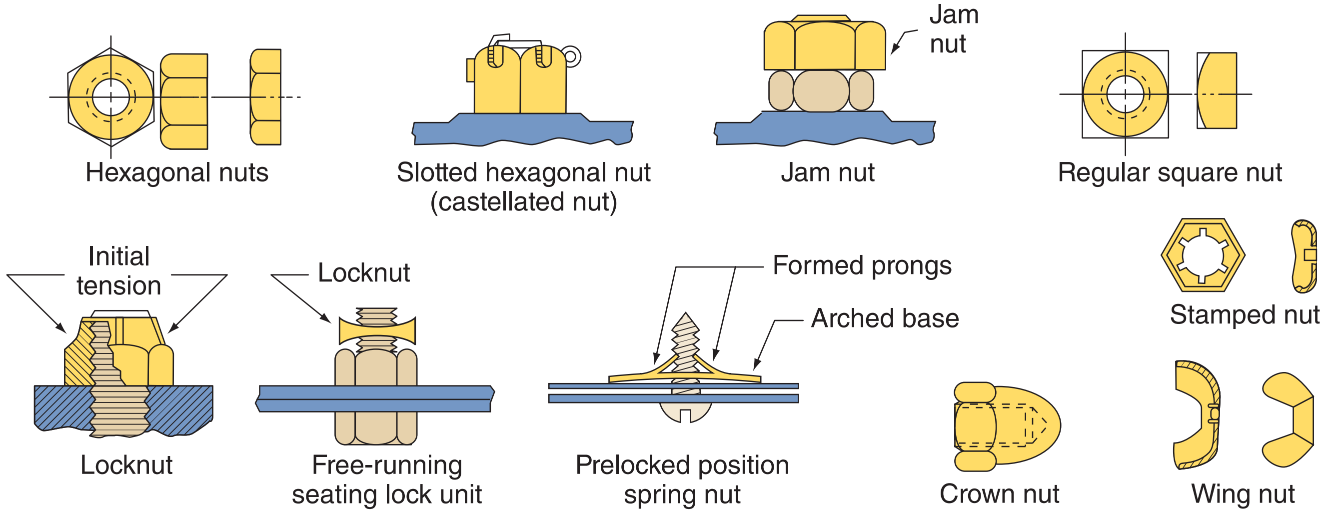


FIGURE 5–8 Many different types of nuts are used on automobiles. Each type has a specific purpose.

onto the stud. Studs are used when the clamping pressures of a fine thread are needed and a bolt will not work. If the stud is being screwed into soft (such as aluminum) or granular (such as cast iron) material, that end of the stud will have coarse threads. The opposite end will have fine threads. As a result, a coarse thread is used to hold the stud in a component and a fine-threaded nut is used to clamp the other part to it. This provides for the clamping force of fine threads and the holding power of coarse threads.

Cap Screws Cap screws are similar to bolts, but they do not have a shoulder. The threads travel from the head to the end of the screw. Never use a cap screw in place of a bolt.

Setscrews Setscrews are used to prevent rotary motion between two parts, such as a pulley and shaft. Setscrews have a square head and are moved with a wrench, or they are headless and require an Allen wrench or screwdriver to move them.

Machine Screws The length of machine screws is entirely threaded. These screws have a head on one end and a flat bottom on the other. Machine screws are used to mount one component to another that has a threaded bore. They are also used with a nut to hold parts together. Machine screws can have a round, flat, Torx, oval, or fillister head.

Self-Tapping Screws Self-tapping screws are used to fasten sheet metal parts or to join together light metal with wood or plastic parts. These screws form their own threads in the material into which they are screwed.

Thread Lubricants and Sealants

It is often recommended that the threads of a bolt or stud be coated with a sealant or lubricant. The most commonly used lubricant is antiseize compound. Antiseize compound is used where a bolt might become difficult to remove after a period of time—for example, in an aluminum engine block. The amount of torque required to properly tighten a bolt treated with antiseize compound should be reduced. Thread lubricants may also cause hydrostatic lock; oil can be trapped in a blind hole. When the bolt contacts the oil, it cannot compress it; therefore, the bolt cannot be properly tightened or fully seated.

Thread sealants are used on bolts that are tightened into an oil cavity or coolant passage. The sealant prevents the liquid from seeping past the threads. Teflon tape is often used as a sealant. Another commonly used thread chemical, called threadlocker **(Figure 5–9)**, prevents a bolt from working loose as the engine or another part vibrates.

Thread Pitch Gauge

The use of a thread pitch gauge provides a quick and accurate way to check the thread pitch of a fastener. The leaves of the tool are marked with the various pitches. To check the pitch of threads, simply match the teeth of the gauge with the threads of the fastener. Then read the pitch from the leaf. Thread pitch gauges are available for the various threads used by the automotive industry.

Courtesy of Permatex, Inc.

FIGURE 5–9 A container of threadlocker.

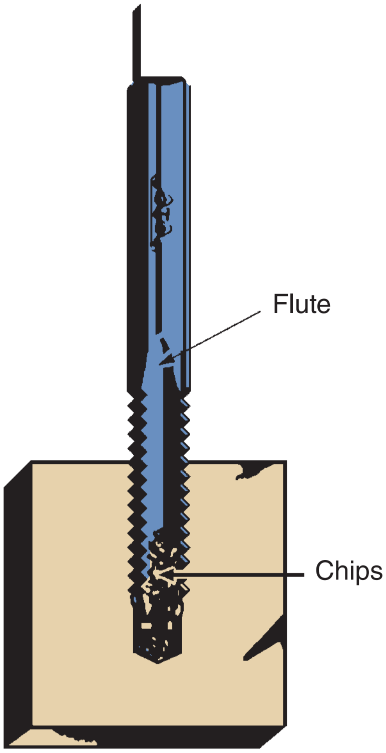


FIGURE 5–10 Metal chips are gathered into the flutes of a tap.

FIGURE 5–11 A tap and die set.

Taps and Dies

The hand **tap** is a small tool used for hand cutting internal threads. An internal thread is cut on the inside of a part, such as a thread on the inside of a nut. Taps are also available that only clean and restore threads that were previously cut. Taps are selected by size and thread pitch. Photo Sequence 1 goes through the correct procedure for repairing damaged threads with a tap.

When tapping a bore, rotate the tap in a clockwise direction. Then, turn the tap counterclockwise about a quarter turn to break off any metal chips that may have accumulated in the threads. These small metal pieces can damage the threads as you continue to tap. These metal chips are gathered in the tap's flutes, which are recessed areas between the cutting teeth of the tap **(Figure 5–10)**. After backing off the tap, continue rotating the tap clockwise. Remember to back off the tap periodically and make sure all of the existing threads in the bore have been recut by the tap.

Hand-threading **dies (Figure 5–11)** are the opposite of taps because they cut external (outside) threads on bolts, rods, and pipes rather than internal threads. Dies are made in various sizes and shapes, depending on the particular work for which they are

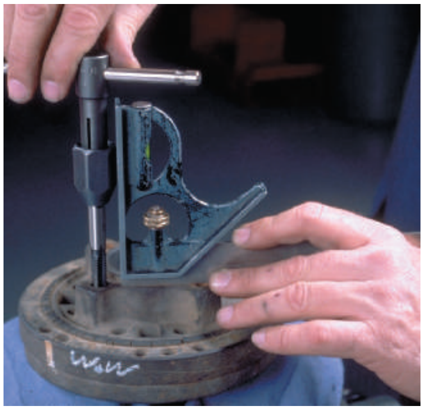
PHOTO SEQUENCE 1

Repairing Damaged Threads with a Tap

P1-1 Using a thread pitch gauge, determine the thread size of the fastener that should fit into the damaged internal threads.

P1-2 Select the correct size and type of tap for the threads and bore to be repaired.

P1-3 Install the tap into a tap wrench.



P1-4 Start the tap squarely in the threaded hole using a machinist square as a guide.

P1-5 Rotate the tap clockwise into the bore until the tap has run through the entire length of the threads. While doing this, periodically turn the tap backward to clean the threads. This prevents breaking the tap.

P1-6 Drive the tap back out of the hole by turning it counterclockwise.

P1-7 Clean the metal chips left by the tap out of the hole.

P1-8 Inspect the threads left by the tap to be sure they are acceptable.

P1-9 Test the threads by threading the correct fastener into the threaded hole.

intended. Dies may be solid (fixed size), split on one side to permit adjustment, or have two halves held together in a collet that provides for individual adjustments. Dies fit into holders called die stocks.

Threaded Inserts

When the threads in a bore are excessively damaged, it is better to replace them than try to tap them. A thread insert can be used to restore the original threads. Inserts require drilling the bore to a larger diameter and tapping that bore to allow the insert to be screwed into it. The inner threaded diameter of the insert will provide fresh threads for the bolt **(Figure 5–12)**.

Spark Plug Thread Repair Sometimes when spark plugs are removed from a cylinder head, the threads have traces of metal on them. This happens more often with aluminum heads. When this occurs, the spark plug bore must be corrected by installing thread inserts.

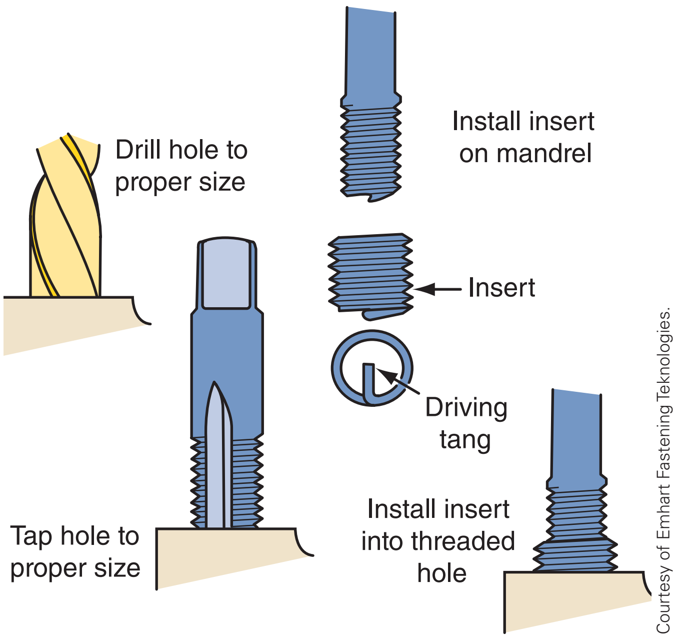


FIGURE 5–12 Using a threaded insert (helicoil®) to repair damaged threads.

SHOP TALK

Never change spark plugs when the cylinder head is hot. The bores for the plugs can take on an oval shape as the cylinder head cools without spark plugs in the bores.

When installing spark plugs, if the plugs cannot be installed easily by hand, the threads in the cylinder head may need to be cleaned with a thread-chasing tap. There are special taps for spark plug bores, simply called spark plug thread taps. Be especially careful not to cross-thread the plugs when working with aluminum heads. Always tighten the plugs with a torque wrench and the correct spark plug socket, following the vehicle manufacturer's specifications. Also, when changing spark plugs in aluminum heads, the temperature of the heads should be ambient temperature before attempting to remove the plugs.

Measuring Tools

Some service work, such as engine repair, requires very exact measurements, often in ten-thousandths (0.0001) of an inch or thousandths (0.001) of a millimeter. Accurate measurements with this kind of precision can only be made by using precise measuring devices.

Measuring tools are precise and delicate instruments. In fact, the more precise they are, the more delicate they are. They should be handled with great care. Never pry, strike, drop, or force these instruments.

Precision measuring instruments, especially micrometers, are extremely sensitive to rough handling. Clean them before and after every use. All measuring should be performed on parts that are at room temperature to eliminate the chance of measuring

SHOP TALK

Check measuring instruments regularly against known good equipment to ensure that they are operating properly and are capable of accurate measurement. Always refer to the appropriate material for the correct specifications before performing any service or diagnostic procedures. The close tolerances required for the proper operation of some automotive parts make using the correct specifications and taking accurate measurements very important. Even the slightest error in measurement can be critical to the durability and operation of an engine and other systems.

something that has contracted because it was cold or has expanded because it was hot.

Machinist's Rule

The machinist's rule looks very much like an ordinary ruler. Each edge of this basic measuring tool is divided into increments based on a different scale. A typical machinist's rule based on the US system of measurement may have scales based on 1/8-, 1/16-, 1/32-, and 1/64-inch intervals **(Figure 5–13)**. Of course, metric machinist rules are also available. Metric rules are usually divided into 0.5 mm and 1 mm increments.

Some machinist's rules may be based on decimal intervals. These are typically divided into 1/10-, 1/50-, and 1/100-inch increments. Decimal machinist's rules are very helpful when measuring dimensions specified in decimals; they make such measurements much easier.

Vernier Caliper

A vernier caliper is a measuring tool that can make inside, outside, or depth measurements. It is marked in both US and metric divisions called a vernier scale. A vernier scale consists of a stationary scale and a movable scale, in this case the vernier bar to the vernier plate. The length is read from the vernier scale.

A vernier caliper has a movable scale that is parallel to a fixed scale **(Figure 5–14)**. The main scale of the caliper is divided into inches; most measure up to 6 inches. Each inch is divided into 10 parts, each equal to 0.100 inch. The area between the 0.100 marks is divided into four. Each of these divisions is equal to 0.025 inch **(Figure 5–15)**.

The vernier scale has 25 divisions, each one representing 0.001 inch. Measurement readings are taken by combining the main and vernier scales. At all times, only one division line on the main scale will line up with a line on the vernier scale **(Figure 5–16)**. This is the basis for accurate measurements.

To read the caliper, locate the line on the main scale that lines up with the zero (0) on the vernier scale. If the zero lined up with the 1 on the main scale, the reading would be 0.100 inch. If the zero on the vernier scale does not line up exactly with a line on the main scale, then look for a line on the vernier scale that does line up with a line on the main scale.

Dial Caliper

The **dial caliper (Figure 5–17)** is an easier-to-use version of the vernier caliper. US calipers commonly measure dimensions from 0 to 6 inches. Metric dial calipers typically measure from 0 to 150 mm in

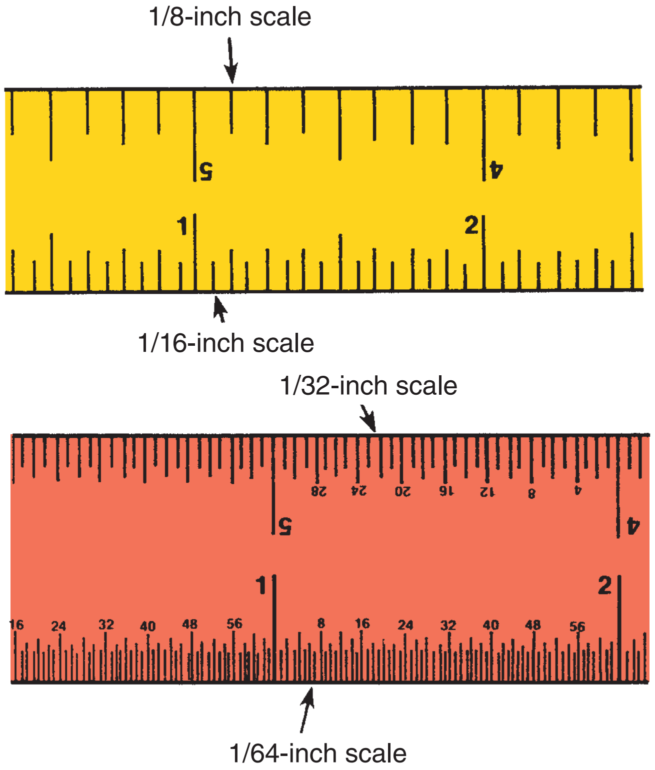


FIGURE 5–13 Graduations on a typical machinist's rule.

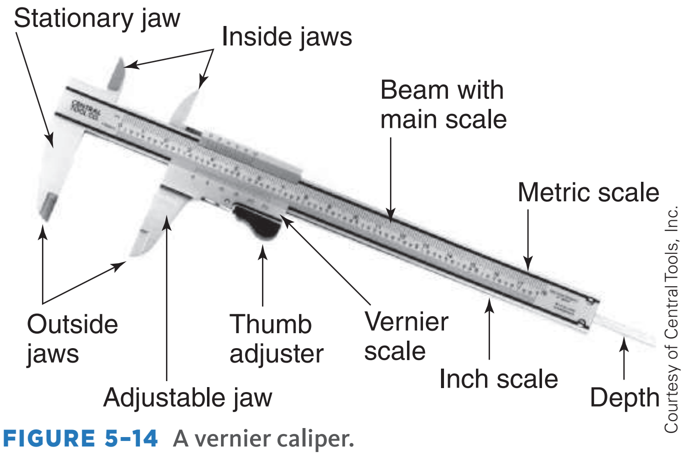


FIGURE 5–14 A vernier caliper.

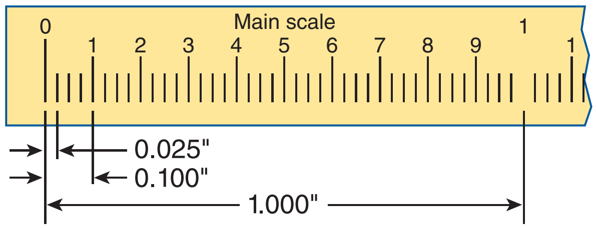


FIGURE 5–15 Each line of the main scale equals 0.025 inch.

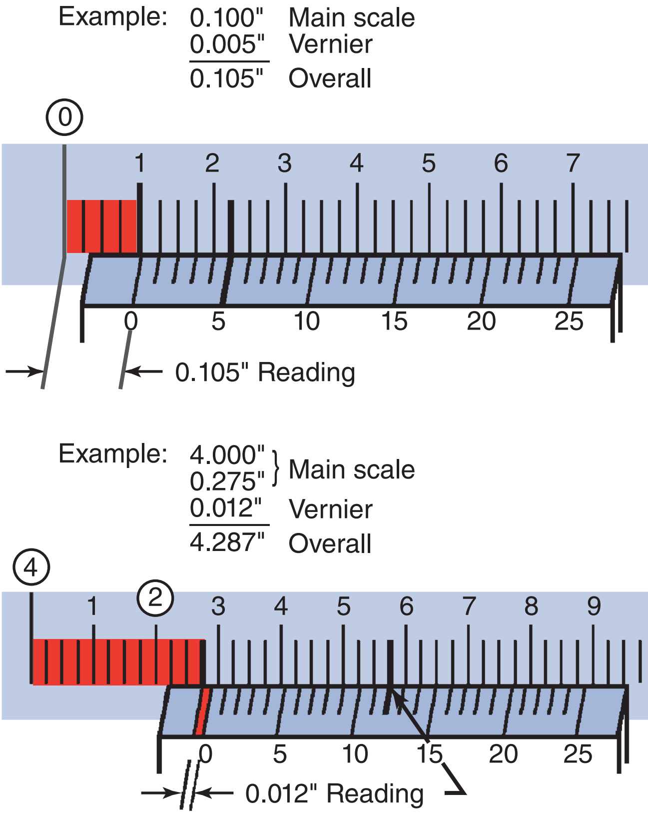


FIGURE 5–16 To get a final measurement, line up the vernier scale line that is exactly aligned with any line on the main scale.

FIGURE 5–17 A dial vernier caliper.

increments of 0.02 mm. The dial caliper features a depth scale, bar scale, dial indicator, inside measurement jaws, and outside measurement jaws.

The main scale of a US dial caliper is divided into one-tenth (0.1) inch graduations. The dial indicator is divided into one-thousandth (0.001) inch graduations. Therefore, one revolution of the dial indicator needle equals one-tenth inch on the bar scale.

A metric dial caliper is similar in appearance; however, the bar scale is divided into 2 mm increments. Additionally, on a metric dial caliper, one revolution of the dial indicator needle equals 2 mm.

Both English and metric dial calipers use a thumb-operated roll knob for fine adjustment. When you use a dial caliper, always move the measuring jaws backward and forward to center the jaws on the object being measured. Make sure the caliper jaws lay flat on or around the object. If the jaws are tilted in any way, you will not obtain an accurate measurement.

Although dial calipers are precision measuring instruments, they are only accurate to plus or minus two-thousandths (±0.002) of an inch. Micrometers are preferred when extremely precise measurements are desired.

Micrometers

The micrometer is used to measure linear outside and inside dimensions. Both outside and inside micrometers are calibrated and read in the same manner. Measurements on both are taken with the measuring points in contact with the surfaces being measured.

The major components and markings of a micrometer include the frame, anvil, spindle, locknut, sleeve, sleeve numbers, sleeve long line, thimble marks, thimble, and ratchet **(Figure 5–18)**. Micrometers are calibrated in either inch or metric graduations and are available in a range of sizes. The proper procedure for

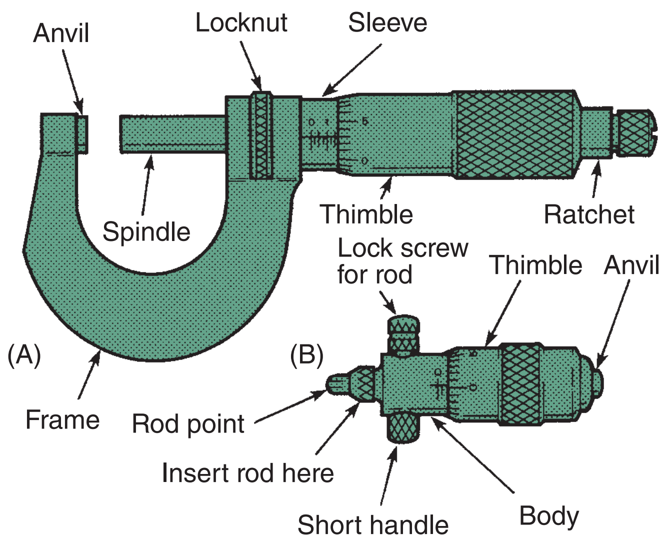
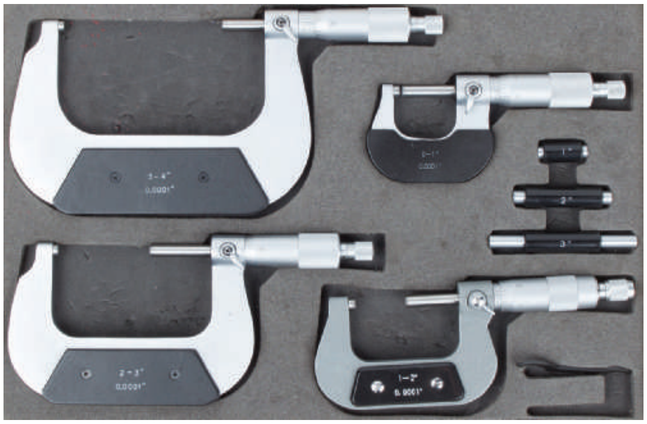


FIGURE 5–18 Major components of (A) an outside and (B) an inside micrometer.

PHOTO SEQUENCE 2

Using a Micrometer



P2-1 Micrometers can be used to measure the diameter of many different objects. By measuring the diameter of a valve stem in two places, the wear of the stem can be determined.

P2-2 Because the diameter of a valve stem is less than 1 inch, a 0- to 1-inch outside micrometer is used.

P2-3 The graduations on the sleeve each represent 0.025 inch. To read a measurement on a micrometer, begin by counting the visible lines on the sleeve and multiplying them by 0.025.

P2-4 The graduations on the thimble assembly define the area between the lines on the sleeve. The number indicated on the thimble is added to the measurement shown on the sleeve.

P2-5 A micrometer reading of 0.500 inch.

P2-6 A micrometer reading of 0.375 inch.

PHOTO SEQUENCE 2

Using a Micrometer *(continued)*

P2-7 Normally, little stem wear is evident directly below the keeper grooves. To measure the diameter of the stem at that point, close the micrometer around the stem.

P2-8 To get an accurate reading, slowly close the micrometer until a slight drag is felt while passing the valve in and out of the micrometer.

P2-9 To prevent the reading from changing while you move the micrometer away from the stem, use your thumb to activate the lock lever.

P2-10 This reading (0.311 inch) represents the diameter of the valve stem at the top of the wear area.

P2-11 Some micrometers are able to measure in 0.0001 (ten-thousandths) of an inch. Use this type of micrometer if the specifications call for this much accuracy. Note that the exact diameter of the valve stem is 0.3112 inch.

P2-12 Most valve stem wear occurs above the valve head. The diameter here should also be measured. The difference between the diameter of the valve stem just below the keepers and just above the valve head represents the amount of valve stem wear.

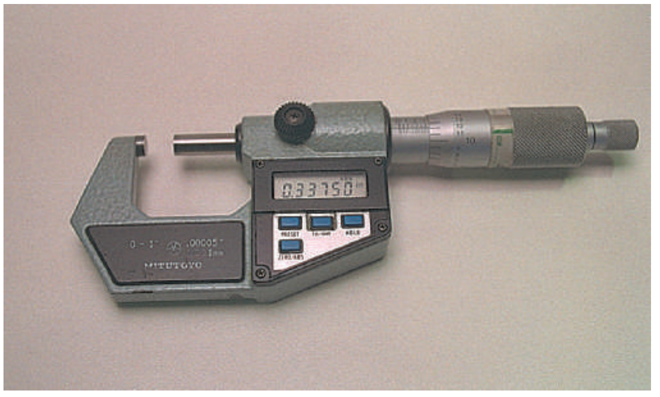


FIGURE 5-19 A digital micrometer eliminates the need to do math.

measuring with an inch-graduated outside micrometer is outlined in Photo Sequence 2.

Most micrometers are designed to measure objects with accuracy to 0.001 (one-thousandth) inch. Micrometers are also available to measure in 0.0001 (ten-thousandths) of an inch. This type of micrometer should be used when the specifications call for this much accuracy. Digital micrometers are also available **(Figure 5–19)**. These eliminate the need to do math and still receive a precise measurement.

Reading a Metric Outside Micrometer The metric micrometer is read in the same manner as the inch-graduated micrometer, except the graduations are expressed in the metric system of measurement. Readings are obtained as follows:

- Each number on the sleeve of the micrometer represents = millimeters (mm) or 0.005 meter (m) **(Figure 5–20A)**.
- Each of the 10 equal spaces between each number, with index lines alternating above and below the horizontal line, represents 0.5 mm or five-tenths of a mm. One revolution of the thimble changes the reading one space on the sleeve scale or 0.5 mm **(Figure 5–20B)**.
- The beveled edge of the thimble is divided into 50 equal divisions with every fifth line numbered: 0, 5, 10, . . . 45. Since one complete revolution of the thimble advances the spindle 0.5 mm, each graduation on the thimble is equal to one hundredth of a millimeter **(Figure 5–20C)**.
- As with the inch-graduated micrometer, the three separate readings are added together to obtain the total reading **(Figure 5–21)**.

To measure small objects with an outside micrometer, open the tool and slip the object between the spindle and anvil. While holding the object

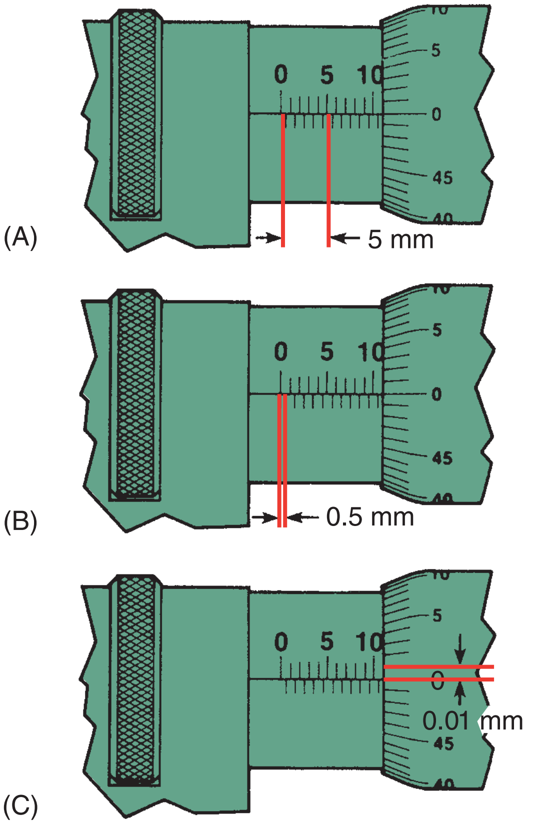


FIGURE 5-20 Reading a metric micrometer: (A) 10 mm plus (B) 0.5 mm plus (C) 0.01 mm equals 10.51 mm.

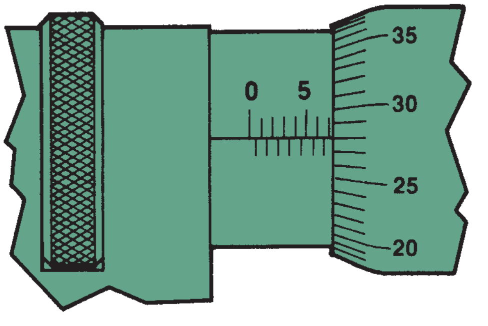


FIGURE 5-21 The total reading on this micrometer is 7.28 mm.

against the anvil, turn the thimble with your thumb and forefinger until the spindle contacts the object. Use only enough pressure on the thimble to allow the object to just fit between the anvil and spindle. Slip the micrometer back and forth over the object until you feel a very light resistance, while at the same time rocking the tool from side to side to make certain the spindle cannot be closed any further **(Figure 5–22)**. After your final adjustment, lock the micrometer and read the measurement.

Micrometers are available in different sizes. The size is dictated by the smallest to the largest

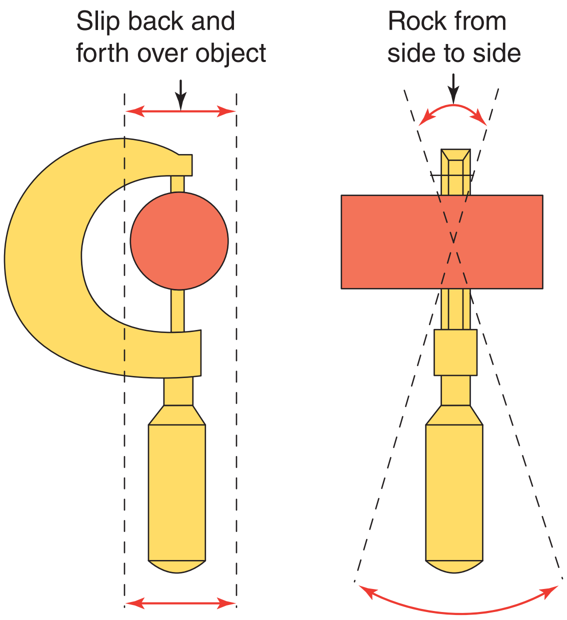


FIGURE 5–22 Slip the micrometer over the object and rock it from side to side.

measurement it can make. Examples of these sizes are the 0- to 1-inch, 1- to 2-inch, 2- to 3-inch, and 3- to 4-inch micrometers.

Reading an Inside Micrometer Inside micrometers are used to measure the inside diameter of a bore or hole. The tool is placed into the bore and extended until each end touches the bore's surface. If the bore is large, it might be necessary to use an extension rod to increase the micrometer's range. These extension rods come in various lengths.

To get a precise measurement, keep the anvil firmly against one side of the bore and rock the micrometer back and forth and side to side. This centers the micrometer in the bore. Make sure there is correct resistance on both ends of the tool before taking a reading.

Reading a Depth Micrometer A depth micrometer **(Figure 5–23)** is used to measure the distance between two parallel surfaces. It operates and is read in the same way as other micrometers. If a depth micrometer is used with a gauge bar, it is important to keep both the bar and the micrometer from rocking. Any movement of either part will result in an inaccurate measurement.

Telescoping Gauge

Telescoping gauges (Figure 5–24) are used for measuring bore diameters and other clearances. They may also be called snap gauges. They are available in sizes ranging from fractions of an inch through 6 inches (150 mm). Each gauge consists of two telescoping plungers, a handle, and a lock screw. Snap gauges are normally used with an outside micrometer.

FIGURE 5–23 A depth micrometer.

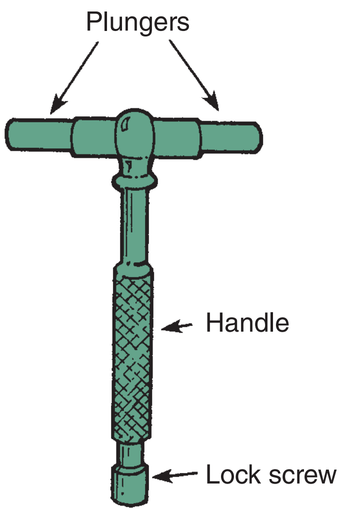


FIGURE 5–24 Parts of a telescoping gauge.

To use the telescoping gauge, insert it into the bore and loosen the lock screw. This will allow the plungers to snap against the bore. Once the plungers have expanded, tighten the lock screw. Then, remove the gauge and measure the expanse with a micrometer.

SHOP TALK

Measurements with any micrometer will be reliable only if the micrometer is calibrated correctly. To calibrate a micrometer, close the micrometer over a micrometer standard. If the reading differs from that of the standard, the micrometer should be adjusted according to the instructions provided by the tool manufacturer. Proper care of a micrometer is also important to ensure accurate measurements. This care includes the following:

- Always clean the micrometer before using it.
- Do not touch the measuring surfaces.
- Store the tool properly. The spindle face should not touch the anvil face; a change in temperature might spring the micrometer.
- Clean the micrometer after use. Wipe it clean of any oil, dirt, or dust using a lint-free cloth.
- Never use the tool as a clamp or tighten the jaws too tightly around an object.
- Do not drop the tool.
- Check the calibration weekly.

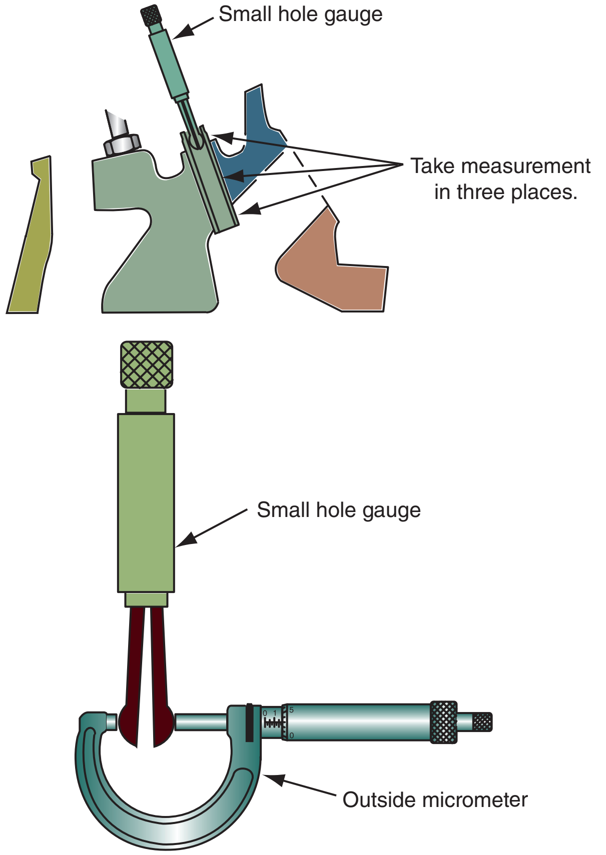


FIGURE 5–25 Insert the ball gauge into the bore to be measured. Then expand it, lock it, and remove it. Now measure it with an outside micrometer.

Small Hole Gauge

A small hole or ball gauge works just like a telescoping gauge. However, it is designed to be used on small bores. After it is placed into the bore and expanded, it is removed and measured with a micrometer **(Figure 5–25)**. Like the telescoping gauge, the small hole gauge consists of a lock, a handle, and an expanding end. The end expands or retracts by turning the gauge handle.

Feeler Gauge

A **feeler gauge** is a thin strip of metal or plastic of known and closely controlled thickness. Several of these metal strips are often assembled together as a feeler gauge set that looks like a pocket knife

FIGURE 5–26 Typical feeler gauge set.

(Figure 5–26). The desired thickness gauge can be pivoted away from others for convenient use. A steel feeler gauge pack usually contains strips or leaves of 0.002- to 0.010-inch thickness (in steps of 0.001 inch) and leaves of 0.012- to 0.024-inch

thickness (in steps of 0.002 inch). Metric feeler gauges are also available.

A feeler gauge can be used by itself to measure piston ring side clearance, piston ring end gap, connecting rod side clearance, crankshaft end play, and other distances.

Round wire feeler gauges are often used to measure spark plug gap. The round gauges are designed to give a better feel for the fit of the gauge in the gap.

Straightedge

A straightedge is no more than a flat bar machined to be totally flat and straight, and to be effective it must be flat and straight. Any surface that should be flat can be checked with a straightedge and feeler gauge set. The straightedge is placed across and at angles on the surface. At any low points on the surface, a feeler gauge can be placed between the straightedge and the surface **(Figure 5–27)**. The size gauge that fills in the gap indicates the amount of warpage or distortion.

Dial Indicator

The **dial indicator (Figure 5–28)** is calibrated in 0.001-inch (one-thousandth inch) increments. Metric dial indicators are also available. Both types are used to measure movement. Common uses of the dial indicator include measuring valve lift, journal concentricity, flywheel or brake rotor runout, gear backlash, and crankshaft end play. Dial indicators are available with various face markings and measurement ranges to accommodate many measuring tasks.

To use a dial indicator, position the indicator rod against the object to be measured. Then, push the indicator toward the work until the indicator needle travels far enough around the gauge face to permit movement to be read in either direction **(Figure 5–29)**. Zero the indicator needle on the gauge. Always be sure the range of the dial indicator is sufficient to allow the amount of movement required by the measuring procedure. For example, never use a 1-inch indicator on a component that will move 2 inches.

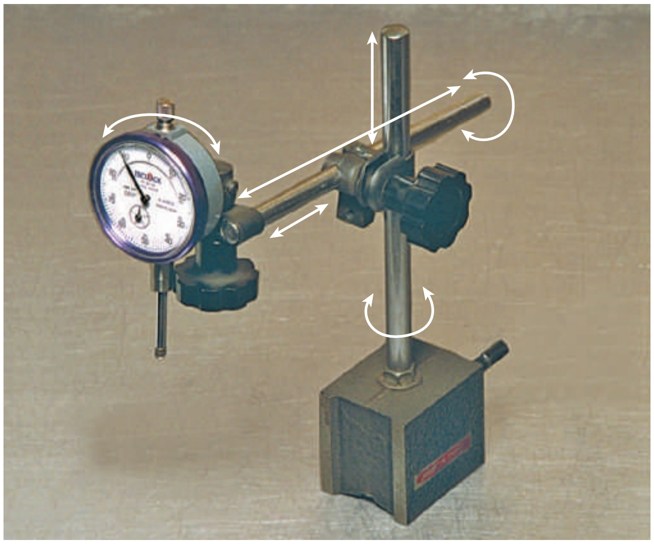


FIGURE 5–28 A dial indicator with a highly adaptive holding fixture.

FIGURE 5–29 This dial indicator setup will measure the amount this axle can move in and out.

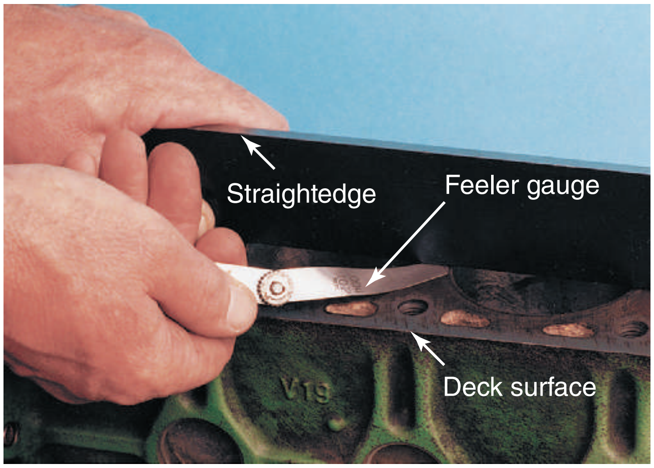


FIGURE 5–27 Using a feeler gauge and precision straightedge to check for warpage.

Hand Tools

Most service procedures require the use of hand tools. Therefore, technicians need a wide assortment of these tools. Each has a specific job and should be used in a specific way. Most service departments and garages require their technicians to buy their own hand tools.

FIGURE 5–30 A technician needs many different sets of wrenches.

Wrenches

The word *wrench* means twist. A wrench is a tool for twisting and/or holding bolt heads or nuts. Nearly all bolt heads and nuts have six sides; the jaw of a wrench fits around these sides to turn the bolt or nut. All technicians should have a complete collection of wrenches. This includes both metric and US wrenches in a variety of sizes and styles **(Figure 5–30)**. The width of the jaw opening determines its size. For example, ½-inch wrench has a jaw opening (from face to face) of ½ inch. The size

SHOP TALK

Metric and US wrenches are not interchangeable. For example, a $\frac{9}{16}$-inch wrench is 0.02 inch larger than a 14-millimeter nut. If the $\frac{9}{16}$-inch wrench is used to turn or hold a 14-millimeter nut, the wrench will probably slip. This may cause rounding of the points of the nut and possibly skinned knuckles as well.

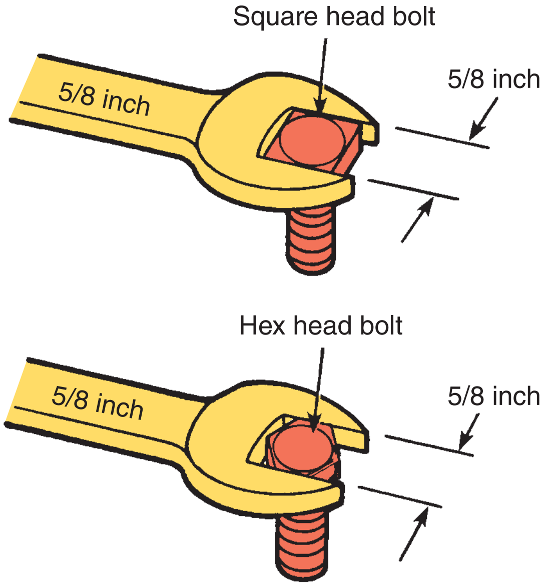


FIGURE 5-31 An open-end wrench grips only two sides of a fastener.

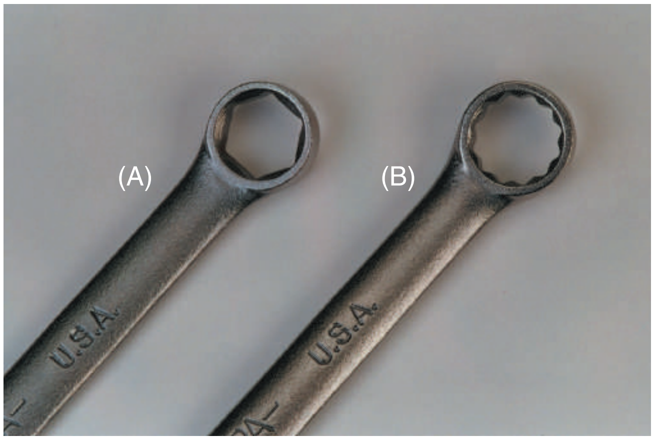


FIGURE 5-32 Six-point (A) and twelve-point (B) box-end wrenches are available.

is actually slightly larger than its nominal size so that the wrench fits around a nut or bolt head of equal size.

The following is a brief discussion of the types of wrenches used by automotive technicians.

Open-End Wrench The jaws of the open-end wrench **(Figure 5–31)** allow the wrench to slide around two sides of a bolt or nut head where there might be insufficient clearance above or on one side of the nut to accept a box wrench.

Box-End Wrench The end of the box-end wrench is boxed or closed rather than open. The jaws of the wrench fit completely around a bolt or nut, gripping each point on the fastener. The box-end wrench is not likely to slip off a nut or bolt. It is safer than an open-end wrench. Box-end wrenches are available as 6 point and 12 point **(Figure 5–32)**. The 6-point box end grips the screw more securely than a 12-point box-end wrench can and avoids damage to the bolt head.

Combination Wrench The combination wrench has an open-end jaw on one end and a box-end on the other **(Figure 5–33)**. Both ends are the same size. Every auto technician should have two sets of wrenches: one for holding and one for turning. The combination wrench is probably the best choice for the second set. It can be used with either open-end or box-end wrench sets and can be used as an open-end or box-end wrench.

FIGURE 5-33 Various types of wrenches including a combination wrench.

Flare Nut (Line) Wrenches Flare nut or line wrenches should be used to loosen or tighten brake line or tubing fittings. Using open-ended wrenches on these fittings tends to round the corners of the nut, which are typically made of soft metal and can distort easily. Flare nut wrenches surround the nut and provide a better grip on the fitting **(Figure 5–34)**. They have a section cut out so that the wrench can be slipped around the brake or fuel line and dropped over the flare nut.

Allen Wrench Setscrews are used to fasten door handles, instrument panel knobs, engine parts, and even brake calipers. A set of fractional and metric hex head wrenches, or Allen wrenches should be in every technician's toolbox. An Allen wrench can be L-shaped or can be mounted in a socket driver and used with a ratchet.

FIGURE 5–34 Various sizes of line wrenches.

> **TOOL CARE**
> Inspect all wrenches for signs of wear or damage. Keep wrenches clean by wiping out the open and box ends with a shop towel. This will help prevent slipping on a fastener during use.

Adjustable-End Wrench An adjustable-end wrench (commonly called a crescent wrench) has one fixed jaw and one movable jaw. The wrench opening can be adjusted by rotating a helical adjusting screw that is mated to teeth in the lower jaw. Because this type of wrench does not firmly grip a bolt's head, it is likely to slip. Adjustable wrenches should be used carefully and *only* when it is absolutely necessary. Be sure to put all of the turning pressure on the fixed jaw.

Sockets and Ratchets

A set of US and metric sockets combined with a ratchet handle and extensions should be included in your tool set. The ratchet allows you to turn the socket in one direction with force and in the other direction without force, which allows you to tighten or loosen a bolt without removing and resetting the wrench after you have turned it. In many situations, a socket wrench is much safer, faster, and easier to use than any other wrench. In fact, sometimes it is the only wrench that will work.

The basic socket wrench set consists of a ratchet handle and several barrel-shaped sockets. The socket fits over and around a bolt or nut **(Figure 5–35)**. Inside, it is shaped like a box-end wrench. Sockets are available in 6, 8, or 12 points. A 6-point socket has stronger walls and improved grip on a bolt compared to a normal 12-point socket. However, 6-point sockets have half the positions of a 12-point socket. Six-point sockets are mostly used on fasteners that are rusted or rounded. Eight-point sockets are available to use on square nuts or square-headed bolts. Some axle and transmission assemblies use square-headed plugs in the fluid reservoir.

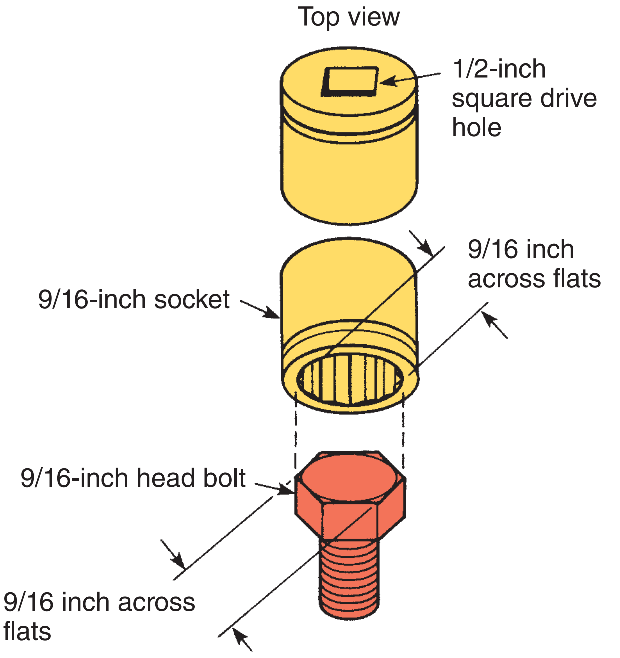


FIGURE 5–35 The size of the correct socket is the same size as the size of the bolt head or nut.

The top side of a socket has a square hole that accepts a square lug on the socket handle. This square hole is the drive hole. The size of the hole and handle lug (¼ inch, ⅜ inch, ½ inch, and so on) indicates the drive size of the socket wrench. One handle fits all the sockets in a set. On better-quality handles, a spring-loaded ball in the square drive lug fits into a depression in the socket. This ball holds the socket to the handle. An assortment of socket (ratchet) handles is shown in **Figure 5–36**.

Not all socket handles are ratcheting. Some, called breaker bars, are simply long arms with a swivel drive

FIGURE 5–36 An assortment of ratchets.

used to provide extra torque onto a bolt to help loosen it. These are available in a variety of lengths and drive sizes. Sometimes nut drivers are used. These handles look like screwdrivers and have a drive shaft on the end of the shaft. Sockets and/or various attachments are inserted on the drive lug. These drivers are only used when bolt tightness is low.

Sockets are available in various sizes, lengths, and bore depths. Both standard US and metric socket wrench sets are necessary for automotive service. Normally, the larger the socket size, the longer the socket or the deeper the well. Deep-well sockets are made extra long to fit over bolt ends or studs. A spark plug socket is an example of a special purpose deep-well socket. Deep-well sockets are also good for reaching nuts or bolts in limited-access areas. Deep-well sockets should not be used when a regular-size socket will do the job. The longer socket develops more twist torque and tends to slip off the fastener.

Heavier-walled sockets are designed for use with an impact wrench and are called impact sockets. Most sockets are chrome-plated, except for impact sockets, which are not **(Figure 5–37)**.

Warning! Never use a nonimpact socket with an impact wrench.

Special Sockets Screwdriver (including Torx® driver) and Allen wrench attachments are also available for use with a socket wrench. **Figure 5–38** shows a typical set of specialty socket drivers. These socket wrench attachments are very handy when a fastener cannot be loosened with a regular screwdriver. The leverage given by the ratchet handle is often just what it takes to break a stubborn screw loose.

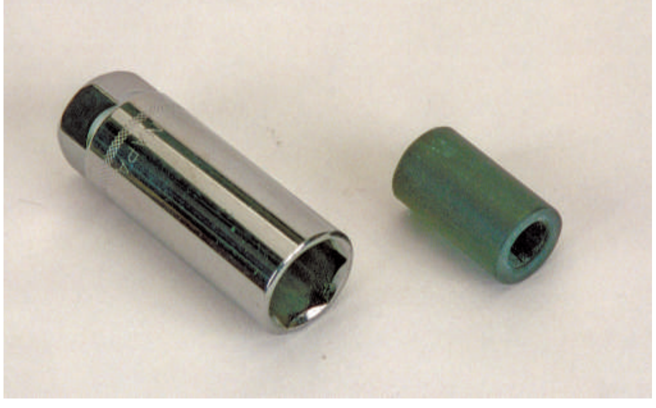


FIGURE 5-37 A chromed deep-well socket and an impact socket.

FIGURE 5-38 A typical set of socket drivers.

Swivel sockets are also available. These sockets are fitted with a flexible joint that accommodates odd angles between the socket and the ratchet handle. These sockets are often used to work bolts that are difficult to reach.

Although crowfoot sockets are not really sockets, they are used with a ratchet or breaker bar. These sockets are actually the end of an open-end or line wrench made with a drive bore, which allows a ratchet to move the socket.

Extensions An extension is commonly used to separate the socket from the ratchet or handle. The extension moves the handle away from the bolt and makes the use of a ratchet more feasible. Extensions are available in all common drive sizes and in a variety of lengths. The most common lengths are 1 inch, 3 inches, 6 inches, and 10 inches; however 2- and 3-foot extensions are also quite common. Flexible adapters are used with extensions to gain access to bolts that cannot be directly tightened or loosened.

Wobble extensions allow a socket to pivot slightly at the drive connection. This type of extension provides for a more positive connection to the socket than swivel joints but only allows approximately 16 degrees of flexibility.

Socket Adapters When sockets of a different drive size must be used with a particular ratchet or handle, an adapter can be inserted between the socket and the drive on the handle. An example of a common adapter is one that allows for the use of a ¼-inch drive socket on a ⅜-inch drive ratchet.

TOOL CARE

Check the ratcheting mechanism each time you use the tool. Over time, wear and lack of maintenance can cause the ratchet to slip, resulting in busted knuckles. Periodically disassemble the ratchet head to clean and lubricate the components. Usually, a light oil or grease is used to keep the ratchet's gears operating smoothly. Inspect sockets for wear and cracks. Loosely fitting sockets can round off bolt heads and lead to cuts and scrapes.

Torque Wrenches

Torque wrenches (Figure 5–39) measure how tight a nut or bolt is. Nearly all of a car's nuts and bolts should be tightened to a certain amount and have a torque specification that is expressed in foot-pounds (US), Newton-meters (metric), or a combination of foot-pounds or Newton-meters plus an angle. A foot-pound is the work or pressure accomplished by a force of 1 pound through a distance of 1 foot. A Newton-meter is the work or pressure accomplished by a force of 1 kilogram through a distance of 1 meter.

A torque wrench is basically a ratchet or breaker bar with some means of displaying the amount of torque exerted on a bolt when pressure is applied to the handle. Torque wrenches are available with the various drive sizes. Sockets are inserted onto the drive and then placed over the bolt. As pressure is exerted on the bolt, the torque wrench indicates the amount of torque.

FIGURE 5–39 The common types of torque wrenches.

SHOP TALK

Following torque specifications is critical. However, there is a possibility that the torque specification is wrong as printed. (In other words, someone made a mistake.) If the torque specification seems way too tight or loose for the size of bolt, find the torque specification in a different source. If the two specifications are the same, use it. If they are different, use the one that seems right.

The common types of torque wrenches are available with inch-pound and foot-pound increments.

- A beam torque wrench is not highly accurate. It relies on a beam metal that points to the torque reading.
- A "click"-type torque wrench clicks when the desired torque is reached. The handle is twisted to set the desired torque reading.
- A dial torque wrench has a dial that indicates the torque exerted on the wrench. The wrench may have a light or buzzer that turns on when the desired torque is reached.
- A digital readout type displays the torque and is commonly used to measure turning effort as well as for tightening bolts **(Figure 5–40)**. Some designs of this type of torque wrench have a light or buzzer that turns on when the desired torque is reached.

The correct torque provides the tightness and stress that the manufacturer has found to be the most desirable and reliable. For example, engine-bearing caps that are too tight distort the bearings, causing excessive wear and incorrect oil clearance. This often results in rapid wear of other engine parts due

FIGURE 5–40 A digital torque wrench.

PROCEDURE

When using a torque wrench, follow these steps to get an accurate reading:

1. Locate the torque specifications and procedures in the service information.
2. Mentally divide the torque specification by three.
3. Hold the wrench so that it is at a 90-degree angle from the fastener being tightened.
4. Tighten the bolt or nut to one-third of the specification.
5. Then tighten the bolt to two-thirds of the specification.
6. Now tighten the bolt to within 10 foot-pounds of the specification.
7. Tighten the bolt to the specified torque.
8. Recheck the torque.

to decreased oil flow. Insufficient torque can result in out-of-round bores and subsequent failure of the parts.

Screwdrivers

A screwdriver drives a variety of threaded fasteners used in the automotive industry. Each fastener requires a specific kind of screwdriver, and a well-equipped technician has several sizes of each.

Screwdrivers are defined by their sizes, their tips **(Figure 5–41)**, and the types of fasteners they should be used with. Your tool set should include both blade and Phillips drivers in a variety of lengths from 2-inch “stubbies” to 12-inch screwdrivers. You also should have an assortment of special screwdrivers, such as those with a Torx® head design.

- *Standard Tip Screwdriver:* A slotted screw accepts a screwdriver with a standard or blade-type tip. The standard tip screwdriver is probably the most common type **(Figure 5–42)**. It is useful for turning carriage bolts, machine screws, and sheet metal

TOOL CARE

Keep torque wrenches in their cases when they are not being used. Click-type torque wrenches should be stored at their lowest or base setting. This helps to keep the torque wrench in calibration by keeping the load of the internal mechanism when not in use. Avoid dropping or using a torque wrench as a breaker bar as this can also lead to inaccurate settings. Torque wrenches should be checked and calibrated yearly and the records kept on file.

SHOP TALK

A screwdriver should not be used as a chisel, punch, or pry bar. Screwdrivers were not made to withstand blows or bending pressures. When misused in such a fashion, the tips will wear, become rounded, and tend to slip out of the fastener. At that point, a screwdriver becomes unusable. Remember a defective tool is a dangerous tool.

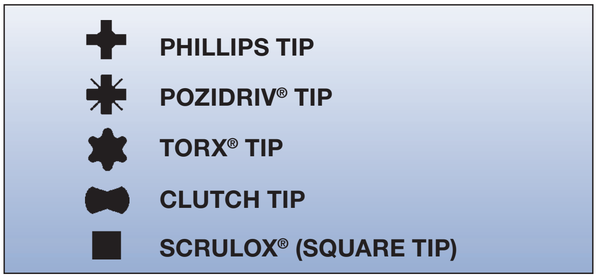


FIGURE 5–41 The various screwdriver tips that are available.

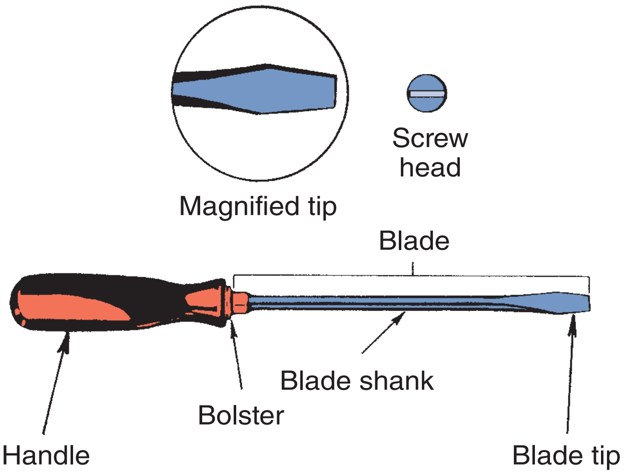


FIGURE 5–42 The blade tip screwdriver is used with slotted head fasteners.

screws. The width and thickness of the blade determine the size of a standard screwdriver. Always use a blade that fills the slot in the fastener.

- *Phillips Screwdriver:* The tip of a Phillips screwdriver has four prongs that fit the four slots in a Phillips head screw. The four surfaces enclose the screwdriver tip so it is less likely that the screwdriver will slip out of the fastener. Phillips screwdrivers come in sizes #0 (the smallest), #1, #2, #3, and #4 (the largest).
- *Reed and Prince Screwdriver:* The tip of a Reed and Prince screwdriver is like a Phillips except that the prongs come to a point rather than to a blunt end.
- *Pozidriv® Screwdriver:* The Pozidriv screwdriver is like a Phillips but its tip is flatter and blunter. The squared tip grips the screw's head and slips less than a Phillips screwdriver.
- *Torx® Screwdriver:* The Torx screwdriver is used to secure headlight assemblies, mirrors, and luggage racks. Not only does the six-prong tip provide greater turning power and less slippage, but the Torx fastener also provides a measure of tamper resistance. Torx drivers come in sizes T15 (the smallest), T20, T25, and T27 (the largest).
- *Clutch Driver:* Fasteners that require a clutch driver are normally used in non-load-bearing places. Clutch head fasteners offer a degree of tamper resistance and offer less slippage than a standard slot screw. The clutch head design has been called a butterfly or figure-eight. Automotive technicians do not often use these drivers.
- *Scrulox® Screwdriver:* The Scrulox screwdriver has a square tip. The tip fits into a square recess in the top of a fastener. This type of fastener is commonly used on truck bodies, campers, and boats.

Impact Screwdriver

An impact screwdriver is used to loosen stubborn screws. Impact screwdrivers have interchangeable heads and bits that allow the handles of the tools to be used with various screw head designs.

To use an impact screwdriver, select the correct bit and insert it into the driver's head. Then hold the bit against the screw slot while firmly twisting the handle in the desired direction. Strike the handle with a hammer. The force of the hammer will exert a downward force on the screw and, at the same time, exert a twisting force on the screw.

TOOL CARE

Standard tip screwdrivers may be able to be dressed, meaning reground on a bench grinder, if damaged. However, a broken tip requires replacement. Do not use damaged screwdrivers as the risk of slipping off and damaging the vehicle or injuring yourself increases if the tool cannot function properly.

Pliers

Pliers **(Figure 5–43)** are gripping tools used for working with wires, clips, and pins. At a minimum, an auto technician should own several types: standard pliers for common parts and wires, needle nose for small parts, and large, adjustable pliers for large items and heavy-duty work. A brief discussion on the different types of pliers follows:

- *Combination pliers* are the most common type of pliers and are frequently used in many kinds of automotive repair. The jaws have both flat and curved surfaces for holding flat or round objects. Also called slip-joint pliers, the combination pliers have many jaw-opening sizes. One jaw can be moved up or down on a pin attached to the other jaw to change the size of the opening.
- *Adjustable pliers*, commonly called *channel locks*, have a multiposition slip joint that allows for many jaw-opening sizes.
- *Needle nose pliers* have long, tapered jaws. They are great for holding small parts or for reaching into tight spots. Many needle nose pliers also have wire-cutting edges and a wire stripper. Curved needle nose pliers allow you to work on a small object around a corner.
- *Locking pliers*, or *vise grips*, are similar to the standard pliers, except they can be tightly locked around an object. They are extremely useful for holding parts together. They are also useful for getting a firm grip on a badly rounded fastener that is impossible to turn with a wrench or socket. Locking pliers come in several sizes and jaw configurations for use in many auto repair jobs.
- *Diagonal-cutting pliers*, or cutters, are used to cut electrical connections, cotter pins, and wires on a vehicle. Jaws on these pliers have extra-hard cutting edges that are squeezed around the item to be cut.

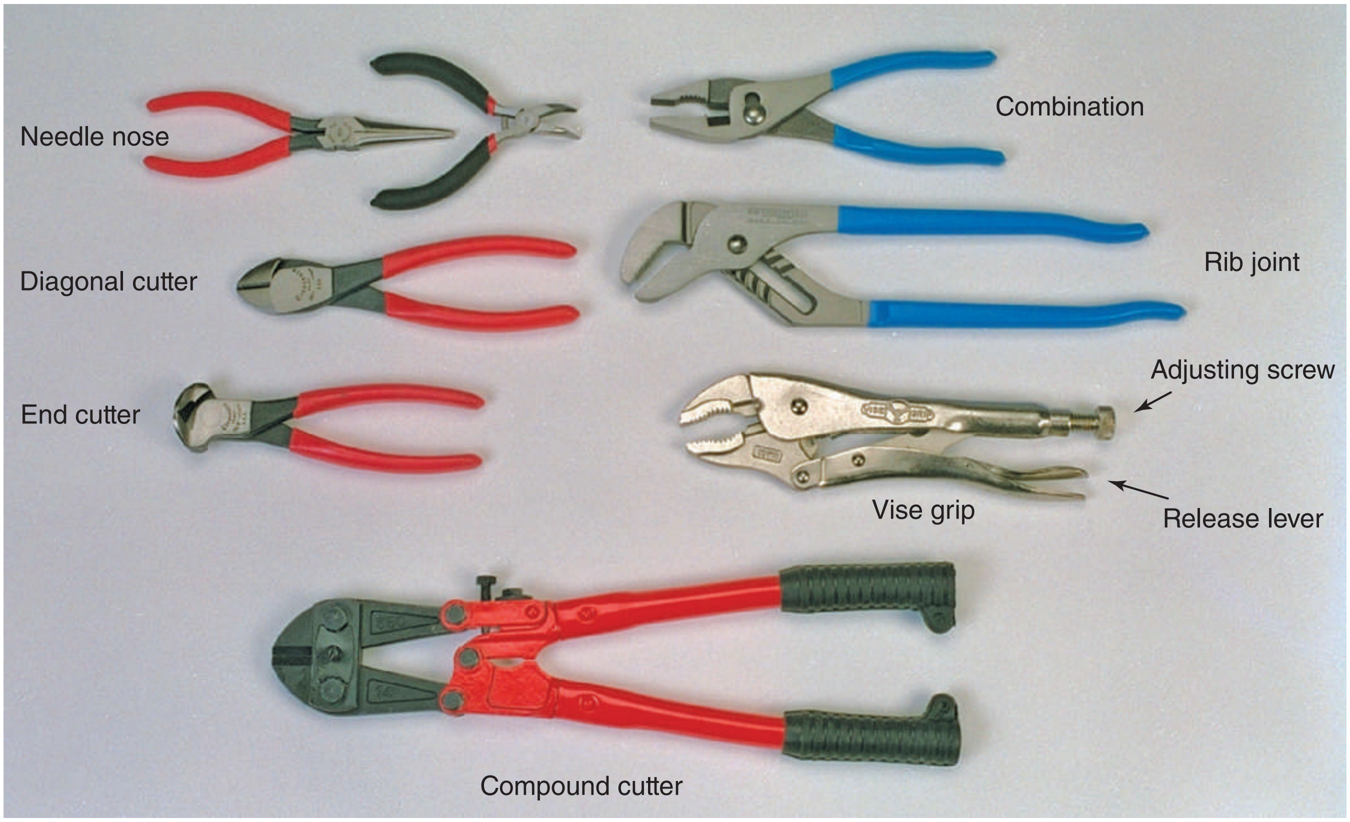


FIGURE 5–43 Various types of pliers.

- *Snap- or lock ring pliers* are made with a linkage that allows the movable jaw to stay parallel throughout the range of opening **(Figure 5–44)**. The jaw surface is usually notched or toothed to prevent slipping.
- *Retaining ring pliers* are identified by their pointed tips that fit into holes in retaining rings. Retaining ring pliers come in fixed sizes but are also available in sets with interchangeable jaws.
- *Spring clamp pliers* are used for removing and installing spring-loaded hose clamps like those used in the cooling system. Curved jaw and locking types are also available.

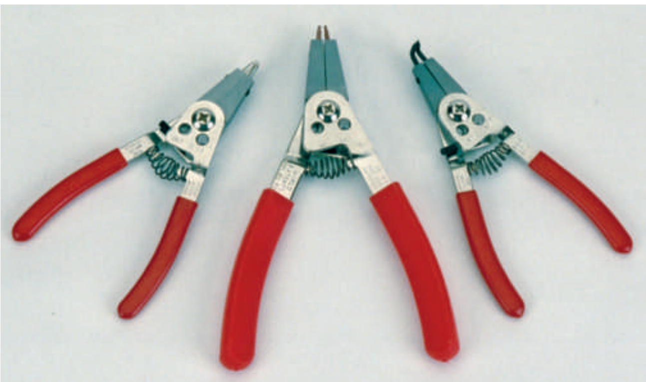


FIGURE 5–44 Snapring and retaining ring pliers.

TOOL CARE

Inspect the pivots and teeth on pliers for wear and damage. Keep the pivot points lubricated with a drop of light oil to keep the pliers working properly.

Hammers

Hammers are identified by the material and weight of the head. There are two groups of hammer heads: steel and soft faced **(Figure 5–45** and **Figure 5–46)**. Your tool set should include at least three hammers: two ball-peen hammers, one 8-ounce and one 12- to 16-ounce hammer, and a small sledgehammer or dead blow hammer. A dead blow hammer contains lead shot to reduce rebound and can be either steel or rubber faced. You should also have a plastic and lead or brass-faced mallet. The heads of steel-faced hammers are made from high-grade alloy steel. The steel is deep forged and heat treated to a suitable degree of hardness. Soft-faced hammers have a surface that yields when it strikes an object. Soft-faced hammers should be used on machined surfaces and when marring a finish is undesirable. For example, a brass hammer should be used to strike gears or shafts because it will not damage them.

FIGURE 5–45 Various steel-faced hammers.

FIGURE 5–46 Soft-faced hammers.

> **TOOL CARE**
>
> Inspect hammer handles and heads for wear and damage. Make sure the heads are secure and tight on the handles. Replace worn or damaged handles before the head of the hammer flies off during use.

Chisels and Punches

Chisels are used to cut metal by driving them with a hammer. Automotive technicians use a variety of chisels for cutting sheet metal, shearing off rivet and bolt heads, splitting rusted nuts, and chipping metal. A variety of chisels are available, each with a specific purpose, including flat, cape, round-nose cape, and diamond point chisels.

Punches **(Figure 5–47)** are used for driving out pins, rivets, or shafts; aligning holes in parts during assembly; and marking the starting point for drilling a hole. Punches are designated by their point diameter and punch shape. Drift punches are used to remove drift and roll pins. Some drifts are made of

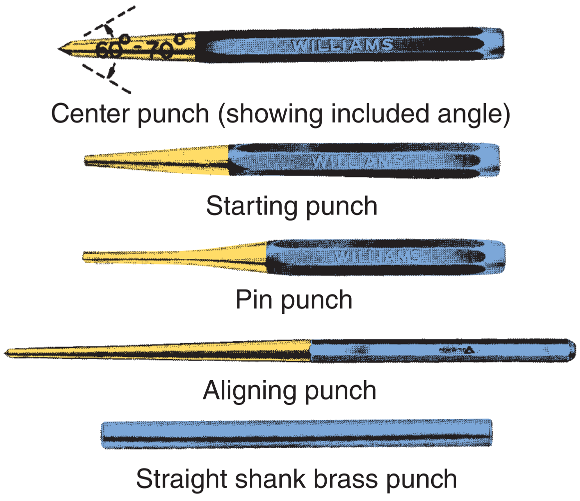


FIGURE 5-47 Punches are defined by their shape and the diameter of the point.

brass; these should be used whenever you are concerned about possible damage to the pin or to the surface surrounding the pin. Tapered punches are used to line up bolt holes. Starter or center punches are used to make an indent before drilling to prevent the drill bit from wandering.

Removers

Rust, corrosion, and prolonged heat can cause automotive fasteners, such as cap screws and studs, to become stuck. A box wrench or socket is used to loosen cap screws. A special gripping tool is designed to remove studs. However, if the fastener breaks off, special extracting tools and procedures must be employed.

One type of stud remover is shown in **Figure 5–48**. These tools are also used to install studs. Stud removers have hardened, knurled, or grooved eccentric rollers or jaws that grip the stud tightly when operated. Stud removers/installers are turned by a socket wrench drive handle, a socket, or wrench.

Extractors are used on screws and bolts that are broken off below the surface. Twist drills, fluted extractors, and hex nuts are included in a screw extractor set. This type of extractor lessens the tendency to expand the screw or stud that has been drilled out by providing gripping power along the full length of the stud.

TOOL CARE Punches and chisels tend to suffer with use. Dress the tools with a grinder to restore tips and chisel edges and replace the tool when it is worn out.

FIGURE 5-48 Stud installation/removal tool.

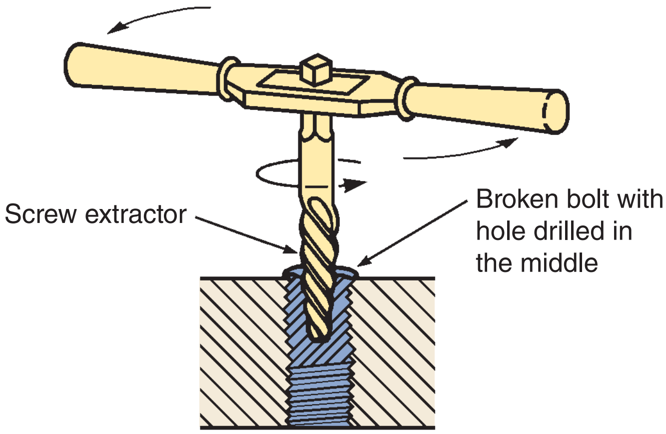


FIGURE 5-49 Using a screw extractor to remove a broken bolt.

Screw extractors are often called easy outs. To use an extractor, the bolt must be drilled and the extractor forced into that bore. The teeth of the extractor grip the inside of the drilled bore and allow the bolt to be turned out **(Figure 5–49)**. Easy outs typically have the size of the required drill bit stamped on one side.

At times a broken bolt can be loosened and removed from its bore by driving it in a counterclockwise direction with a chisel and hammer. A bolt broken off above the surface may be able to be removed with locking pliers.

TOOL CARE Inspect extractors and removers before and after each use. Some tools may only be used one time and then will be damaged beyond use. Do not try to use a damaged extractor as it may break off inside the part being removed.

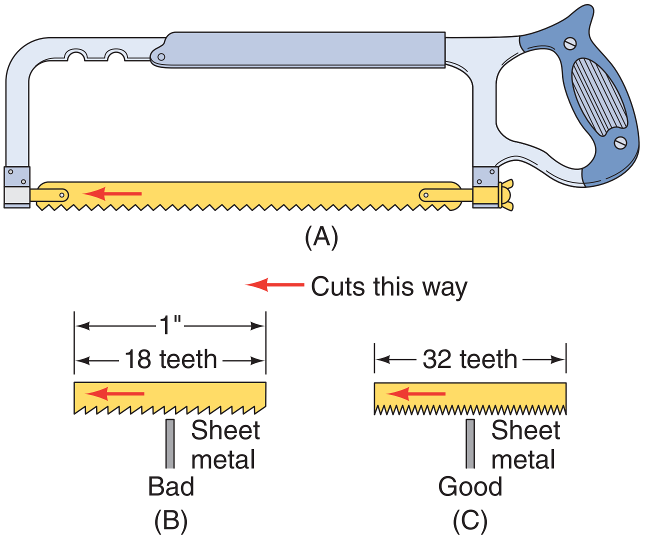


FIGURE 5-50 (A) The teeth on the blade in a hacksaw should face forward. (B) A coarse blade should not be used with sheet metal. (C) A fine blade will work well with sheet metal.

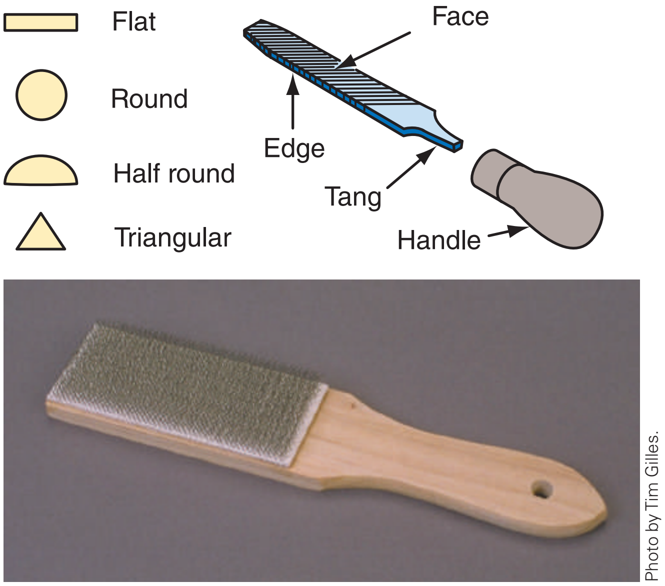


FIGURE 5-51 (A) Files come in a variety of shapes. (B) A file card.

Hacksaws

A hacksaw is used to cut metal **(Figure 5–50)**. The blade only cuts on the forward stroke. The teeth of the blade should always face away from the saw's handle. The number of teeth on the blade determines the type of metal the saw can be used on. A fine-toothed blade is best for thin sheet metal, whereas a coarse blade is used on thicker metals.

When using a hacksaw, never bear down on the blade while pulling it toward you; this will dull the blade. Use the entire blade while cutting.

Files

Files are commonly used to shape or smooth metal edges. Files typically have square, triangular, rectangular (flat), round, or half-round shapes **(Figure 5–51)**. They also vary in size and coarseness. The most commonly used files are the half-round and flat with either single-cut or double-cut designs. A single-cut file has its cutting grooves lined up diagonally across the face of the file. The cutting grooves of a double-cut file run diagonally in both directions across the face. Double-cut files are considered first cut or roughening files because they can remove large amounts of metal. Single-cut files are considered finishing files because they remove small amounts of metal.

To avoid personal injury, files should always be used with a plastic or wooden handle. Like hacksaws, files only cut on the forward stroke. Coarse files are used for soft metals, and smoother, or finer, files are used to work steel and other hard metals.

TOOL CARE

Keep files clean, dry, and free of oil and grease. To clean filings from the teeth of a file, use a special tool called a file card.

Gear and Bearing Pullers

Many precision gears and bearings have a slight interference fit (**press fit**) when installed on a shaft or housing. For example, the inside diameter of a bore is 0.001 inch smaller than the outside diameter of a shaft. When the shaft is fitted into the bore it must be pressed in to overcome the 0.001-inch interference fit. This press fit prevents the parts from moving on each other. The removal of gears and bearings must be done carefully. Prying or hammering can break or bind the parts. A puller with the proper jaws and adapters should be used when applying force to remove gears and bearings. Using proper tools, the force can be applied with a slight and steady motion.

Pullers are available in many different designs and therefore are designed for specific purposes. Most pullers come with various jaw lengths and shapes to allow them to work in a number of different situations.

Some pullers are fitted to the end of a slide hammer **(Figure 5–52)** and are used to remove slightly press-fit items. After the mounting plate of the puller is secure in or on the object to be removed, the weight on the tool's hammer is slid back with force

FIGURE 5-52 Using a slide hammer-type puller to remove a drive axle.

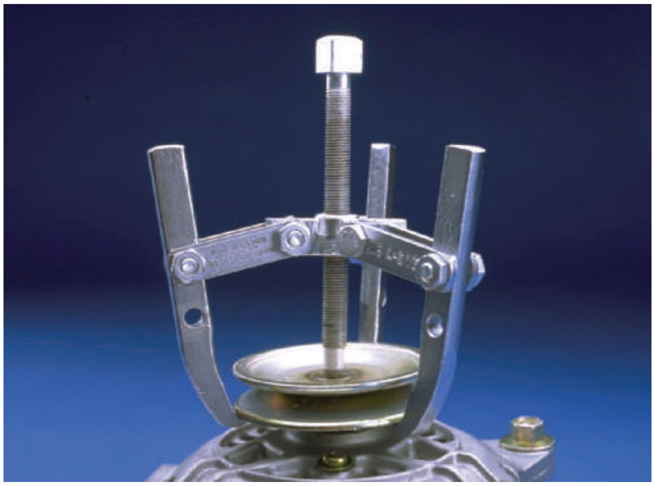


FIGURE 5-53 The jaws on this puller are reversible to allow for inside and outside pulls.

against the handle of the tool, generating a pulling force and jerking the object out of its bore.

To pull something out of a bore, the puller must be designed to expand its jaws outward. The jaws also must be small enough to reach into the bore without damaging the bore while still firmly gripping the object that is being removed. This type puller is commonly used to remove seals, bushings, and bearing cups.

Jaw-type pullers are used to pull an object off a shaft. These pullers are available with two or three jaws **(Figure 5–53)**. Jaw-type pullers are commonly used to remove bearings, pulleys, and gears.

Some pullers are actually pushers. A push-puller is used to push a shaft out of its bore in a housing. It is often difficult to grip the end of the shaft with a puller, so a push-puller is used to move the shaft out of the bore.

TOOL CARE

Inspect the puller before and after each use. Do not use a damaged puller as serious injury may result. Lubricate the threads on a puller with a graphite-based lubricant to reduce wear on the threads.

Bearing, Bushing, and Seal Drivers

Another commonly used group of special tools includes the various designs of bearing, bushing, and seal drivers. Auto manufacturers supply their dealerships with drivers for specific components. However, universal sets of drivers are also available. These sets include a variety of driver plates, each of a different diameter. The plates are often reversible. The flat side of the plate is used to install seals and the tapered side is used to install tapered bearing races. A driver handle is threaded into the appropriate plate. The bearing or seal is driven into place by tapping on the driver hammer.

Always make sure you use the correct tool for the job; bushings and seals are easily damaged if the wrong tool or procedure is used. Car manufacturers and specialty tool companies work closely together to design and manufacture special tools required to repair cars.

Trouble Light

Adequate light is necessary when working under and around automobiles. A trouble light can be battery powered (like a flashlight) or need to be plugged into a wall socket. Some shops have trouble lights that pull down from a reel suspended from the ceiling. Trouble lights should have LED or fluorescent bulbs. Incandescent bulbs should not be used because they can pop and burn. Take extra care when using a trouble light. Make sure its cord does not get caught in a rotating object. The bulb or tube should be surrounded by a cage or enclosed in clear plastic to prevent accidental breaking and burning.

Creeper

Rather than crawl on your back to work under a vehicle, use a creeper. A creeper is a platform with small wheels. It allows you to slide under a vehicle and easily maneuver while working. To protect yourself and others around you, never have the creeper lying on the floor when you are not using it.

TOOL CARE Check the casters on the creeper before using it. Apply a light oil to each caster to keep it rolling smoothly.

Accidentally stepping on it can result in a serious fall. Always keep it standing on its end when it is not being used.

Shop Equipment

Some tools and equipment are supplied by the service facility and few technicians have these as part of their tool assortment. These tools are commonly used but there is no need for each technician to own them. Many shops have one or two of each.

Bench Vises

Often repair work is completed with a part or assembly removed from the vehicle. The repairs are typically safely and quickly made by securing the assembly. Small parts are usually secured with a bench vise. The vise is bolted to a workbench to give it security. The object to be held is placed into the tool's jaws and the jaws are tightened around the object. If the object could be damaged or marred by the jaws, brass jaw caps are installed over the jaws before the object is placed between them. When not in use, leave the vise loose with the handle free and hanging downward.

Bench Grinder

This electric power tool is generally bolted to a workbench. The grinder should have safety shields and guards. Always wear face protection when using a grinder. A bench grinder is classified by wheel size. Six- to ten-inch wheels are the most common in auto repair shops. Three types of wheels are available with this bench tool:

1. Grinding wheel, for a wide variety of grinding jobs from sharpening cutting tools to deburring
2. Wire wheel brush, for general cleaning and buffing, removing rust, scale, and paint, deburring, and so forth
3. Buffing wheel, for general purpose buffing, polishing, and light cutting

Before using the bench grinder, check the condition of the power cord, shields, and tool rests. The tool rest should be no more than ¼ inch away from the wheel. Stand to the side of the grinder when turning it on so that if a wheel fails and breaks apart on startup, you won't be standing in the way of the debris.

Presses

Many automotive jobs require the use of powerful force to assemble or disassemble parts that are press fit together. Removing and installing piston pins, servicing rear axle bearings, pressing brake drum and rotor studs, and performing transmission assembly work are just a few examples. Presses can be hydraulic, electric, air, or hand driven. Capacities range up to 150 tons of pressing force, depending on the size and design of the press. Smaller arbor and C-frame presses can be bench or pedestal mounted, while high-capacity units are freestanding or floor mounted **(Figure 5–54)**.

Warning! Always wear safety glasses when using a press.

FIGURE 5-54 A floor-mounted hydraulic press.

Grease Guns

Some shops are equipped with air-powered grease guns, while in others, technicians use a manually operated grease gun. Both types can force grease into a grease fitting. Hand-operated grease guns are often preferred because the pressure of the grease can be controlled by the technician. However, many shops use low air pressure to activate a pneumatic grease gun. The suspension and steering system may have several grease or zerk fittings.

Oxyacetylene Torches

Oxyacetylene torches **(Figure 5–55)** have many purposes. In the automotive service industry they are used to heat metal when two parts are difficult to separate, to cut metal (such as when replacing exhaust system parts), and to weld or connect two metal parts together.

Oxyacetylene welding and cutting equipment uses the combustion of acetylene in oxygen to produce a flame temperature of about 5,600 °F (3,100 °C). Acetylene is used as the fuel and oxygen is used to aid in the combustion of the fuel.

The equipment includes cylinders of oxygen and acetylene, two pressure regulators, two flexible hoses (one for each cylinder), and a torch. The torches are selected for the job being done—welding torch for welding, brazing, soldering, and heating and cutting torch for cutting metal.

There are three sets of valves for each gas: the tank valve, the regulator valve, and the torch valve. The oxygen hose is colored green, and the acetylene hose is red. The acetylene connections have left-hand threads and the oxygen connectors have right-hand threads.

Welding and Heating Torch The hoses connect the cylinders to the torch. On the torch there are separate valves for each gas. The torch is comprised of the valves, a handle, a mixing chamber (where the fuel gas and oxygen mix), and a tip (where the flame forms). Many different tips can be used with a welding torch. Always select the correct size for the job.

Cutting Torch A cutting torch is used to cut metal. It is similar to a welding torch. However, the cutting torch has a third tube from the valves to the mixing chamber. It carries high-pressure oxygen, which is controlled by a large lever on the torch. During cutting, the metal is heated until it glows orange, and then a lever on the torch is pressed to pass a stream of oxygen through the heated metal to burn it away where the cut is desired.

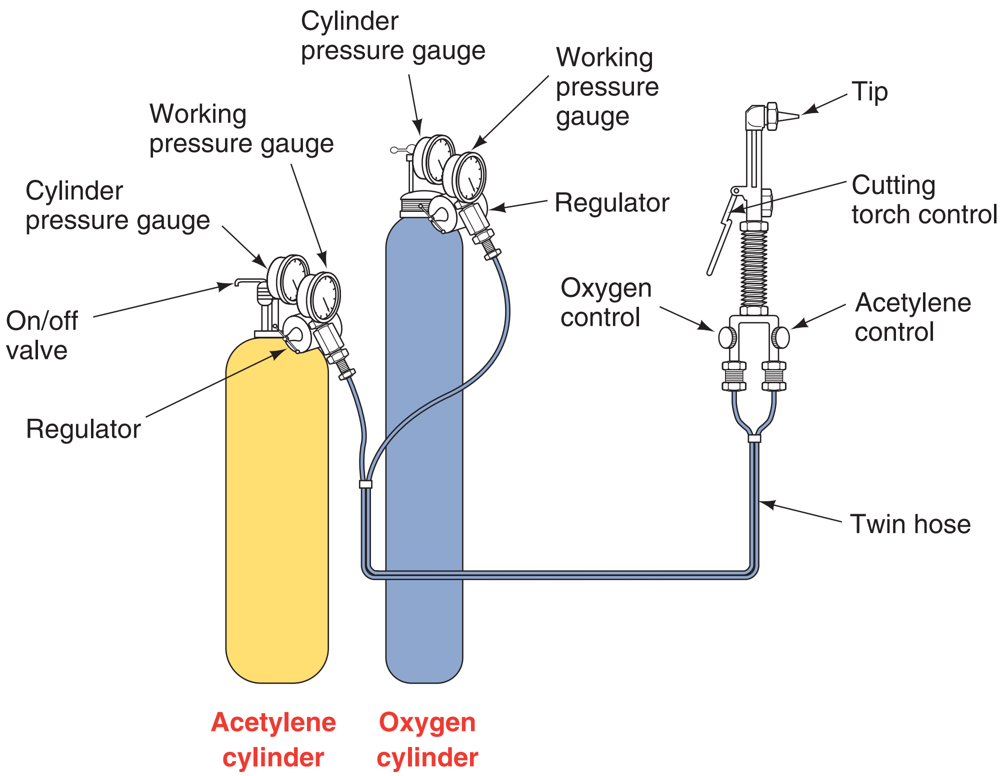


FIGURE 5–55 Oxyacetylene welding equipment shown with a cutting torch.

Precautions Never use oxyacetylene equipment unless you have been properly trained to do so. Also, adhere to all safety precautions, including:

- While using a torch, severe and fatal burns and violent explosions can result from inattention and carelessness.
- Before using an oxyacetylene torch, make sure that all flammable materials such as grease, oil, paint, sawdust, and so on are cleared from the area.
- Keep oxygen away from all combustibles.
- Wear approved shaded goggles with enclosed sides, or a shield with a shaded lens to protect your eyes from glare and sparks.
- Wear leather gloves to protect your hands from burns.
- Wear clothes and shoes/boots appropriate for welding.
- Make sure the gas cylinders are securely fastened upright to a wall, post, or portable cart.
- Never move an oxygen tank around without its valve cap screwed in place.
- Never lay an acetylene tank on its side while being used.

Mini-Ductor® This tool uses the principle of electrical induction to create heat **(Figure 5–56)**. It is faster and safer than a torch, inductive heating heats and removes seized nuts, bearings, pulleys and other metal or mechanical hardware and parts from corrosion and/or threadlock compounds. It relies on a high frequency electromagnet that heats only metal objects or objects containing metal when they are exposed to the tool's magnetic field. It provides immense heat without the danger of an open flame or damage to nearby plastics. The magnetic field moves through non-metals, without heating them, and heats the metal underneath the non-metals.

FIGURE 5-56 A Mini-Ductor®.

SHOP TALK

Safety is critical when using power tools. Carelessness or mishandling of power tools can cause serious injury. Do not use a power tool without obtaining permission from your instructor. Be sure you know how to operate the tool properly before using it. Prior to using a power tool, read the instructions carefully.

Power Tools

Power tools make a technician's job easier. They operate faster and with more torque than hand tools. However, power tools require greater safety measures. Power tools do not stop unless they are turned off. Power is furnished by air (pneumatic), electricity, or hydraulic fluid. *Power tools should only be used for loosening nuts and/or bolts.*

Impact Wrench

An impact wrench **(Figure 5–57)** is a portable handheld reversible wrench. A heavy-duty model can deliver up to 450 foot-pounds (607.5 N-m) of torque. When triggered, the output shaft, onto which the impact socket is fastened, spins freely at 2,000 to 14,000 rpm, depending on the wrench's make and model. When the impact wrench meets resistance, a small spring-loaded hammer situated near the end of the tool strikes an anvil attached to the drive shaft onto which the socket is mounted. Each impact moves the socket around a little until torque equilibrium is reached, the fastener breaks, or the trigger is released. Torque equilibrium occurs when the torque

FIGURE 5-57 A typical air impact wrench.

SHOP TALK

When using an impact wrench, it is important that only impact sockets and adapters be used. Other types of sockets and adapters, if used, might shatter and fly off, endangering the safety of the operator and others in the immediate area.

of the bolt equals the output torque of the wrench. Impact wrenches can be powered either by air or by electricity.

An impact wrench uses compressed air or electricity to hammer or impact a nut or bolt loose or tight. Light-duty impact wrenches are available in three drive sizes—¼, ⅜, and ½ inch—and two heavy-duty sizes—¾ and 1 inch.

Warning! Impact wrenches should not be used to tighten critical parts or parts that may be damaged by the hammering force of the wrench.

Many technicians are using battery-powered electric impact wrenches. The tools currently on the market can provide several hundred foot-pounds of torque, making them more than adequate for removing lug nuts and other fasteners.

Air/Electric Ratchet

An air or electric ratchet, like the hand ratchet, has a special ability to work in hard-to-reach places. Its angle drive reaches in and loosens or tightens where other hand or power wrenches just cannot work **(Figure 5–58)**. Air ratchets look like ordinary ratchets but have a fat handgrip that contains the air vane motor and drive mechanism. Electric ratchets tend to be larger than air ratchets due to the battery packs. Air ratchets usually have a ⅜-inch drive. Air ratchets are not torque sensitive; therefore, a torque wrench should be used on all fasteners after snugging them up with an air ratchet.

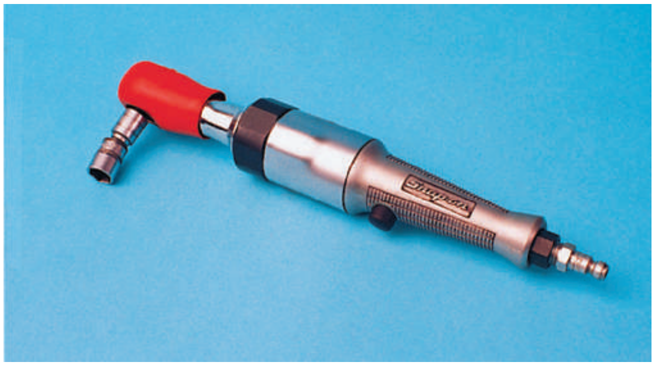


FIGURE 5–58 An air ratchet.

Air Drill

Air drills are usually available in ¼-, ⅜-, and ½-inch sizes. They operate in much the same manner as an electric drill, but are smaller and lighter. This compactness makes them a great deal easier to use for drilling operations in auto work.

Blowgun

Blowguns are used for blowing off parts during cleaning. Never point a blowgun at yourself or anyone else. A blowgun **(Figure 5–59)** snaps into one end of an air hose and directs airflow when a button is pressed. Always use an OSHA-approved air blowgun. Before using a blowgun, be sure it has not been modified to eliminate air-bleed holes on the side.

Jacks and Lifts

Jacks are used to raise a vehicle off the ground and are available in a variety of sizes. The most common one is a hydraulic floor jack, which is classified by

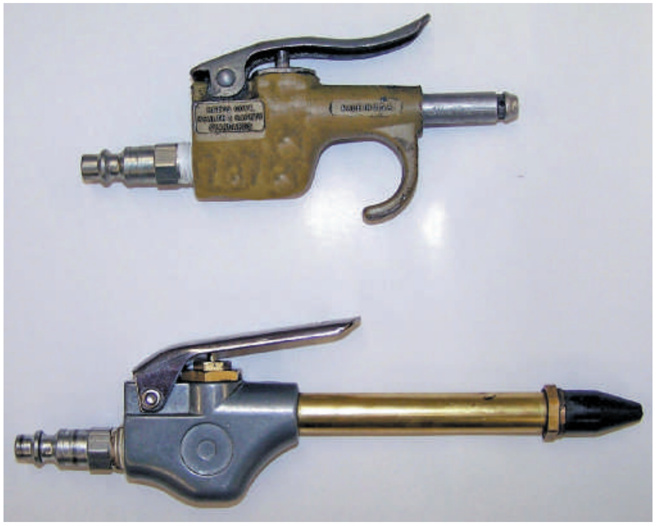


FIGURE 5–59 Two types of air nozzles (blowguns).

TOOL CARE

Add a few drops of air tool oil to each tool daily. This helps prevent rusting of the internal parts and keeps the tool in good working condition.

Caution! Before lifting a vehicle with air suspension, turn off the system. The switch is usually in the trunk.

the weights it can lift: 1½, 2, and 2½ tons, and so on. The other design of portable floor jack uses compressed air. Pneumatic jacks are operated by controlling air pressure at the jack.

Floor Jack

A floor jack is a portable unit mounted on wheels. The lifting pad on the jack is placed under the chassis of the vehicle, and the jack handle is operated with a pumping action. This forces fluid into a hydraulic cylinder in the jack, and the cylinder extends to force the jack lift pad upward and lift the vehicle. Always be sure that the lift pad is positioned securely under one of the car manufacturer's recommended lifting points. To release the hydraulic pressure and lower the vehicle, the handle or release lever must be turned slowly.

The maximum lifting capacity of the floor jack is usually written on the jack decal. Never lift a vehicle that exceeds the jack lifting capacity. This action may cause the jack to break or collapse, resulting in vehicle damage or personal injury.

Before using a floor jack, check the wheels to make sure each can roll smoothly and without dragging. As the vehicle is raised, the jack has to roll a little. If a wheel is seized, it could cause the jack to kick out from under the vehicle. Inspect the hydraulic cylinder for signs of oil loss. Do not use the jack if the cylinder is leaking hydraulic oil as it may fail when trying to raise the vehicle.

When a vehicle is raised by a floor jack, it should be supported by safety stands **(Figure 5–60)**. Never work under a car with only a jack supporting it; always use safety stands. Hydraulic seals in the jack can let go and allow the vehicle to drop.

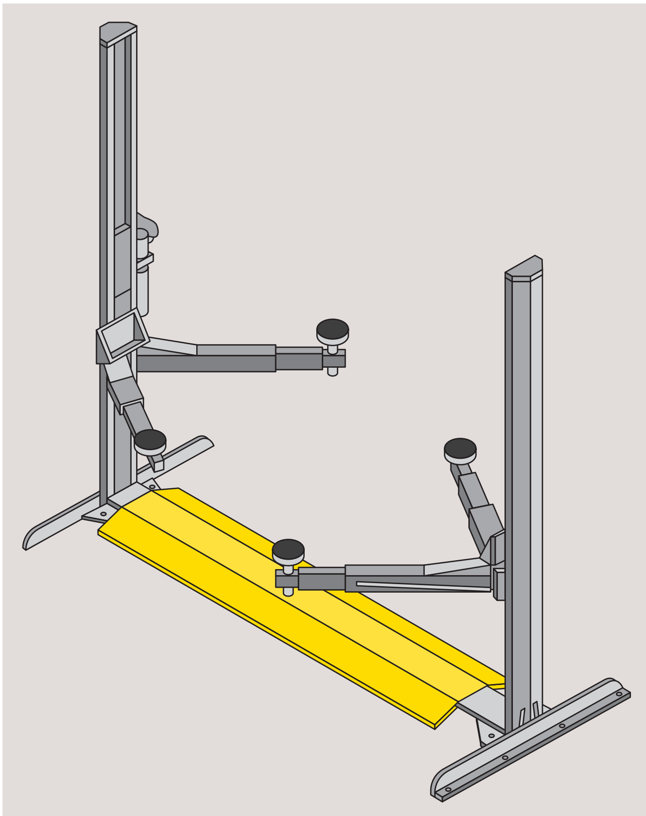
FIGURE 5-60 Whenever you have raised a vehicle with a floor jack, the vehicle should be supported with jack stands.

Lift

A floor lift is the safest lifting tool and is able to raise the vehicle high enough to allow you to walk and work under it. Various safety features prevent a hydraulic lift from dropping if a seal does leak or if air pressure is lost. Before lifting a vehicle, make sure the lift is correctly positioned. The lift arms must be placed under the car manufacturer's recommended lifting points prior to raising a vehicle.

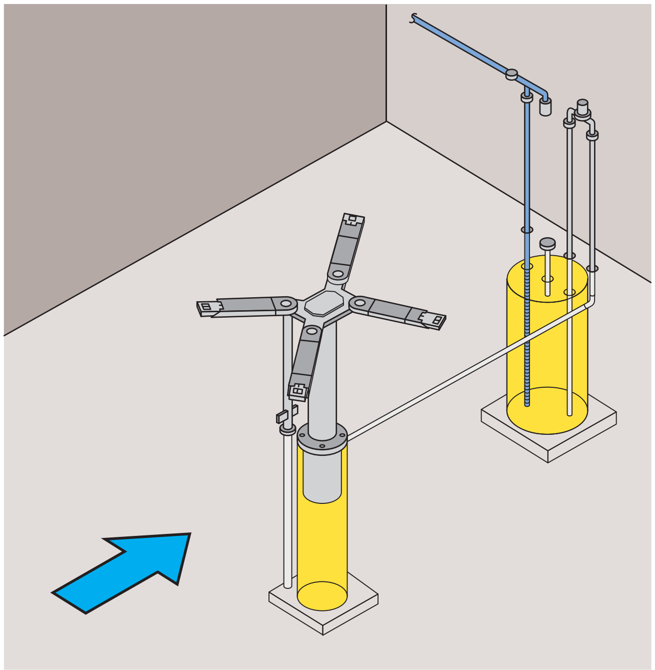
There are three basic types of lifts: frame contact **(Figure 5–61)**, wheel contact, and axle engaging. These categories define where the frame contact points align with the vehicle.

In the near past, most lifts were single post in-ground type **(Figure 5–62)**. These lifts rely on one or more pistons, moved by compressed air to lift a vehicle. Today, surface mounted lifts are the most common. Surface mounted lifts are normally bolted to the floor and are powered by an electric motor, which operates either a hydraulic pump or a screw type drive.



Courtesy of Automotive Lift Institute.

FIGURE 5-61 An aboveground or surface mount frame-contact lift.



Courtesy of Automotive Lift Institute.

FIGURE 5–62 The typical setup for a single post lift.

Two post surface mounted lifts are the most common type of surface mounted lift. The lift arms ride up each post and their movement is synchronized mechanically, hydraulically, or electronically.

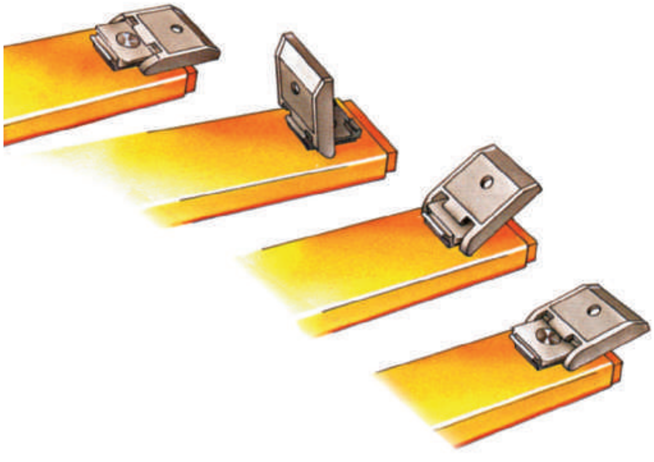
A four post surface-mounted drive on lift is mostly used by muffler, oil change, transmission, and alignment shops. It allows the vehicle to be driven onto two runways and lifted by its tires, exposing the underside of the vehicle. Another form of surface-mounted drive on lift is the parallelogram lift. These use a lifting mechanism that moves the vehicle a short distance forward and backward while it is lifting or lowering a vehicle. Another similar type lift is the scissors lift, which has a lifting mechanism similar to the parallelogram lift.

A recent type of lift is the Y-Lift. This is a drive-on hinged lift that uses Y-shaped legs to provide faster rise/descent speeds and greater vehicle access than traditional scissor lifts **(Figure 5–63)**. It provides increased clear floor space under the vehicle and allows technicians to have full vehicle access from side-to-side and front-to-rear. The Y-Lift was designed for general service work and alignments.

The arms of a lift are fitted with **foot pads (Figure 5–64)** or adapters that can be lifted up to contact the vehicle's lift points to add clearance between the arms and the vehicle. This clearance allows for secure lifting without damaging any part of the body or underbody of the vehicle.

Before using any lift, make sure you understand how to use it properly. Ensure that the safety catches engage and that there are no leaks or other concerns with the lift.

FIGURE 5–63 A vehicle raised on a scissors-type lift.



Courtesy of Automotive Lift Institute.

FIGURE 5–64 Foot pads on the arms of a lift.

Portable Crane

To remove and install an engine, a portable crane, frequently called a cherry picker, is used. To lift an engine, attach a pulling sling or chain to the engine. Some engines have eye plates for use in lifting. If they are not available, the sling must be bolted to the engine. The sling attaching bolts must be large enough to support the engine and must thread into the block a minimum of 1½ times the bolt diameter. Connect the crane to the chain. Raise the engine slightly and make sure the sling attachments are secure. Carefully lift the engine out of its compartment.

Lower the engine close to the floor so the transmission and torque converter or clutch can be removed from the engine, if necessary.

Engine Stands/Benches

After the engine has been removed, use the crane to raise the engine. Position the engine next to an engine stand. Most stands use a plate with several holes or adjustable arms. The engine must be supported by at least four bolts that fit solidly into the engine. The engine should be positioned so that its center is in the middle of the engine's stand adapter plate. The adapter plate can swivel in the stand. By centering the engine, the engine can be easily turned to the desired working positions.

Some shops have engine mounts bolted to the top of workbenches. The engine is suspended off the side of the workbench. These have the advantage of a good working space next to the engine, but they are not mobile and all engine work must be done at that location.

After the engine is secured to its mount, the crane and lifting chains can be removed and disassembly of the engine can begin.

Service Information

There is no way a technician can remember all of the procedures and specifications needed to repair an automobile correctly, therefore having accurate service information is important. While most service information (SI) is now provided electronically via the Internet, information is still available in books and on DVDs. Good information plus knowledge allows a technician to fix a problem with the least amount of frustration and at the lowest cost to the customer.

Auto Manufacturers' Service Information

The primary source for repair and specification information for any car, van, or truck is the manufacturer. The manufacturer publishes appropriate service each year, for every vehicle built.

The information may be divided into sections such as chassis, suspension, steering, emission control, fuel systems, brakes, basic maintenance, engine, transmission, body, and so on **(Figure 5–65)**. Each major section is divided into subsystems **(Figure 5–66)**. These cover all repairs, adjustments, specifications, diagnostic procedures, and any required special tools.

Since many technical changes occur on specific vehicles each year, manufacturers' service manuals need to be constantly updated. Updates are published

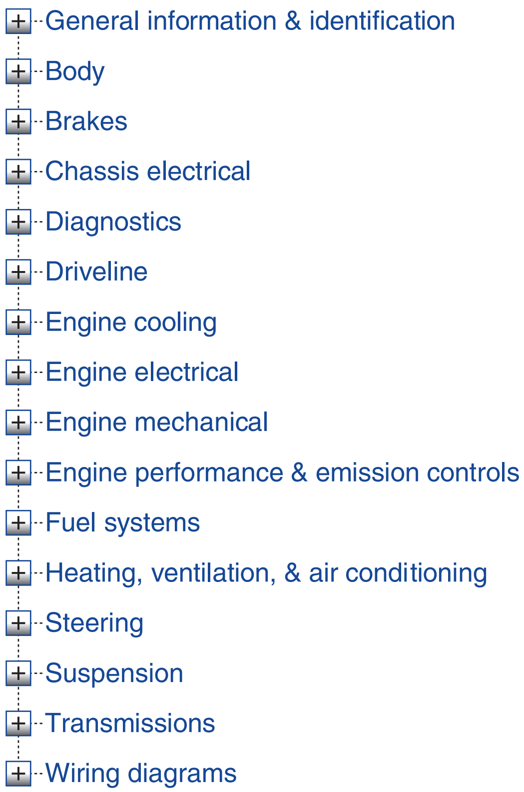


FIGURE 5–65 The main index of service information showing that it is divided by major vehicle systems.

FIGURE 5–66 After the basic system is selected on the main screen, the program moves to the subsystems of that main system.

as service bulletins (often referred to as technical service bulletins or TSBs) that show the changes in specifications and repair procedures during the model year **(Figure 5–67)**. These changes do not appear in the service manual until the next year. The car manufacturer provides these bulletins to dealers and repair facilities on a regular basis.

Automotive manufacturers also publish a series of technician reference books. The publications provide general instructions about the service and repair

00-08-48-00 SD: Distortion in Outer Surface of Vehicle Glass - (Sep 10, 2010)

Subject: **Distortion in Outer Surface of Vehicle Glass**

Models: **2011 and Prior GM Passenger Cars and Trucks**
2009 and Prior HUMMER H2
2010 and Prior HUMMER H3
2005-2009 Saab 9-7X
2010 and Prior Saturn

This bulletin is being revised to add model years. Please discard Corporate Bulletin Number 00-08-48-005 C (Section 08 - Body and Accessories).

Distortion in the outer surface of the windshield glass, door glass or backlite glass may appear after the vehicle has:

- Accumulated some mileage.
- Been frequently washed in automatic car washes, particularly "touchless" car washes.

This distortion may look like a subtle orange peel pattern, or may look like a drip or sag etched into the surface of the glass.

Some car wash solutions contain a buffered solution of hydrofluoric acid which is used to clean the glass. This should not cause a problem if used in the correct concentration. However, if not used correctly, hydrofluoric acid with attack the glass, and over time, will cause visual distortion in the outer surface of the glass which cannot be removed by scraping or polishing.

If this condition is suspected, look at the area of the windshield under the wipers or below the belt seal on the side glass. The area of the glass below the wipers or belt seal will not be affected and what looks like a drip or sag may be apparent at the edge of the wiper or belt seal. You may also see a line on the glass where the wiper blade or the belt seal contacts the glass.

Important: The repair will require replacing the affected glass and is not a result of a defect in material or workmanship. Therefore, is not covered by New Vehicle Warranty.

Chilton, an imprint of Cengage Learning Inc.

FIGURE 5–67 A technical service bulletin.

of the manufacturers' vehicles and also indicate their recommended techniques.

General and Specialty Repair Providers

Service information is also available from independent companies. These companies pay for and get most of their information from the car makers. Examples of these companies are Chilton, Mitchell 1, and ALLDATA.

Finding Information

Although the information from different publishers vary in presentation and the arrangement of topics, all are easy to use after you become familiar with their organization. Most are divided into a number of sections, each covering different aspects of the vehicle. The beginning sections commonly provide vehicle identification and basic maintenance information **(Figure 5–68)**. The remaining sections deal with each different vehicle system in detail, including diagnostic, service, and overhaul procedures. Each section has an index indicating more specific areas of information.

To obtain the correct system specifications and other information, you must first identify the exact system you are working on. The best source for vehicle identification is the VIN **(Figure 5–69)**. The available information may also help you identify the system through the identification of key components or other identification numbers and/or markings.

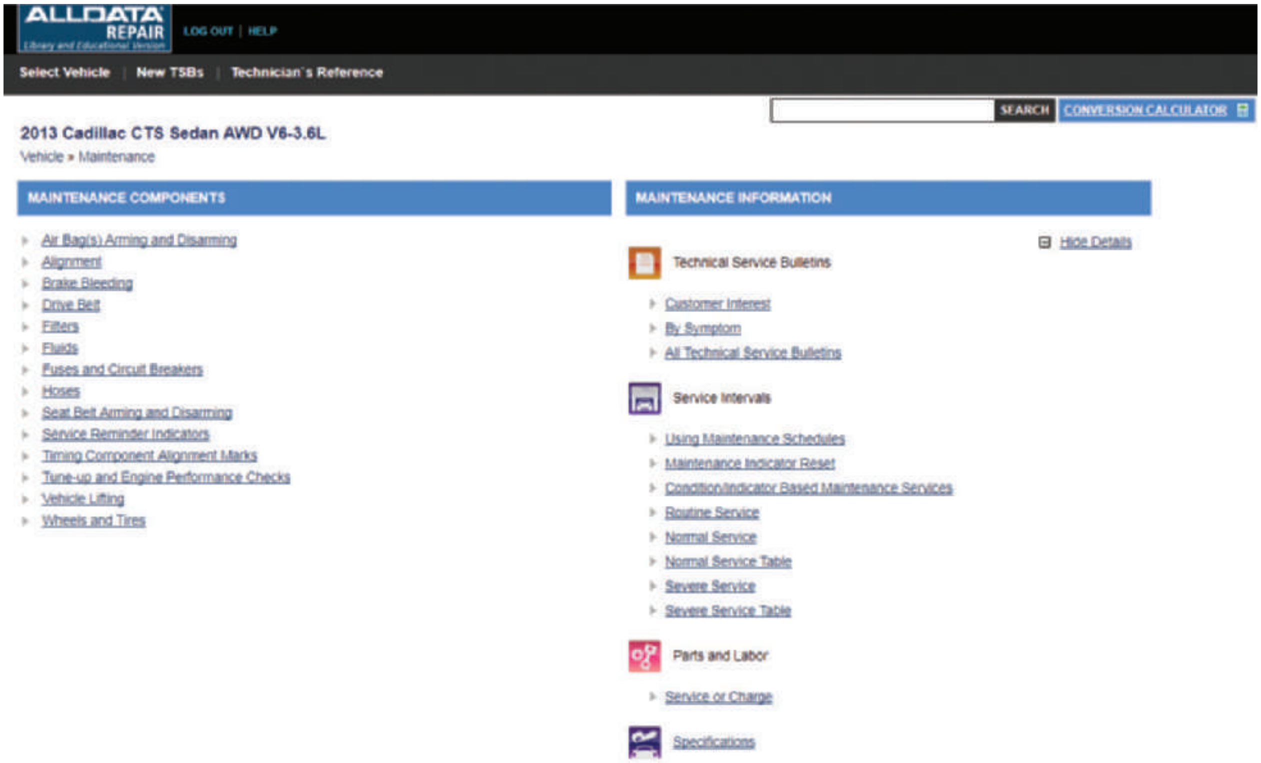


FIGURE 5-68 An example of maintenance information from ALLDATA.

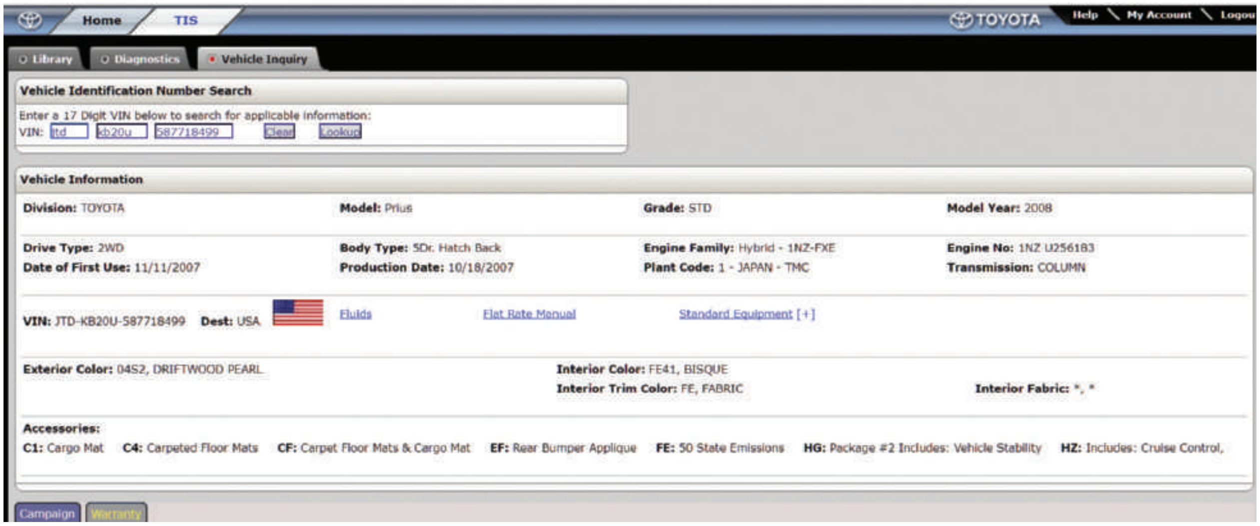


FIGURE 5-69 Using the VIN to access vehicle-specific information on an OEMs service information website.

Aftermarket Suppliers' Guides and Catalogs

Many of the larger parts manufacturers have excellent guides on the various parts they manufacture or supply. They also provide updated service bulletins on their products. Other sources for up-to-date technical information are trade magazines and trade associations.

Lubrication Guides

These specially designed service manuals contain information on lubrication, maintenance, capacities, and underhood service. The lubrication guide includes lube and maintenance instructions, lubrication diagrams and specifications, vehicle lift points, and preventive maintenance mileage/time intervals. The capacities listed include cooling system, air

conditioning, cooling system air bleed locations, wheel and tire specifications, and wheel lug torque specifications. The underhood information includes specifications for tune-up; mechanical, electrical, and fuel systems; diagrams; and belt tension.

Owner's Manuals

An owner's manual comes with the vehicle when it is new. It contains operating instructions for the vehicle and its accessories. It also contains valuable information about checking and adding fluids, safety precautions, a complete list of capacities, and the specifications for the various fluids and lubricants for the vehicle.

Hotline Services

Hotline services provide answers to service concerns by telephone. Manufacturers provide help by telephone for technicians in their dealerships. There are subscription services for independents to be able to get repair information by phone. Some manufacturers also have a phone modem system that can transmit computer information from the car to another location. The vehicle's diagnostic link is connected to the modem. The technician in the service bay runs a test sequence on the vehicle. The system downloads the latest updated repair information on that particular model of car. If that does not repair the problem, a technical specialist at the manufacturer's location will review the data and propose a repair.

iATN

The International Automotive Technician's Network (iATN) is comprised of a group of thousands of professional automotive technicians from around the world. The technicians in this group exchange technical knowledge and information with other members. The Web address for this group is www.iatn.net.

The Internet

The Internet has had a major impact on automotive repair. Both do-it-yourselfers (DIY'ers) and professional technicians have access to a seemingly endless supply of information. This can be good and bad. With the ability to find diagnostic and repair information online, many consumers take on repairing their cars and trucks on their own. When using the Internet to help solve a problem or make a repair, you will need to learn how to determine what is good information and what is not. This judgment call often comes down to experience and understanding what you are working on.

KEY TERMS

Bolt diameter
Bolt head
Bolt shank
Dial caliper
Dial indicator
Die
Feeler gauge
Fillet
Foot pads
Grade marks
Press fit
Tap
Telescoping gauge
Thread pitch
Torque wrench

SUMMARY

- Repairing the modern automobile requires the use of many different hand and power tools. Units of measurement play a major role in tool selection. Therefore, it is important to be knowledgeable about the US and the metric systems of measurement.
- Measuring tools must be able to measure objects to a high degree of precision. They should be handled with care at all times and cleaned before and after every use.
- A micrometer can be used to measure the outside diameter of shafts and the inside diameter of holes. It is calibrated in either inch or metric graduations.
- Telescoping gauges are designed to measure bore diameters and other clearances. They usually are used with an outside micrometer. Small hole gauges are used in the same manner as the telescoping gauge, usually to determine valve guide diameter.
- The screw pitch gauge provides a fast and accurate method of measuring the threads per inch (pitch) of fasteners. This is done by matching the teeth of the gauge with the fastener threads and reading the pitch directly from the leaf of the gauge.
- It is crucial to use the proper amount of torque when tightening nuts or cap screws on any part

of a vehicle, particularly the engine. A torque-indicating wrench makes it possible to duplicate the conditions of tightness and stress recommended by the manufacturer.

- Metric and US size wrenches are not interchangeable. An auto technician should have a variety of both types.
- A screwdriver, no matter what type, should never be used as a chisel, punch, or pry bar.
- The hand tap is used for hand cutting internal threads and for cleaning and restoring previously cut threads. Hand-threading dies cut external threads and fit into holders called die stocks.
- Carelessness or mishandling of power tools can cause serious injury. Safety measures are needed when working with such tools as impact and air ratchet wrenches, blowguns, bench grinders, lifts, hoists, and hydraulic presses.
- Today the primary source of repair and specification information for any vehicle is the manufacturer's service manual, available through the Internet. Service bulletins include changes made during the model year.

REVIEW QUESTIONS

Short Answer

1. Explain how to properly use and care for a micrometer.
2. List some common uses of the dial indicator.
3. Wrenches are available in several styles. List and describe three types of wrenches.
4. How do manufacturers inform technicians about changes in vehicle specifications and repair procedures during the model year?
5. List the steps that should be followed to precisely tighten a bolt to specifications.
6. Describe three sources of service information available to technicians.

Multiple Choice

1. Technician A says a metric bolt with the marking of 8.9 has more yield strength than a 10.9 bolt. Technician B says only grade 8 nuts should be used on 10.9 rated bolt. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. Which of the following wrenches is the best choice for torquing a bolt?
   a. Open-end
   b. Box-end
   c. Combination
   d. None of the above
3. Technician A says that a micrometer can be used to measure the outside diameter of something. Technician B says that a vernier caliper can be used to measure the diameter of a bore. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. Technician A says that a tap cuts external threads. Technician B says that a die cuts internal threads. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Which of the following screwdrivers is like a Phillips but has a flatter and blunter tip?
   a. Standard
   b. Torx®
   c. Pozidriv®
   d. Clutch head
6. Technician A says most US bolts have a thread pitch between 1.0 and 2.0 threads per millimeter. Technician B says 1.0 thread pitch is a finer thread than a 2.0 thread pitch. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. Technician A uses a punch to align holes in parts during assembly. Technician B uses a chisel to drive out rivets. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. An extractor is used for removing broken ___.
   a. seals
   b. bushings
   c. pistons
   d. bolts

9. Which of the following statements about items that are press fit is *not* true?
   a. Many precision gears and bearings have a slight interference fit when installed on a shaft or housing.
   b. The press fit allows slight motion between the parts and therefore prevents wear.
   c. The removal of gears and bearings that are press fit must be done carefully to avoid breaking or binding the parts.
   d. A puller with the proper jaws and adapters should be used when applying force to remove press-fit gears and bearings.
10. Technician A uses a blowgun to blow off parts during cleaning. Technician B uses a blowgun to clean off his uniform after working. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
11. Technician A says that flare nut or line wrenches should be used to loosen or tighten brake line or tubing fittings. Technician B says that open-end wrenches will surround the fitting's nut and provide a positive grip on the fitting. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
12. Technician A uses a dial indicator to take inside and outside measurements. Technician B uses a dial caliper to take inside, outside, and depth measurements. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
13. For a measurement that must be made within one ten-thousandth of an inch, Technician A uses a machinist's rule. For the same accuracy, Technician B uses a standard micrometer. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
14. Technician A says that jack stands should always be used with portable floor jacks. Technician B says lifting capacity and operation should be checked before using a floor jack. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
15. When using an air impact wrench, Technician A uses impact sockets and adapters. Technician B uses chrome-plated sockets. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
16. While discussing thread sealants and lubricants: Technician A says that antiseize compound is used where a bolt might become difficult to remove after a period of time. Technician B says that thread sealants are used on bolts that are tightened into an oil cavity or coolant passage. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
17. The metric equivalent to 10 miles is ___.
    a. 0.06895 bar
    b. 10.6895 bars
    c. 1.6093 kilometers
    d. 16.093 kilometers
18. Which of the following thread designs typically has tapered threads to provide for sealing at a joint?
    a. UNC
    b. NPT
    c. UNF
    d. UNEF
19. Which of the following is *not* measured with a feeler gauge set?
    a. Piston ring side clearance
    b. Flywheel runout
    c. Crankshaft end play
    d. Spark plug gap

CHAPTER 6

DIAGNOSTIC EQUIPMENT AND SPECIAL TOOLS

OBJECTIVES

- Describe the various diagnostic and service tools used to check and repair an engine and its related systems.
- Describe the various diagnostic tools and service tools used to check and repair electrical and electronic systems.
- Describe the various diagnostic and service tools used to check and repair engine performance systems.
- Describe the various diagnostic and service tools used to check and repair hybrid vehicles.
- Describe the various diagnostic and service tools used to check and repair a vehicle's drivetrain.
- Describe the various diagnostic and service tools used to check and repair a vehicle's running gear.
- Describe the various diagnostic and service tools used to check and repair a vehicle's heating and air-conditioning system.

Diagnosing and servicing the various systems of an automobile require many different tools. Tools that are used to check the performance of a system or component are commonly referred to as diagnostic tools. Tools designed for a particular purpose or system are referred to as special tools. This chapter looks at the common diagnostic and special tools required for the different systems of a vehicle.

Engine Repair Tools

Engine repair **(Figure 6–1)** service and diagnostic tools are discussed in this chapter. This discussion does not cover all of the required tools; only the most common are discussed. More details on these tools are presented in Section 2 of this book.

Compression Testers

The operation of an engine depends on the compression of the air-fuel mixture within its cylinders. If the combustion chamber leaks, some of the mixture will escape while it is being compressed, resulting in a loss of power and a waste of fuel.

A compression gauge is used to check cylinder compression. The dial face on the gauge indicates pressure in both pounds per square inch (psi) and metric kilopascals (kPa). The range is usually 0 to 300 psi and 0 to 2,100 kPa. There are two basic types of compression gauges: the push-in gauge and the screw-in gauge.

The push-in type has a short stem that is either straight or bent at a 45-degree angle. The stem ends

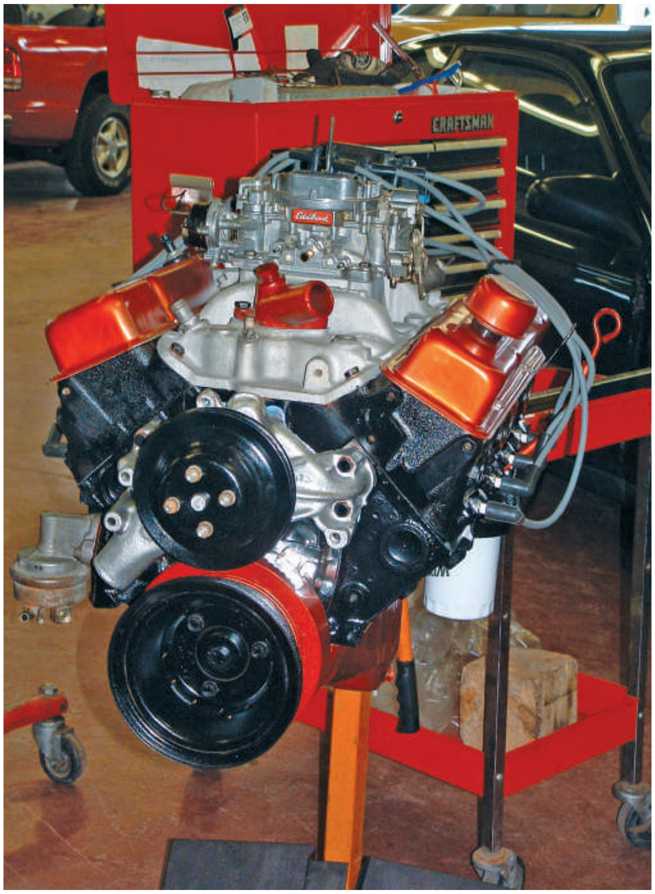


FIGURE 6–1 Proper engine rebuilding requires many different tools.

FIGURE 6–2 A screw-in compression gauge set.

with a tapered rubber tip that fits any size spark plug hole. After the spark plugs are removed, the tip is placed in the spark plug hole and held there while the engine is cranked through several compression cycles. Although simple to use, the push-in gauge will give inaccurate readings if it is not held tightly in the hole.

The screw-in gauge has a long, flexible hose that ends in a threaded adapter **(Figure 6–2)**. This type of compression tester is often used because its flexible hose can reach into areas that are difficult to reach with a push-in-type tester. The threaded adapters are changeable and come in several thread sizes to fit 10 mm, 12 mm, 14 mm, and 18 mm diameter holes. The adapters screw into the spark plug holes.

Most compression gauges have a vent valve that holds the highest pressure reading on its meter. Opening the valve releases the pressure when the test is complete.

Many technicians are using pressure transducers instead of mechanical compression testers. The transducer connects to a compression tester hose and plugs into a scope. Using a pressure transducer provides much greater detail about what is happening in the cylinder than a standard compression gauge.

Cylinder Leakage Tester

If a compression test shows that any of the cylinders may be leaking, a cylinder leakage test can be used to measure the amount of compression loss and to help locate the source of leakage.

A cylinder leakage tester **(Figure 6–3)** applies compressed air through the spark plug hole and into a cylinder, with the piston at the top of its bore. At the end of the pressure hose is the threaded adapter, which is screwed into the spark plug hole. A pressure regulator in the tester controls the pressure applied to the cylinder. A gauge registers the percentage of air pressure lost from the cylinder when the compressed air is applied. The scale on the dial face reads 0 percent to 100 percent.

A zero reading means there is no leakage in the cylinder. A reading of 100 percent indicates that the cylinder will hold zero pressure. The location of the compression leak can be found by listening and feeling around various parts of the engine.

FIGURE 6–3 A cylinder leakage tester.

FIGURE 6–4 A stethoscope.

FIGURE 6–5 An "electronic ear" kit.

Oil Pressure Gauge

Checking the engine's oil pressure gives information about the condition of the oil pump, the pressure regulator, and the entire lubrication system. Lower-than-normal oil pressures can be caused by excessive engine bearing clearances. Oil pressure is checked at the sending unit passage with an externally mounted mechanical oil pressure gauge. Various fittings are usually supplied with the oil pressure gauge to fit different openings in the lubrication system.

Stethoscope

A stethoscope is used to locate the source of engine and other noises. The stethoscope pickup is placed on the suspected component, and the stethoscope's receptacles are placed in the technician's ears **(Figure 6–4)**. Some sounds can be heard without using a listening device, but others are impossible to hear unless amplified, which is what a stethoscope does. It can also help you distinguish between normal and abnormal noise.

Electronic Stethoscope While trying to locate the source of a noise, the best results are obtained with an electronic listening device **(Figure 6–5)**. With this tool you can tune into the noise, which allows you to eliminate all other noises that might distract or mislead you. Also, many electronic stethoscopes can record the sounds they amplify. The recordings can be played back on the stethoscope or audio equipment. Electronic stethoscopes digitize the sound waves. Once the sound waves are digitized, they can be amplified and carefully listened to.

Engine Removal and Installation Equipment

The engine in most RWD vehicles is removed through the engine compartment by lifting it out with a crane. Likewise, the engines of some FWD vehicles are removed in the same way. Other engines in FWD vehicles must be removed from the bottom and this requires special equipment that varies with manufacturer and vehicle model.

To remove the engine from under the vehicle, the vehicle is raised. A crane and/or support fixture is used to hold the engine and transaxle assembly in place while the engine is being readied for removal. Then the engine is lowered onto an engine cradle. The cradle is similar to a floor jack and lowers the engine further so it can be rolled out from under the vehicle.

Often a transverse-mounted engine is removed with the transaxle. The transaxle is separated from the engine after it has been removed.

Ridge Reamer

After many miles of use, a ridge forms at the top of the engine's cylinders. This ridge of unworn metal is present because the top piston ring stops traveling before it reaches the top of the cylinder. And, as the piston moves up and down in the bore, wear occurs on the cylinder walls. This ridge must be removed in order to push the pistons out of the block without damaging them during engine rebuilding. The ridge is removed with a ridge reamer **(Figure 6–6)**. The tool is adjusted for the size of the bore, inserted into it, and rotated with a wrench until the ridge is removed.

Ring Compressor

A ring compressor is used to install a piston into a cylinder bore. The compressor wraps around the piston rings to make their outside diameter smaller than the inside diameter of the bore. With the compressor tool adjusted properly, the piston assembly can be easily pushed into the bore without damaging the bore or piston.

There are three basic types of ring compressors. One style has an adjustable band with a ratchet mechanism to tighten it around the piston. Another style uses ratcheting pliers to tighten a steel band around the piston **(Figure 6–7)**. The bands are available in a variety of sizes. The third type has a single band that is wrinkled. The band is tightened by moving a lever. Once the rings are totally compressed into the piston, a thumbscrew is tightened to hold the band in position.

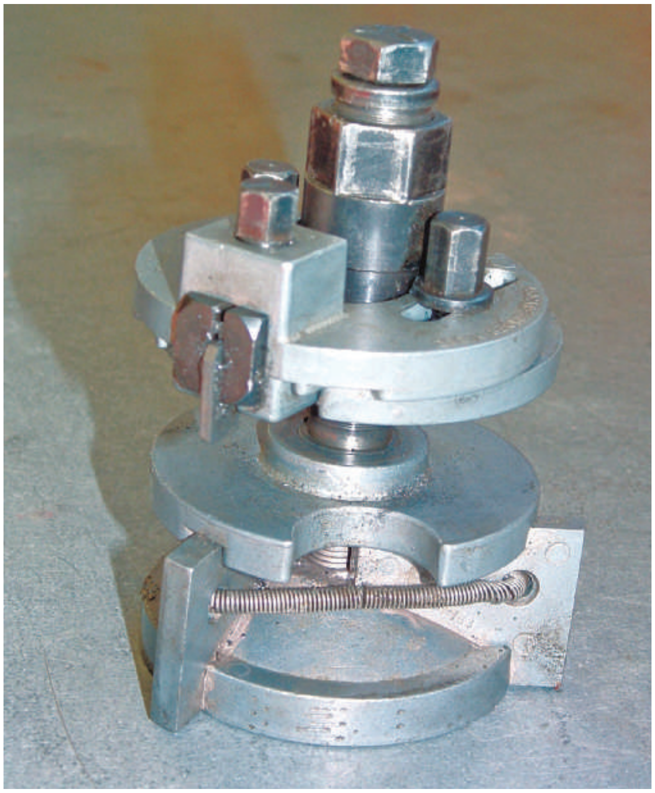


FIGURE 6–6 A ridge reamer.

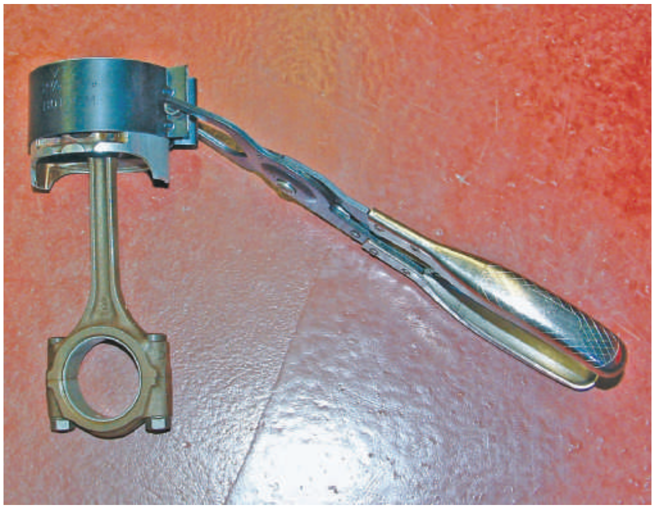


FIGURE 6–7 A piston ring compressor with a steel band and ratcheting pliers.

Ring Expander

To prevent damage to the piston rings during removal and installation, a ring expander should be used. While installing a piston ring, the ring must be made large enough to fit over the piston. To do this, the rings are placed into the jaws of the expander and the handle of the tool is squeezed to expand the ring **(Figure 6–8)**. The rings should only be expanded enough to fit over the piston. The tool helps to prevent damage to the rings and cut fingers caused by the edges of the rings.

FIGURE 6–8 A piston ring expander.

Ring Groove Cleaner

Before installing piston rings onto a piston, the ring grooves should be cleaned. The carbon and other debris that may be built up in the back of the groove will not allow the rings to compress evenly and completely into the grooves. Piston ring grooves are best cleaned with a ring groove cleaner. This tool is adjustable to fit the width and depth of the groove. Make sure it is properly adjusted before using it.

Dial Bore Indicator

Cylinder bore taper and out-of-roundness can be measured with a micrometer and a telescoping gauge. However, most shops use a **dial bore gauge**. This gauge consists of a handle, guide blocks, a lock, an indicator contact, and an indicator. They also come with extensions to make them adaptable to various size bores. As the gauge is moved inside the bore, the indicator will show any change in the bore's diameter.

Cylinder Hone and Deglazer

The proper surface finish on a cylinder wall is important as it acts as a reservoir for oil to lubricate the piston rings and prevent piston and ring scuffing. On many late-model engines, cylinder sleeves or inserts provide this finish, and when they are damaged or worn, the sleeves are replaced. However, on other engines, the cylinder walls can be refurbished. When the walls have minor problems, the bore can be honed. Honing sands the walls to remove imperfections. A cylinder hone usually consists of two or three stones. The hone rotates at a selected speed and is moved up and down the cylinder's bore. Honing oil flows over the stones and onto the cylinder wall to control the temperature and flush out any metallic and abrasive residue. The correct stones should be used to ensure that the finished walls have the correct surface finish. Honing stones are classified by grit size; typically, the lower the grit number, the coarser the stone.

Cylinder honing machines can be manual or automatic models. The advantage of the automatic type is that it allows for the selection of the desired surface on the walls.

If the cylinder walls have surface conditions, taper, and out-of-roundness that are within acceptable limits, the walls only need to be deglazed. Combustion heat, engine oil, and piston movement combine to form a thin residue on the cylinder walls that is commonly called glaze.

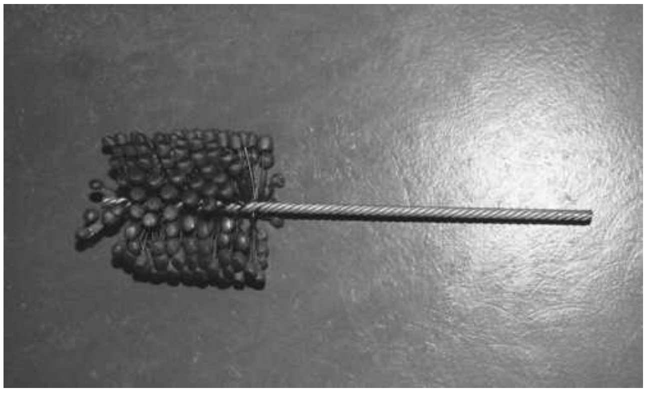


FIGURE 6–9 A cylinder deglazer.

Most cylinder deglazers or glaze breakers use an abrasive with about 220 or 280 grit. The glaze breaker is installed in a slow-moving electric drill or in a honing machine. Many deglazers use round stones that extend on coiled wire from the center shaft **(Figure 6–9)**. This type of deglazer may also be used to lightly hone the bore. Various sizes of resilient-based hone-type brushes are available for honing and deglazing.

When cylinder surfaces are badly worn or excessively scored or tapered, a boring bar is used to cut the cylinders for oversize pistons or sleeves. A boring bar leaves a pattern similar to uneven screw threads. Therefore, the bore should be honed to the correct finish after it has been bored.

Cam Bearing Driver Set

The camshaft is supported by several friction-type bearings, or bushings. They may be designed as a one piece unit, which is pressed into the camshaft bore in the cylinder head or block. The bearings are press fit into the block or head using a bushing driver and hammer. Many overhead camshaft (OHC) engines use split bearings to support the camshaft. Camshaft bearings are normally replaced during engine rebuilding.

V-Blocks

The various shafts in an engine must be straight. Visually it is impossible to see any distortions unless the shaft is severely damaged. Warped or distorted shafts will cause many problems, including premature wear of the bearings they ride on. The best way to check a shaft is to place the ends of the shaft onto V-blocks. These blocks support the shaft and allow you to rotate the shaft. To check for straightness, place the plunger of a dial indicator on the shaft's

journals and rotate the shaft. Any movement of the indicator's needle suggests a problem.

Valve and Valve Seat Resurfacing Equipment

The most critical sealing surface in the valvetrain is between the face of the valve and its seat in the cylinder head. Leakage between these surfaces reduces the engine's compression and power, and can lead to valve burning. To ensure proper seating of the valve, the seat area on the valve face and seat must be the correct width, at the correct location, and concentric with the guide. These conditions are accomplished by renewing the surface of the valve face **(Figure 6–10)** and seat.

Valve and valve seat grinding or refacing is done by using a grinding stone or metal cutters to achieve a fresh, smooth surface on the valve faces and stem tips. Valve faces suffer from burning, pitting, and wear caused by opening and closing millions of times during the life of an engine. Valve stem tips wear because of friction from the rocker arms or actuators.

Valve Guide Repair Tools

The amount of valve guide wear can be measured with a ball gauge and micrometer. If wear or taper is excessive, the guide must be machined or replaced. If the original guide can be removed and a new one inserted, press out the old guide with a properly sized driver. Then install a new guide with a press and the same driver.

Some technicians knurl the old guide to restore the inside diameter dimension (ID) of a worn valve guide. Knurling raises the surface on the inside of the guide by plowing tiny furrows through the surface. This effectively decreases the ID of the guide. A burnisher is used to flatten the ridges and produce a proper-sized hole to restore the correct guide-to-stem clearance.

Reaming is often done to increase a guide's ID to accept an oversized valve stem or a guide insert. Some valve guide liners or inserts are not precut to length and the excess must be milled off before finishing.

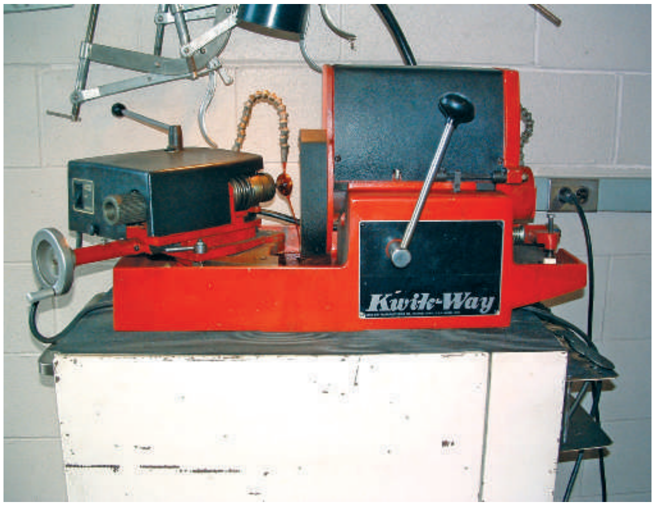


FIGURE 6–10 A valve grinding machine.

Valve Spring Compressor

To remove the valves from a cylinder head, the valve spring assemblies must be removed. To do this, the valve spring must be compressed enough to remove the valve keepers, then the retainer. There are many types of valve spring compressors. Some are designed to allow valve spring removal while the cylinder head is still on the engine block. Other designs are only used when the cylinder head is removed.

The pry bar-type compressor is used while the cylinder head is still mounted to the block. With the cylinder's piston at TDC, shop air is fed into the cylinder to hold the valve up and prevent it falling into the cylinder.

Some OHC engines require the use of a special spring compressor **(Figure 6–11)**. Often these tools can be used when the cylinder head is attached to the block or when it is on a bench. It bolts to the cylinder head and has a threaded plunger that fits onto the retainer. As the plunger is tightened down on the retainer, the spring compresses.

C-clamp-type spring compressors can only be used on cylinder heads after they have been removed **(Figure 6–12)**. These are normally equipped with

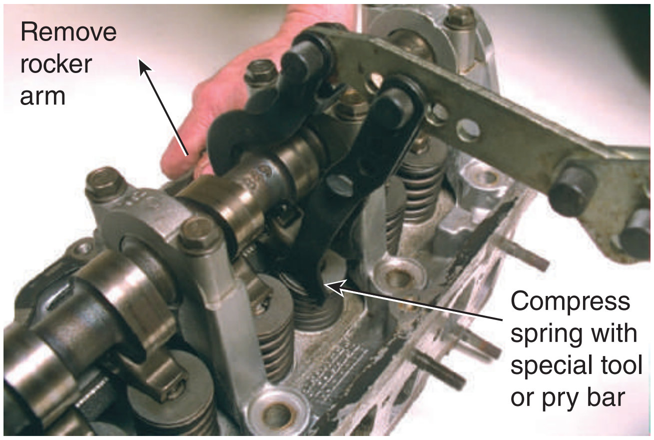


FIGURE 6–11 A typical spring compressor for OHC valves.

FIGURE 6–12 A C-clamp valve spring compressor.

interchangeable jaws and can be pneumatically or manually operated. One end of the clamp is positioned on the valve head and the other on the valve's retainer. After the compressor is adjusted, it will squeeze down on the spring. Once the spring is compressed, the valve keepers can be removed. Then the tension of the compressor is slowly released and the valve retainer and spring can be removed.

Valve Spring Tester

Before valve springs are reused, they should be checked to make sure they are within specifications. This includes their freestanding height and squareness. If those two dimensions are good, the spring should be checked with a valve spring tester. A valve spring tester checks the spring's open and close pressure. Correct close pressure guarantees a tight seal. The open pressure closes the valve when it should close. The tester's gauge reflects the pressure of the spring when it is compressed to the installed or valve-closed height. Read the pressure on the tester and compare this reading to specifications. Any pressure outside the pressure range given in the specifications indicates the spring should be replaced.

Torque Angle Gauge

Most manufacturers recommend the torque-angle method for tightening cylinder head bolts, which requires the use of a torque angle gauge. Typically two steps are involved: Tighten the bolt to the specified torque, and then tighten the bolt an additional amount. The latter is expressed in degrees. To

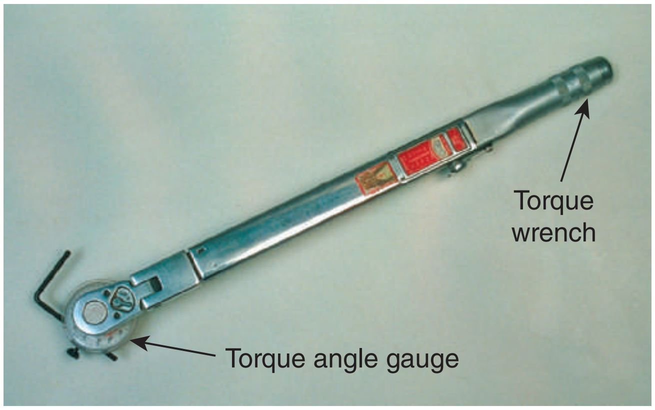


FIGURE 6–13 A torque angle gauge attached to the drive lug of a torque wrench.

accurately measure the number of degrees added to the bolt, a torque angle gauge **(Figure 6–13)** is attached to the wrench. The additional tightening will stretch the bolt and produce a very reliable clamp load that is much higher than can be achieved just by torquing.

Oil Priming Tool

Prior to starting a freshly rebuilt engine, the oil pump must be primed. There are several ways to prelubricate, or prime, an engine. One method is to drive the oil pump with an electric drill. This entails running the oil pump for several minutes and checking to see if there is oil flow to the rocker arms. If oil reaches the cylinder head, the engine's lubrication system is full of oil and is operating properly. If no oil reaches the cylinder head, there is a problem either with the pump, with the alignment of an oil hole in a bearing, or perhaps with a plugged gallery.

Using a prelubricator **(Figure 6–14)**, which is an oil reservoir attached to a continuous air supply, is the best method of prelubricating an engine. When the

FIGURE 6–14 An engine prelubricator kit.

FIGURE 6–15 Cooling system pressure tester.

reservoir is attached to the engine and the air pressure is turned on, the prelubricator will supply the engine's lubrication system with oil under pressure.

Cooling System Pressure Tester

A cooling system pressure tester **(Figure 6–15)** contains a hand pump and a pressure gauge. A hose is connected from the hand pump to an adapter that fits on the radiator filler neck. This tester is used to pressurize the cooling system and check for coolant leaks. Additional adapters are available to connect the tester to the radiator cap. This test checks the pressure relief action of the cap.

Coolant Hydrometer

A coolant **hydrometer** is used to check the amount of antifreeze in the coolant. This tester contains a pickup hose, a coolant reservoir, and a squeeze bulb. The pickup hose is placed in the coolant inside the radiator. When the squeeze bulb is squeezed and released, coolant is drawn into the reservoir. As coolant enters the reservoir, a float moves upward with the coolant level. A pointer on the float indicates the freezing point of the coolant on a scale located on the reservoir housing.

Refractory Testers For many shops, the preferred way to check coolant is with a refractometer **(Figure 6–16)**. This tester works on the principle that light bends as it passes through a liquid. A sample of the coolant is placed in the tester. As light passes through the sample of coolant, it bends and shines on a scale in the tester. A reading is taken at the point on the scale where there is a separation of light and dark. Most refractory coolant testers can also check the electrolyte in a battery.

FIGURE 6–16 A refractometer checks the condition of the engine's coolant.

Measuring pH Acids produced by bacteria and other contaminants can reduce the effectiveness of coolant. Some shops measure the pH of coolant to determine deterioration of the coolant. The pH is measured by placing test strips or a digital pH tester into the coolant.

Coolant Recovery and Recycle System

A coolant recovery and recycle machine **(Figure 6–17)** can drain, recycle, fill, flush, and pressure test a cooling system. Usually additives are mixed into the

FIGURE 6–17 A coolant recycling machine that drains, back flushes, and fills the cooling system.

used coolant during recycling. These additives either bind to contaminants in the coolant so they can be easily removed, or they restore some of the chemical properties in the coolant.

Electrical/Electronic System Tools

Electrical system service and diagnostic tools are discussed in the following paragraphs. This discussion does not cover all of the tools you may need; rather, these tools are the most commonly used by the service industry. Many automotive systems are electrically controlled and operated; therefore, these tools are also used in those systems. Details of when and how to use these tools are presented in Section 3, as well as in the sections that discuss various other automotive systems.

Computer Memory Saver

Memory savers are an external power source used to maintain the memory circuits in electronic accessories and the engine, transmission, and body computers when the vehicle's battery is disconnected. The saver is plugged into the vehicle's cigarette lighter outlet. It can be powered by a 9- or 12-volt battery **(Figure 6–18)**.

Some have the following features:

- The capability to connect to a vehicle's cigarette lighter receptacle, standard 120 VAC power outlet, or the OBDII port
- Use with 9 volt battery (not included)
- Maintains memory of the on-board vehicle computer when the power source is disconnected
- LEDs indicate state of internal battery charge
- LEDs confirm circuit between the cigarette lighter and the vehicle's battery with the ignition on or off
- Can scan engine codes while also acting as a memory saver, which stores the vehicle data for review and analysis

Circuit Tester

Circuit testers **(Figure 6–19)** are used to check for voltage in an electrical circuit. A circuit tester, commonly called a **testlight**, looks like a stubby ice pick. Its handle is transparent and contains a light bulb. A probe extends from one end of the handle and a ground clip and wire from the other end. When the ground clip is attached to a good ground and the probe touched to a live connector, the bulb in the handle will light up. If the bulb does not light, voltage is not available at the connector.

Warning! Never use a 12-volt testlight to diagnose components and wires in computer systems. The current draw of testlights may damage the computer-system components. High-impedance testlights are available for diagnosing computer systems.

FIGURE 6–18 A memory saver assembly.

FIGURE 6–19 Typical circuit tester, commonly called a testlight.

A self-powered testlight is called a continuity tester. It is used on open circuits. It looks like a regular testlight but has a small internal battery. When the ground clip is attached to one end of the wire or circuit and the probe touched to the other end, the lamp will light if there is continuity in the circuit. If an open circuit exists, the light will not illuminate.

Warning! Do not use any type of testlight or circuit tester to diagnose automotive air bag systems. Use only the manufacturer's recommended equipment on these systems.

Multimeters

A **multimeter** is a must for diagnosing the individual components of an electrical system. Multimeters have different names, depending on what they measure and how they function. A volt-ohm-milliamp meter is referred to as a VOM or DVOM, if it is digital. A **digital multimeter (DMM)** can measure many more things than volts, ohms, and low current.

Most multimeters **(Figure 6–20)** measure direct current (DC) and alternating current (AC) amperes, volts, and ohms. More advanced multimeters may also measure diode continuity, frequency, temperature, engine speed, and dwell, and/or duty cycle.

FIGURE 6–20 Typical multifunctional, low-impedance multimeter.

Multimeters are available with either digital or analog displays. DMMs provide great accuracy by measuring in tenths, hundredths, or thousandths of a unit. Several test ranges are usually provided for each of these functions. Some meters have multiple test ranges that must be manually selected; others are autoranging.

Analog meters use a sweeping needle against a scale to display readings and are not as precise as digital meters. Analog meters have low input impedance and should not be used on sensitive electronic circuits or components. Digital meters have high impedance and can be used on electronic circuits as well as electrical circuits.

Voltmeter A **voltmeter** measures the voltage available at any point in an electrical system. A voltmeter can also be used to check the voltage drop across an electrical circuit, component, switch, or connector. A voltmeter can be used to check for proper circuit grounding as well.

A voltmeter relies on two leads: a red positive lead and a black negative lead. The red lead should be connected to the positive side of the circuit or component. The black lead should be connected to ground or to the negative side of the component. Voltmeters should be connected across, meaning in parallel, with the circuit or component being tested.

Ohmmeter

An **ohmmeter** measures the resistance in a circuit. In contrast to the voltmeter, which operates by the voltage available in the circuit, an ohmmeter is battery powered. The circuit being tested must have no power applied. If the power is on in the circuit, the reading will not be correct and the ohmmeter may be damaged.

The two leads of the ohmmeter are placed across or in parallel with the circuit or component being tested. The red lead is placed on the positive side and the black lead is placed on the negative side of the circuit. The meter sends current through the component and determines the amount of resistance based on the voltage dropped across the load. The scale of an ohmmeter reads from 0 to infinity (∞). A zero reading means there is no resistance in the circuit and may indicate a short in a component that should show a specific resistance. An infinity reading indicates a number higher than the meter can measure, which usually indicates an open circuit.

Ammeter

An **ammeter** measures current flow in a circuit. Current is measured in amperes. Unlike the voltmeter and ohmmeter, the ammeter must be placed into the circuit or in series with the circuit being tested. Normally, this requires disconnecting a wire or connector from a component and connecting the ammeter between the wire or connector and the component. The red lead of the ammeter should always be connected to the side of the connector closest to the positive side of the battery and the black lead should be connected to the other side.

It is much easier to test current using an ammeter with an inductive pickup **(Figure 6–21)**. The pickup clamps around the wire or cable being tested. The ammeter determines amperage based on the magnetic field created by the current flowing through the wire. This type of pickup eliminates the need to separate the circuit to insert the meter.

Volt/Ampere Tester

A volt/ampere tester **(VAT)** is used to test batteries, starting systems, and charging systems **(Figure 6–22)**. The tester contains a voltmeter, ammeter, and carbon pile. The carbon pile is a variable resistor. When the tester is attached to the battery and turned on, the carbon pile draws current out of the battery. The ammeter will read the amount of current draw. The maximum current draw from the battery, with acceptable voltage, is compared to the rating of the battery to see if the battery is okay. A VAT also measures the current draw of the starter and current output from the charging system.

Courtesy of SPX Service Solutions.

FIGURE 6–21 An ammeter with an inductive pickup is called a current probe.

FIGURE 6–22 The volt/ampere tester checks batteries and the starting and charging systems.

Battery Capacitance Tester

Many manufacturers recommend that a capacitance or conductance test be performed on batteries **(Figure 6–23)**. Conductance describes a battery's ability to conduct current. It is a measurement of the plate surface available in a battery for chemical reaction. Measuring conductance provides a reliable indication of a battery's condition and is correlated to battery capacity. Conductance can be used to detect cell defects, shorts, normal aging, and open circuits, which can cause the battery to fail.

FIGURE 6–23 A battery capacitance tester.

To measure conductance, the tester creates a small signal that is sent through the battery, and then measures a portion of the AC current response. The tester displays the service condition of the battery. The tester will indicate that the battery is good, needs to be recharged and tested again, has failed, or will fail shortly.

Lab Scopes

An oscilloscope or lab scope is a visual voltmeter **(Figure 6–24).** A lab scope converts electrical signals to a visual image representing voltage changes over a period of time. This information is displayed in the form of a continuous voltage line called a **waveform** or **trace**. A scope displays any change in voltage as it occurs.

An upward movement of the trace on an oscilloscope indicates an increase in voltage, and a downward movement represents a decrease in voltage. As the voltage trace moves across an oscilloscope screen, it represents a specific length of time.

The size and clarity of the displayed waveform is dependent on the voltage scale and the time reference selected. Most scopes are equipped with controls that allow voltage and time interval selection.

Dual-trace scopes can display two different waveform patterns at the same time. This type of scope is especially important for diagnosing intermittent problems.

Most new lab scopes can display more than two waveforms and are either hand-held or PC-based units. Some scopes have an electronic library of known good signals, which allow technicians to compare what they see with what they should be seeing. Some also include wiring diagrams and additional diagnostic and testing information.

FIGURE 6–24 Many shops use PC-based lab scopes.

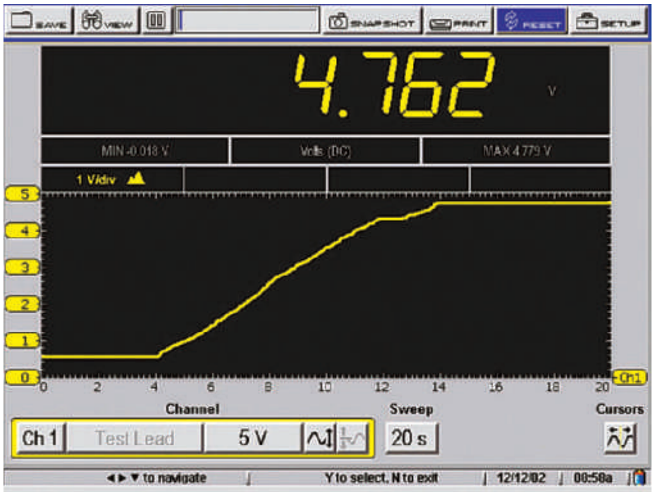


FIGURE 6–25 The screen of a graphing multimeter.

Graphing Multimeter

A graphing digital multimeter displays readings over time, similar to a lab scope. The graph shows the minimum and maximum readings on a graph, as well as displaying the current reading **(Figure 6–25)**. By observing the graph, a technician can detect any undesirable changes during the transition from a low reading to a high reading, or vice versa. These glitches are some of the more difficult problems to identify without a graphing meter or a lab scope.

Wire and Terminal Repair Tools

Many automotive electrical problems can be traced to faulty wiring. Loose or corroded terminals; frayed, broken, or oil-soaked wires; and faulty insulation are the most common causes.

Wires and connectors are often repaired or replaced. Sometimes an entire length of wire is replaced; other times only a section is. In either case, the wire must have the correct terminal or connector to work properly in the circuit. Wire cutters, stripping tools, terminal crimpers, and connector picks are the most commonly used tools for wire repair. Also, soldering equipment is used to provide the best electrical connection for a wire to another wire and for a wire to a connector.

Connector picks are designed to reach into electrical connectors and release the locking tabs on the terminals. Doing this allows the terminal and the attaching wire to be removed from the terminal.

Headlight Aimers

Headlights must be kept in adjustment to obtain maximum illumination. Properly adjusted headlights

will cover the correct range and afford the driver a proper nighttime view. Headlights can be adjusted using headlamp-adjusting tools or by shining the lights on a chart. Headlight-aiming tools give the best results with the least amount of work. Many late-model vehicles have levels built into the headlamp assemblies that are used to correctly adjust the headlights. When using any headlight-aiming equipment, follow the instructions provided by the equipment manufacturer.

Engine Performance Tools

Diagnostic and special tools for the air, fuel, ignition, emission, and engine-control systems are discussed in the following paragraphs. This discussion does not cover all of the tools you may need; rather, these tools are the most commonly used by the industry. Some are also used when diagnosing or servicing the controls of other automotive systems. Details of when and how to use these tools are covered in Section 4, as well as in other sections where necessary.

Scan Tools

A **scan tool (Figure 6–26)** is a computer designed to communicate with the vehicle's computers. Connected to the electronic control system through diagnostic connectors, a scan tool can access diagnostic trouble codes (DTCs), run tests to check system operations, and monitor the activity of the system. Trouble codes and test results are displayed on a screen or printed out on the scan tool's printer. While one use of a scan tool is for diagnosing engine performance concerns, they are also used to access body electrical, antilock brake, steering and suspension, and other on-board computer systems.

FIGURE 6–26 A Snap-On Solus Edge scan tool.

The scan tool is connected to specific diagnostic connectors on the vehicle. Some manufacturers have one diagnostic connector. This connects the data wire from each computer to a specific terminal in this connector. Other manufacturers have several diagnostic connectors on each vehicle, and each of these connectors may be connected to one or more computers. The scan tool must be programmed for the model year, make of vehicle, and type of engine.

With OBD-II, the diagnostic connectors (commonly called data link connectors, or DLCs) are located in the same area on all vehicles. Most OBD-II scan tools have the ability to store, or "freeze," data during a road test **(Figure 6–27)** and then play back this data when the vehicle is returned to the shop.

There are many different scan tools available. Some are a combination of other diagnostic tools, such as a lab scope and graphing multimeter. These may have the following capabilities:

- Retrieve DTCs.
- Monitor system operational data.
- Reprogram the vehicle's electronic control modules.
- Perform systems diagnostic tests.
- Display appropriate service information, including electrical diagrams.
- Display TSBs and troubleshooting instructions.

Some scan tools work directly with a PC through uncabled communication links, such as Bluetooth or through a smart phone. These small hand-held units allow you to read DTCs, monitor the activity of sensors, and view inspection/maintenance system test results to quickly determine what service the vehicle requires. Most of these scan tools also have the ability to:

- Perform system and component tests.
- Report test results of monitored systems.
- Print DTC/freeze frame and display full diagnostic code descriptions.
- Observe live sensor data.
- View and print files on a PC.
- Generate emissions reports.
- View IM/Mode 6 information.
- Display relative TSBs.

FIGURE 6-27 Scan tools can record data during a test drive for playback later at the shop.

Fuel Pressure Gauge

A fuel pressure gauge is essential for diagnosing fuel injection systems **(Figure 6–28)**. These systems rely on fuel pressures, from 35 to 70 psi. A drop in fuel pressure reduces the amount of fuel delivered to the injectors and results in a lean air-fuel mixture.

A fuel pressure gauge is used to check the discharge pressure of fuel pumps, the regulated pressure of fuel injection systems, and injector pressure drop. These tests can identify faulty pumps, regulators, or injectors and identify restrictions in the fuel delivery system. Restrictions are typically caused by a dirty fuel filter, collapsed hoses, or damaged fuel lines.

Some fuel pressure gauges have a valve and outlet hose for testing fuel pump discharge volume. The specification for discharge volume is given as a number of pints or liters of fuel that should be delivered in a certain number of seconds.

Caution! While testing fuel pressure, be careful not to spill gasoline. Gasoline spills may cause explosions and fires, resulting in serious personal injury and property damage.

FIGURE 6-28 A fuel pressure gauge and adapters.

Pressure Transducer

A pressure transducer **(Figure 6–29)** measures pressure and changes it into an electrical signal so it can be displayed on a lab scope of graphing DMM. A pressure transducer can measure such things as: fuel pressure, oil pressure, exhaust pressure, intake pressure (vacuum), crankcase pressure, radiator pressures, and cylinder compression.

FIGURE 6–29 A pressure transducer.

A fuel pressure transducer connects to the Schrader valve on the fuel rail. The resultant trace on the lab scope shows the changes in fuel pressure at the fuel rail. If the pattern is uniform and consistent, a normal operating fuel system is noted.

Injector Balance Tester

The injector balance tester **(Figure 6–30)** tests the injectors in a port fuel injected engine. A fuel pressure gauge is used during the injector balance test. The injector balance tester contains a timing circuit, and some injector balance testers have an on-off switch. A pair of tester leads must be connected to the battery with the correct polarity. The injector terminals are disconnected, and the other leads on the tester are attached to the injector terminals.

The fuel pressure gauge is connected to the fuel rail, and the ignition switch is cycled two or three times until the specified fuel pressure is shown on the pressure gauge. When the tester's push button is depressed, the tester energizes the injector for a specific length of time, and the technician records the pressure decrease on the fuel pressure gauge. This procedure is repeated on each injector.

If the pressure drops little, or if there is no pressure drop, the injector's orifice is restricted or the injector is faulty. If there is an excessive amount of pressure drop, the injector plunger is sticking open, which results in a rich air-fuel mixture.

Warning! Electronic fuel injection systems are pressurized, and these systems require depressurizing prior to fuel pressure testing and other service procedures.

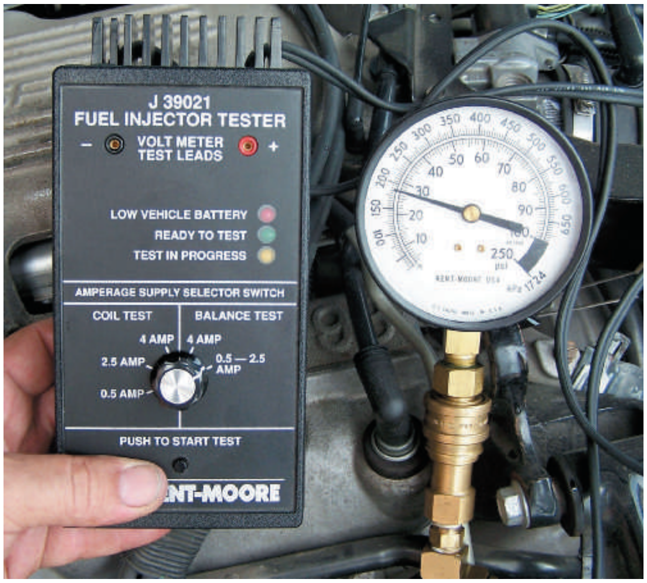


FIGURE 6–30 A fuel injection balance tester.

Injector Circuit Testlight

A special testlight, called a noid light, can be used to determine if a fuel injector is receiving its proper voltage pulse from the computer **(Figure 6–31)**. The wiring harness connector is disconnected at the injector and the noid light is plugged into the connector. After disabling the ignition, the engine is turned over by the starter. The noid light will flash rapidly if a voltage signal is present. No flash

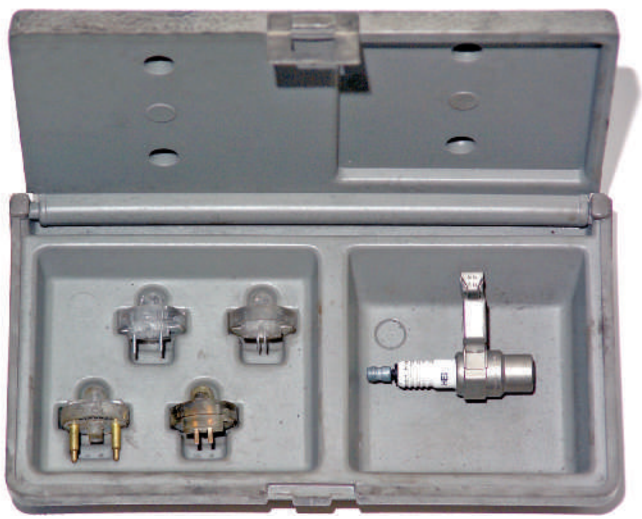


FIGURE 6–31 A set of noid lights and a test spark plug.

usually indicates an open in the power feed or ground circuit to the injector.

Fuel Injector Cleaners

Fuel injectors spray a certain amount of fuel into the intake system. If the fuel pressure is low, not enough fuel will be sprayed. Low pressure may also result if the fuel injector is dirty. Normally, clogged injectors are caused by the inconsistencies in gasoline detergent levels and the high sulfur content of gasoline. When fuel injectors become partially clogged, fuel flow is restricted. Spray patterns are altered, causing poor performance and reduced fuel economy.

A sulfated and/or plugged fuel injector should be cleaned. There are two kinds of fuel injector cleaners. One is a pressure tank. A mixture of solvent and unleaded gasoline is placed in the cleaner's tank. The vehicle's fuel pump is disabled and, on some vehicles, the fuel line must be blocked between the pressure regulator and the return line. Then, the hose on the pressure tank is connected to the service port in the fuel system. The inline valve is then partially opened and the engine is started. It should run at approximately 2,000 rpm for about 10 minutes to clean the injectors thoroughly.

An alternative to the pressure tank is a pressurized canister in which the solvent solution is premixed. Use of the canister-type cleaner is similar to the above procedure, but does not require mixing or pumping. The canister is connected to the injection system's servicing fitting, and the valve on the canister is opened. The engine is started and allowed to run until it dies. Then, the canister is discarded.

Fuel Line Tools

Many vehicles are equipped with quick-connect line couplers. These work well to seal the connection but are nearly impossible to disconnect if the correct tools are not used. There is a variety of quick-connect fittings and tools **(Figure 6–32)**.

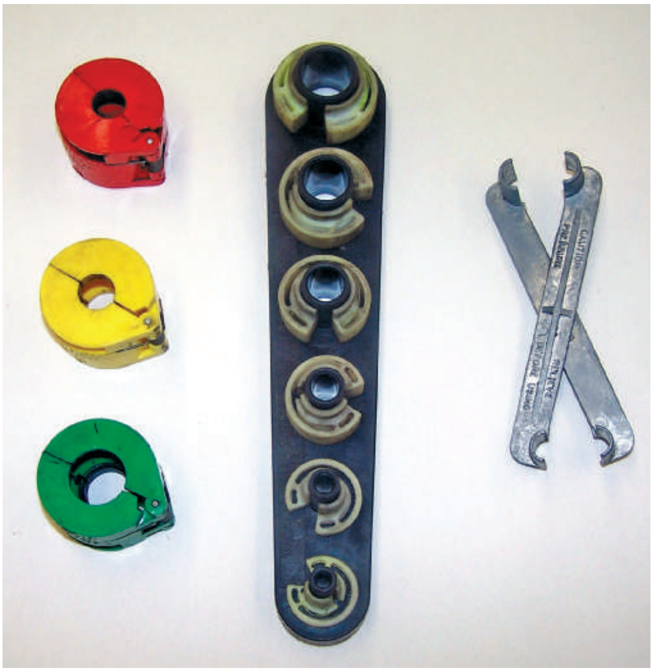


FIGURE 6-32 Various fuel line disconnect tools.

Pinch-Off Pliers

The need to temporarily close off a rubber hose is common during diagnostics and service. Special pliers are designed to do this without damaging the hose **(Figure 6–33)**. These pliers are much like vise-grip pliers in that they hold their position until they are released. The jaws of the pliers are flat and close in a parallel motion, which prevents damage to the hose.

FIGURE 6-33 Pinch-off pliers closing off a vacuum hose.

Vacuum Gauge

Measuring intake manifold vacuum can diagnose the condition of an engine. Manifold vacuum is tested with a vacuum gauge. **Vacuum** is formed on a piston's intake stroke. As the piston moves down, it lowers the pressure of the air in the cylinder—if the cylinder is sealed. This lower cylinder pressure is called engine vacuum. Vacuum is measured in inches of mercury (in. Hg) and in kilopascals (kPa).

To measure vacuum, a hose on the vacuum gauge **(Figure 6–34)** is connected to a source of

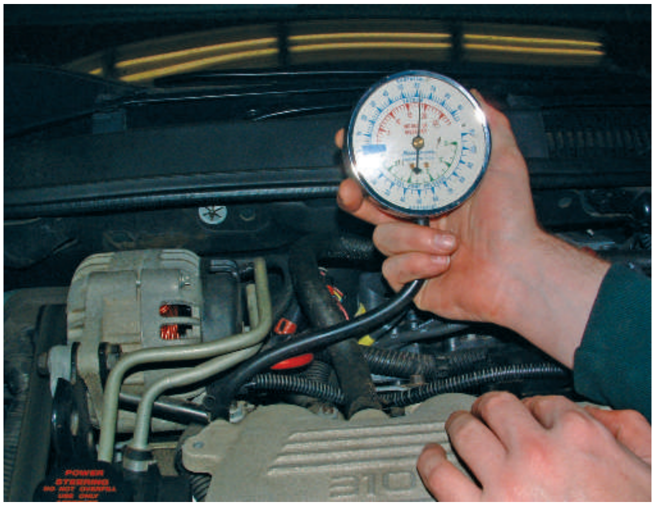


FIGURE 6–34 A vacuum/pressure tester used to measure engine vacuum.

manifold vacuum, either on the manifold or at a point below the throttle plates. The test is made with the engine cranking or running. A good vacuum reading is typically at least 16 in. Hg. However, a reading of 15 to 20 in. Hg (50 to 65 kPa) is normally acceptable. Since the intake stroke of each cylinder occurs at a different time, the production of vacuum occurs in pulses. If the amount of vacuum produced by each cylinder is the same, the vacuum gauge will show a steady reading. If one or more cylinders are producing different amounts of vacuum, the gauge will show a fluctuating reading.

Vacuum Pump

There are many vacuum-operated devices and vacuum switches on cars. These devices use engine vacuum to cause a mechanical action or to switch something on or off. The tool used to test vacuum-actuated components is the vacuum pump. There are two types of vacuum pumps: an electrical-operated pump and a hand-held pump. The hand-held pump is most often used for diagnostics. A hand-held vacuum pump consists of a hand pump, a vacuum gauge, and a length of rubber hose used to attach the pump to the component being tested. Tests with the vacuum pump can usually be performed without removing the component from the vehicle.

A vacuum pump is also used to locate vacuum leaks by connecting the vacuum pump to a suspect vacuum hose or component and applying vacuum. If the needle on the vacuum gauge begins to drop after the vacuum is applied, a leak exists somewhere in the system.

Vacuum Leak Detector

A vacuum leak might be revealed by a compression check, a cylinder leakage test, or a manifold vacuum test. Finding the location of the leak can be very difficult.

A simple, but time-consuming, way to find leaks in a vacuum system is to check each component and vacuum hose with a vacuum pump. Simply apply vacuum to the suspected area and watch the gauge for any loss of vacuum. A good vacuum component holds the vacuum applied to it.

Another method of leak detection uses an ultrasonic leak detector. Air rushing through a vacuum leak creates a high-frequency sound higher than the range of human hearing. An ultrasonic leak detector is designed to hear the frequencies of the leak. When the tool is passed over a leak, it responds to the high-frequency sound by emitting a warning beep. Some detectors also have a series of light emitting diodes (LEDs) that light up as the frequencies are received. The closer the detector is moved to the leak, the more LEDs light up or the faster the beeping occurs, allowing the technician to zero in on the leak. An ultrasonic leak detector can sense leaks as small as $^{1}/_{500}$ inch and accurately locate the leak to within $^{1}/_{16}$ inch.

Tachometer

A tachometer measures engine speed. Like other meters, tachometers are available in analog and digital types. Tachometers are connected to the ignition system to monitor ignition pulses, which are then converted to engine speed by the meter.

Spark Tester

A spark tester (see Figure 6–31) is a fake spark plug. The tester is constructed like a spark plug but does not have a ground electrode. In place of the electrode there is a grounding clamp. Using spark testers is an easy way to determine if an ignition problem is caused by something in the primary or secondary circuit.

The spark tester is inserted in the spark plug end of an ignition cable. When the engine is cranked, a spark should be seen from the tester to a ground.

Logic Probes

In some circuits, pulsed or digital signals pass through the wires. These on-off digital signals either carry information or provide power to drive a component. Many sensors, used in a computer-controlled

circuit, send digital information back to the computer. To check the continuity of the wires that carry digital signals, a logic probe can be used.

A logic probe is similar in appearance to a test-light. It contains three different-colored LEDs. A red LED lights when there is high voltage at the point being probed. A green LED lights to indicate low voltage. A yellow LED indicates the presence of a voltage pulse. The logic probe is powered by the circuit and reflects only the activity at the point being probed. When the probe's test leads are attached to a circuit, the LEDs display the activity.

Sensor Tools

Oxygen sensors are replaced as part of the preventive maintenance program and when they are faulty. Because they are shaped much like a spark plug with wires or a connector coming out of the top, ordinary sockets do not fit well. For this reason, tool manufacturers provide special sockets for these sensors **(Figure 6–35)**. Special sockets are also available for other sending units and sensors.

Static Strap

Because electronic components are sensitive to voltage, static electricity can destroy them. Static straps are worn while working on or around electronic components. These straps typically are worn around a wrist and connected to a known good ground on the vehicle. The straps send all static electricity to the ground of the vehicle, thereby eliminating the chance of static moving to the electronic components.

Pyrometers

A **pyrometer** is an electronic device that measures temperature. These are used to:

- Check for blockages across the radiator

Courtesy of SPX Service Solutions.

FIGURE 6–35 A heated oxygen sensor socket.

FIGURE 6–36 A hand-held digital infrared temperature gauge.

- Measure temperatures on air conditioning system lines, hoses, and condenser **(Figure 6–36)**
- Find dragging brakes

Pyrometers are also used to check tire, especially on race cars, to determine tire pressures and suspension setup.

Spark Plug Sockets

Special sockets are available for the installation and removal of spark plugs **(Figure 6–37)**. These deep sockets have a hex nut drive at the end to allow a technician to turn them with a ratchet or an open-end wrench. The sockets are available in the common sizes of spark plugs ($^5/_8$-inch, $^9/_{16}$-inch, and $^{13}/_{16}$-inch)

FIGURE 6–37 A spark plug socket.

and have a 3/8-inch drive. The socket has a rubber sleeve that surrounds the insulator part of the spark plug to prevent cracking or other damage to the plug while it is being removed or installed.

Exhaust Analyzers

Federal laws require that cars and trucks meet specific emissions levels. State governments also have laws requiring that owners maintain their vehicles so that the emissions remain below the specified level. One of the ways these standards are met is through the use of an exhaust analyzer.

Exhaust analyzers are also very valuable diagnostic tools. By looking at the quality of an engine's exhaust, a technician is able to look at the engine's combustion process and the efficiency of the vehicle's emission controls.

Exhaust analyzers measure the amount of HC and CO in the exhaust. HC is measured in parts per million (ppm) or grams per mile (g/mi) and CO is measured as a percent of the total exhaust. In addition to measuring HC and CO levels, an exhaust analyzer also monitors CO_2 and O_2 levels. Most exhaust analyzers also measure a fifth gas **(Figure 6–38)**, oxides of nitrogen (NO_x).

By measuring NO_x, CO_2, and O_2, in addition to HC and CO, a technician gets a look at the engine's efficiency. There is a desired relationship among the five gases. Any deviation from this relationship can be used to diagnose a driveability problem.

FIGURE 6–38 A hand held five-gas exhaust analyzer.

Chassis Dynamometer

A chassis **dynamometer**, commonly called a dyno, is used to simulate a road test. A vehicle can be driven through a wide assortment of operating conditions without leaving the shop. Because the vehicle is stationary, test equipment can be connected and monitored while the vehicle is driven under various loads. This is extremely valuable when diagnosing a problem. A chassis dyno can also be used for performance tuning.

The vehicle's drive wheels are positioned on large rollers. The electronically controlled rollers offer rotational resistance to simulate the various loads a vehicle may face.

Some performance shops have an engine dynamometer that directly measures the output from an engine. A chassis dynamometer measures the engine's output after it has passed through the driveline.

Hybrid Tools

A hybrid vehicle is an automobile and as such is subject to many of the same problems as a conventional vehicle. Most systems in a hybrid vehicle are diagnosed in the same way as well. However, a hybrid vehicle has unique systems that require special procedures and test equipment. Also, make sure you follow all test procedures precisely as they are given.

Gloves Always wear safety gloves when working on or around the high-voltage systems. These gloves must be class "0" rubber insulating gloves **(Figure 6–39)**, rated at 1,000 volts (these are commonly called "**lineman's gloves**"). gloves over the insulating gloves while performing certain services that may damage the lineman's gloves.

Test Equipment An important diagnostic tool is a DMM. However, the meter used on hybrids (and EVs and FCEVs) must be classified as a category III meter. There are basically four categories for low-voltage electrical meters, each built for specific purposes and to meet certain standards. Low voltage, in this case, means voltages less than 1,000 volts. The categories define how safe a meter is when measuring certain circuits. The standards for the various categories are defined by the American National Standards Institute (ANSI), the International

Caution! The condition of the gloves must be checked before each use. Make sure there are no tears or signs of wear. Electrons are very small and can enter through the smallest holes in your gloves. To check the condition of the gloves, blow enough air into each one so they balloon out. Then fold the open end over to seal the air in. Continue to slowly fold that end of the glove toward the fingers. This will compress the air. If the glove continues to balloon as the air is compressed, it has no leaks. If any air leaks out, the glove should be discarded. All gloves, new and old, should be checked before they are used.

FIGURE 6-39 A pair of lineman's gloves covered with thick sturdy gloves to protect them.

Electrotechnical Commission (IEC), and the Canadian Standards Association (CSA). A CAT III meter **(Figure 6–40)** is required for testing hybrid vehicles because of the high voltages, three-phase current, and the potential for high transient voltages. Transient voltages are voltage surges that occur in AC circuits. To be safe, you need a CAT III 1000V meter. A meter's voltage rating reflects its ability to withstand transient voltages. Therefore, a CAT III 1000V meter offers more protection than a CAT III meter rated at 600 volts.

Warning! Always follow the test procedures defined by the manufacturers when using their equipment.

FIGURE 6-40 Only meters with this symbol should be used on the high-voltage systems in a hybrid vehicle.

FIGURE 6-41 A wire insulation tester.

The probes for the meter's leads should have safety ridges or finger positioners. These help prevent contact between your fingertips and the meter's test leads.

Another important tool is an **insulation resistance tester**. These are used to check for voltage leakage through the insulation of the high-voltage cables. Obviously no leakage is desired and any leakage can cause a safety hazard as well as damage to the vehicle. Minor leakage can also cause hybrid system-related driveability problems. This meter should be used by anyone who might service a damaged hybrid vehicle, such as doing body repair **(Figure 6–41)**. This should also be a CAT III meter.

Transmission and Driveline Tools

The following paragraphs discuss the commonly used repair and diagnostic tools for manual and automatic transmissions, as well as those required for driveline service. Details of when and how to use these tools are covered in Sections 5 and 6.

Transaxle Removal and Installation Equipment

The removal and replacement (R&R) of transaxles mounted to transversely mounted engines require different tools than those needed to remove a transmission from a RWD vehicle.

To remove the engine and transmission from under the vehicle, the vehicle must be raised. A crane and/or support fixture is used to hold the engine and transaxle assembly in place while the assembly is being readied for removal. When everything is set for removal of the assembly, the crane is used to lower the assembly onto a cradle. The cradle is similar to a hydraulic floor jack and is used to lower the assembly so it can be rolled out from under the vehicle. The transaxle can be separated from the engine once it has been removed from the vehicle.

When the transaxle is removed without the engine, the engine must be supported while it is in the vehicle before, during, and after transaxle removal. Special fixtures **(Figure 6–42)** mount to the vehicle's upper frame or suspension parts. These supports attach to the engine and support it so the transaxle can be removed.

Transmission/Transaxle Holding Fixtures

Special holding fixtures should be used to support the transmission or transaxle after it has been removed from the vehicle **(Figure 6–43)**. These holding fixtures may be stand-alone units or may be bench mounted. They allow the transmission to be easily repositioned during repair work.

Courtesy of SPX Service Solutions.

FIGURE 6–42 An engine support is used to hold the engine in place while the transaxle is removed on many FWD vehicles.

FIGURE 6–43 A transmission holding fixture.

FIGURE 6–44 A typical transmission jack.

Transmission Jack

A transmission jack **(Figure 6–44)** is designed to help you while removing a transmission from under the vehicle. The transmission's weight makes it difficult and unsafe to remove it without assistance and/or a transmission jack. The transmission's weight rests on the jack's saddle. Normally these

jacks are equipped with holddown chains, which are used to secure the transmission to the jack.

Transmission jacks are available in two basic styles. One is used when the vehicle is raised by a hydraulic jack and sitting on jack stands. The other style is used when the vehicle is raised on a lift.

Axle Pullers

Axle pullers are used to pull rear axles in RWD vehicles. Most rear axle pullers are slide hammer type.

Special Tool Sets

Vehicle manufacturers and specialty tool companies work closely together to design and manufacture the tools required to repair transmissions. Most of these special tools are listed in the appropriate service information and are part of each manufacturer's "essential tool kit."

Clutch Alignment Tool

To keep the clutch disc centered on the flywheel while assembling the clutch, a clutch alignment tool is used. The tool is inserted through the input shaft opening of the pressure plate and is passed through the clutch disc. The tool then is inserted into the pilot bushing or bearing. The outside diameter (OD) of the alignment tool that goes into the pilot must be only slightly smaller than the ID of the pilot bushing. The OD of the tool that holds the disc in place must likewise be only slightly smaller than the ID of the disc's splined bore. The effectiveness of the tool depends on these diameters, so it is best to have various sizes of clutch alignment tools **(Figure 6–45)**.

Clutch Pilot Bearing/Bushing Puller/Installer

To remove and install a clutch pilot bearing or bushing, special tools are needed. These tools not only make the job easier but also prevent damage to the bore in the flywheel.

FIGURE 6–45 A clutch alignment tool set with various adapters, pilots, and alignment cones.

Universal Joint Tools

Although servicing universal joints can be done with hand tools and a vise, many technicians prefer the use of specifically designed tools. One such tool is a C-clamp modified to include a bore that allows the joint's caps to slide in while tightening the clamp over an assembled joint to remove it **(Figure 6–46)**. Other tools are the various drivers used with a press to press the joint in and out of its yoke.

Hydraulic Pressure Gauge Set

A common diagnostic tool for automatic transmissions is a hydraulic pressure gauge **(Figure 6–47)**. The gauge measures pressure in pounds per square inch (psi) and/or kilopascals (kPa). The gauge kit normally contains various fittings and adapters.

FIGURE 6–46 A universal joint bearing press with adapters.

FIGURE 6–47 Pressure gauges are used to diagnose automatic transmission and other hydraulic systems.

Suspension and Steering Tools

Common suspension and steering repair and diagnostic tools as well as wheel alignment tools and equipment are discussed in the following paragraphs. Details on when and how to use these tools are covered in Section 7.

Tire Tread Depth Gauge

A tire tread depth gauge measures the depth of a tire's tread to determine the wear of the tire. This measurement should be taken at three or four locations around the tire's circumference to obtain an average tread depth. This gauge is used to determine the remaining life of a tire as well as comparing the wear of one tire to the other tires. It is also used when making tire warranty adjustments.

Tire Pressure Monitoring (TPM) Tools

These are required for checking and resetting TPM systems after service. The tool is also used to program a replacement tire pressure monitoring sensor (TPMS) **(Figure 6–48)**.

FIGURE 6-48 A tire pressure monitoring system tester.

FIGURE 6-49 A TPM sensor tool kit.

TPM tool kits contain the special tools needed to service and replace TPMS **(Figure 6–49)**. These kits often include special torque wrenches for the clamp-in sensor caps and valve cores.

Power-Steering Pressure Gauge

A power-steering pressure gauge is used to check power-steering pumps **(Figure 6–50)**. The pressure gauge, with a shutoff valve, is installed between the pump and the steering gear. This tester is also used to check hydraulic boost brake systems. Because the power-steering pump delivers extremely high pressure, the manufacturer's recommended procedure must be followed.

FIGURE 6-50 A power-steering pressure gauge.

Control Arm Bushing Tools

A variety of tools are available to remove and replace control arm bushings. Old bushings are pressed out of the control arm. A C-clamp tool can be used to remove the bushing. The C-clamp is installed over the bushing. An adapter is selected to fit on the bushing and push the bushing through the control arm. Turning the handle on the C-clamp pushes the bushing out of the control arm.

New bushings can be installed by driving or pressing them in place. Adapters are available for the C-clamp tool to press the new bushings into their bore. After the correct adapters are selected, position the bushing and tool on the control arm. Turning the C-clamp handle pushes the bushing into the control arm.

Tie-Rod End and Ball Joint Puller

A tie-rod end and ball joint puller can be used to remove tie-rod ends and pull ball joint studs from the steering knuckle. Ball joint removal and installation tools are designed to remove and replace pressed-in ball joints in steering knuckles and control arms on front and rear suspension systems **(Figure 6–51)**. Often these tools are used in conjunction with a hydraulic press. The size of the removal and pressing tool must match the size of the ball joint.

Front Bearing Hub Tool

Front bearing hub tools are designed to remove and install front wheel bearings on FWD cars. These bearing hub tools are usually designed for a specific make of vehicle and the correct tools must be used for each application. Failure to do so may result in damage to the steering knuckle or hub. Also, the use of the wrong tool will waste quite a bit of your time.

Pitman Arm Puller

A pitman arm puller is a heavy-duty puller designed to remove the pitman arm from the pitman shaft

FIGURE 6–51 A ball joint removal tool.

Courtesy of SPX Service Solutions.

FIGURE 6–52 A pitman arm puller is designed to remove the pitman arm from the pitman shaft.

(Figure 6–52). These pullers can also be used to separate tie-rod ends and ball joints.

Tie-Rod Sleeve-Adjusting Tool

A tie-rod sleeve-adjusting tool **(Figure 6–53)** is required to rotate the tie-rod sleeves to make wheel alignment adjustments. Never use other tools to adjust the tie-rod sleeves. Tools, such as pipe wrenches, will damage the sleeves.

Steering Column Special Tool Set

A wheel puller is used to remove the steering wheel from its shaft. Mount the puller over the wheel's hub after the horn button and air bag have been removed. Screw the bolts into the threaded bores in the steering wheel. Then tighten the puller's center bolt against the steering wheel shaft until the steering wheel is free.

Special tools are also required to service the lock mechanism and ignition switch.

Shock Absorber Tools

Often shock absorbers can be removed with regular hand tools, but there are times when special tools

Courtesy of SPX Service Solutions.

FIGURE 6–53 A tie-rod sleeve-adjusting tool.

may be necessary. Shocks are subject to dirt and moisture, which may make it difficult to loosen the mounting nut from the stud of the shock. Wrenches are available to hold the stud while attempting to loosen the nut. There are also tools for pneumatic chisels that help to work off the nut.

Spring/Strut Compressor Tool

Many types of coil spring compressors are available. These tools are designed to compress a coil spring and hold it in the compressed position while removing the spring from a short-long arm (SLA) suspension, removing the strut from the coil spring **(Figure 6–54)**, or performing other suspension work. Various types of spring compressor tools are required for different types of front suspension systems.

One type of spring compressor uses a threaded rod that fits through two plates, an upper and lower ball nut, a thrust washer, and a forcing nut. The two plates are positioned at either end of the spring. The rod fits through the plates with a ball nut at either end. The upper ball nut is pinned to the rod. The thrust washer and forcing nut are threaded onto the end of the rod. Turning the forcing nut draws the two plates together and compresses the spring.

FIGURE 6–54 A spring compressor for a strut suspension.

Power-Steering Pump Pulley Special Tool Set

When a power-steering pump pulley must be replaced, it should never be hammered off or on. Doing so will cause internal damage to the pump. Normally the pulley can be removed with a gear puller, although special pullers are available. To install a pulley, a special tool is used to press it in place.

Brake Pedal Depressor

A brake pedal depressor must be installed between the front seat and the brake pedal to apply the brakes while checking some front wheel alignment angles to prevent the vehicle from moving **(Figure 6–55)**.

Wheel Alignment Equipment—Four Wheel

Most shops are equipped with a computerized four-wheel alignment machine **(Figure 6–56)** that can check all front-and rear-wheel alignment angles quickly and accurately. Once the machine is set up and the correct information keyed into the machine, the alignment measurements are instantly displayed. Also displayed are the specifications for that vehicle. In addition to the normal alignment specifications, the screen may display asymmetric tolerances, different left- and right-side specifications, and cross specifications. (A difference is allowed between left and right sides.)

FIGURE 6–55 The technician is installing a brake pedal depressor; also note that a steering wheel lock is in place.

FIGURE 6-56 A computerized four-wheel alignment rack.

Graphics and text on the screen show the technician where and how to make the necessary adjustments. As the adjustments are made, the technician can observe the changes.

Tire Changer

Tire changers are used to demount and mount tires. A wide variety of tire changers are available, and each one has somewhat different operating procedures. Always follow the procedure in the equipment operator's manual and the directions provided by your instructor.

Wheel Balancer—Electronic Type

The most commonly used wheel balancer requires that the tire/wheel assembly be mounted on the balancer's spindle **(Figure 6–57)**. The assembly is rotated and the machine indicates the amount of weight and location of the weight that should be added to the assembly. The weights are added to balance the assembly.

Several electronic dynamic/static balancer units are available that permit balancing while the wheel and tire are on the vehicle. Often a strobe light flashes at the heavy point of the tire and wheel assembly.

Wheel Weight Pliers

Wheel weight pliers are combination tools designed to install and remove clip-on lead wheel weights **(Figure 6–58)**. The pliers' jaws hook into a hole in the weight's bracket. The pliers are then moved toward the outside of the wheel and the weight is pried off. Opposite of the jaws on the tool is a plastic hammer head used to tap the weights onto the rim.

FIGURE 6-57 An electronic wheel balancer.

FIGURE 6-58 Wheel weight pliers.

Road Force Balancer

A fairly new tire and wheel balancing machine is a road force balancer **(Figure 6–59)**. The primary purpose of the machine is to see if a wheel and tire assembly is round while it is rolling down the road. To do this, the wheel/tire assembly is mounted to the

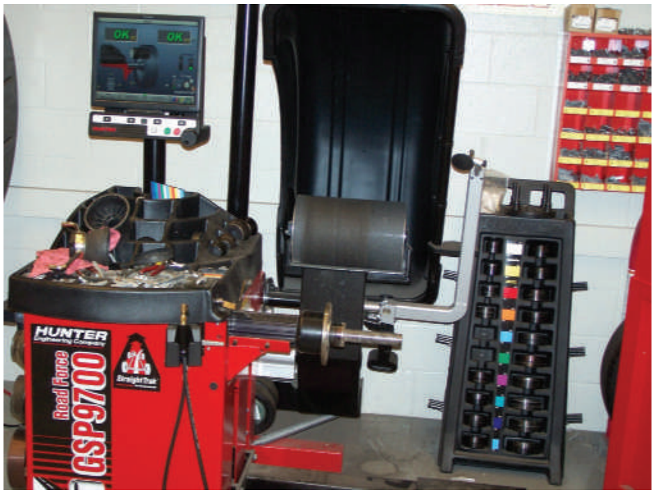


FIGURE 6-59 A road force tire and wheel balancer.

machine and a roller is pressed against the tire as the shaft slowly rotates. The roller presses with a constant force. If the tire is round, the roller will simply roll with the tire. If the tire is not round, the roller will move back and forth to measure the “loaded runout” of the tire.

Once the loaded runout is determined, the machine calculates how to minimize the loaded runout of the assembly. This normally requires the dismounting and remounting of the tire onto the wheel, but in a different location. After road force balance is rechecked, the assembly is rebalanced conventionally with weights.

Brake System Tools

Common repair and diagnostic tools for brake service are discussed in the following paragraphs. Additional details of when and how to use these tools are presented in Section 8.

Cleaning Equipment and Containment Systems

Special equipment is used to safely contain asbestos while doing brake work. A negative-pressure enclosure and high-efficiency particulate air (HEPA) vacuum system allow you to clean and inspect brake assemblies while preventing the release of asbestos fibers into the air.

Low-pressure wet cleaning systems wash dirt from the brake assembly and catch the contaminated cleaning agent in a basin. This system uses water mixed with an organic solvent or wetting agent. The brake assembly is gently flooded to prevent any asbestos-containing brake dust from becoming airborne.

Holddown Spring and Return Spring Tools

Drum brake shoe return springs are very strong and require special tools for removal and installation. Most return spring tools have special sockets and hooks to release and install the spring ends. Some are built like pliers **(Figure 6–60)**.

Brake shoe holddown springs are much lighter than return springs, and many such springs can be released and installed by hand, however using this special tool makes the job easier. A holddown spring tool **(Figure 6–61)** looks like a cross between a screwdriver and a nut driver. A specially shaped end grips and rotates the spring retaining washer.

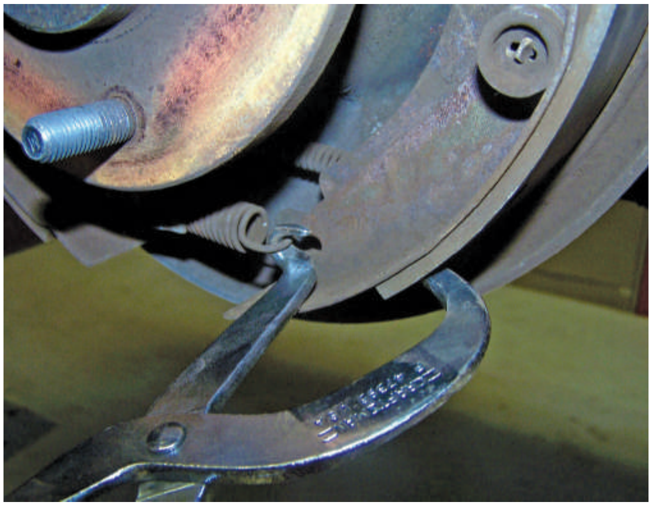


FIGURE 6-60 Brake spring pliers.

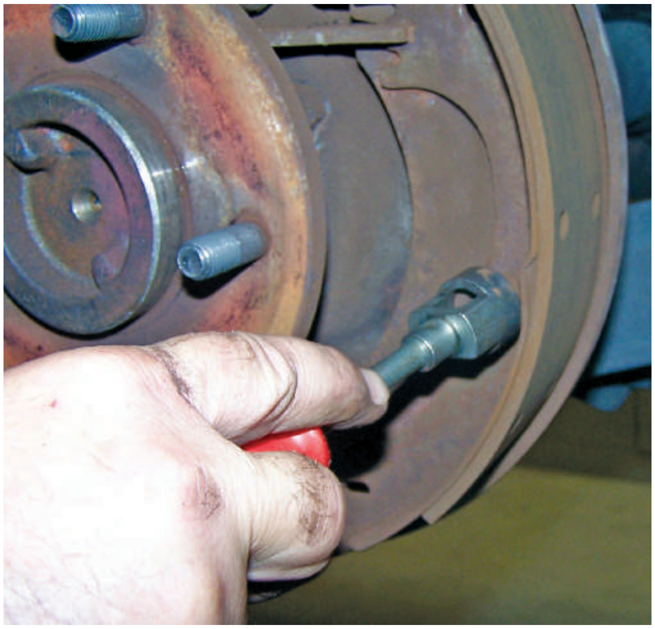


FIGURE 6-61 A holddown spring compressor tool.

Boot Drivers, Rings, and Pliers

Dust boots attach between the body of a brake caliper and pistons of disc brakes to keep dirt and moisture out of the caliper bores. A special driver is used to install the dust boot with a metal ring that fits tightly on the caliper body. The circular driver is centered on the boot after it is placed against the caliper and then hit with a hammer to drive the boot into place. Other kinds of dust boots fit into a groove in the caliper bore before the piston is installed. Special rings or pliers are then needed to expand the opening in the dust boot and let the piston slide through it for installation.

Caliper Piston Removal Tools

A caliper piston can usually be slid or twisted out of its bore by hand. Rust and corrosion (especially where road salt is used in the winter) can make piston removal difficult. One simple tool that will help with the job is a set of special pliers that grips the inside of the piston and allows you to move it by hand with more force. These pliers work well on pistons that are only mildly stuck.

For a severely stuck caliper piston, a hydraulic piston remover can be used. This tool requires that the caliper be removed from the car and installed in a holding fixture. A hydraulic line is connected to the caliper inlet and a hand-operated pump is used to apply up to 1,000 psi of pressure to loosen the piston. Because of the danger of spraying brake fluid, always wear eye protection when using this equipment.

Drum Brake Adjusting Tools

Although drum brakes have some type of self-adjuster, brake shoes still require an initial adjustment after they are installed. The star wheel adjusters of many drum brakes can be adjusted with a flat-blade screwdriver. Brake adjusting spoons **(Figure 6–62)** and wire hooks designed for this specific purpose can make the job faster and easier.

Tubing Tools

The rigid brake lines, or pipes, of the hydraulic system are made of steel tubing to withstand high pressure and to resist damage from vibration and corrosion. Brake lines often can be purchased in preformed lengths to fit specific locations on specific vehicles. Straight brake lines can also be purchased in many lengths and several diameters and need to be bent to fit specific vehicle locations. The tools **(Figure 6–63)** you should have are:

- A tubing cutter and reamer
- Tube benders
- A double flaring tool for SAE flares
- An International Standards Organization (ISO) flaring tool for European-style ISO flares

FIGURE 6–62 A drum brake adjustment tool.

FIGURE 6–63 A typical tubing tool set.

Brake Disc Micrometer

A special micrometer is used to accurately check the thickness of a brake rotor. A brake disc micrometer has pointed anvils that allow the tip to fit into grooves worn on the rotor **(Figure 6–64)**. This type of micrometer is read in the same way as other micrometers but is made with a range from 0.300 to 1.300 inches. Digital calipers are also used to measure disc brake thickness.

Drum Micrometer

A drum micrometer is a single-purpose instrument used to measure the inside diameter of a brake

FIGURE 6-64 A micrometer for measuring brake disc thickness.

drum. A drum micrometer has two movable arms on a shaft **(Figure 6–65)**. One arm has a precision dial indicator; the other arm has an outside anvil that fits against the inside of the drum. In use, the arms are secured on the shaft by lock screws that fit into grooves every 1/8 inch (0.125) on the shaft. The dial indicator is graduated in 0.005-inch increments.

Metric drum micrometers work the same way except that the shaft is graduated in 1 cm major increments and the lock screws fit in notches every 2 mm.

Brake Shoe Adjusting Gauge (Calipers)

A brake shoe adjusting gauge is an inside-outside measuring device **(Figure 6–66)**. This gauge is often called a brake shoe caliper. During drum brake ser-

FIGURE 6-65 A drum micrometer.

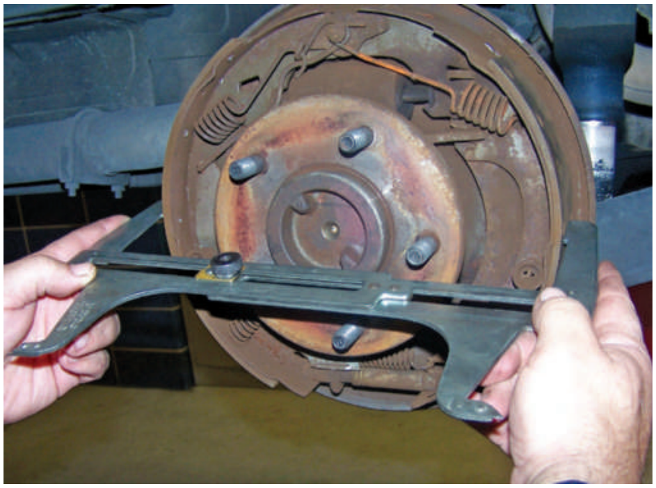


FIGURE 6-66 A drum brake shoe adjusting gauge.

vice, the inside part of the gauge is placed inside a newly surfaced drum and expanded to fit the drum diameter. The lock screw is then tightened and the gauge moved to the brake shoes installed on the backing plate. The brake shoes are then adjusted until the outside part of the gauge just slips over them. This action provides a rough adjustment of the brake shoes. Final adjustment must still be done after the drum is installed, but the brake shoe gauge makes the job faster.

Brake Lathes

Brake lathes are special power tools used only for brake service. They are used to resurface brake rotors and drums. This involves cutting away very small amounts of metal to restore the surface of the rotor or drum. The traditional brake lathe is an assembly mounted on a stand or workbench. A bench lathe requires that the drum or rotor be removed from the vehicle and mounted on the lathe **(Figure 6–67)**.

As the drum or rotor is turned on the lathe spindle, a carbide steel cutting bit is passed over the drum or rotor friction surface to remove a small amount of metal. The cutting bit is rigidly mounted on a lathe fixture for precise control as it passes across the friction surface.

An on-car lathe **(Figure 6–68)** is bolted to the vehicle's suspension or mounted on a rigid stand to provide a stable mounting point for the tool. The rotor may be turned by the vehicle's engine or drive train (for a FWD vehicle) or by an electric motor and drive attachment on the lathe. As the rotor is turned, the cutting tool is moved across both surfaces of the rotor to refinish it. An on-car lathe not only has the obvious advantage of speed, it also rotates the rotor on the vehicle wheel bearings and hub so that these

FIGURE 6–67 A bench brake lathe.

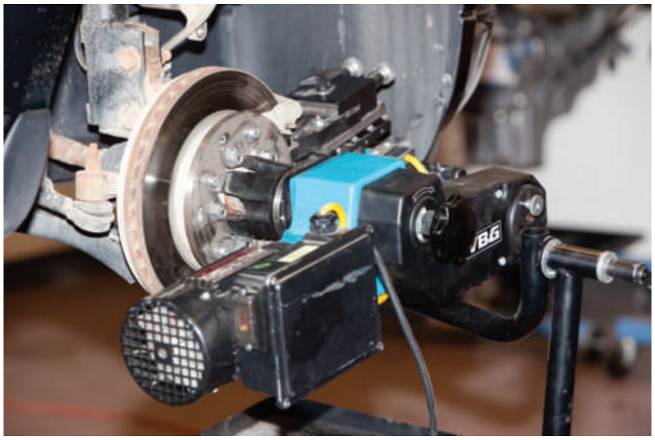


FIGURE 6–68 An on-car disc brake lathe.

sources of runout, or wobble, are compensated for during the refinishing operation.

Bleeder Screw Wrenches

Special bleeder screw wrenches are often used to open bleeder screws. Bleeder screw wrenches are small, 6-point box wrenches with strangely offset handles for access to bleeder screws in awkward locations. The 6-point box end grips the screw more securely than a 12-point box wrench can and avoids damage to the screw.

Bleeding Tools

Removing the air from the closed hydraulic brake system is very important. This is done by bleeding the system. Bleeding can be done manually, with a vacuum pump, or with a pressure bleeder. The latter two are preferred because they are quick and very efficient, and the technician can do without an assistant.

Heating and Air- Conditioning Tools

Common repair and diagnostic tools for the heating, ventilation, and air-conditioning (A/C) systems are discussed in the following paragraphs. Details of when and how to use these tools are covered in Section 9.

Manifold Gauge Set

A manifold gauge set **(Figure 6–69)** is used when discharging, charging, evacuating, and diagnosing an A/C system. The low-pressure gauge is graduated into pounds of pressure from 1 to 120 (with cushion to 250) in 1-pound graduations, and, in the opposite direction, in inches of vacuum from 0 to 30. This is the gauge that should always be used in checking pressure on the low-pressure side of the system. The high-pressure gauge is graduated from 0 to 500 pounds pressure in 10-pound graduations. This gauge is used for checking pressure on the high-pressure side of the system.

The gauge manifold is designed to control refrigerant flow. When the manifold test set is connected into the system, pressure is registered on both gauges at all times.

Currently, all new passenger vehicles sold in the United States use R-134a refrigerant. The EPA recently approved HFO-1234yf (hydrofluoro-olefin) refrigerant for use in mobile air-conditioning systems. Because 1234yf, R-134a, and R-12 are not

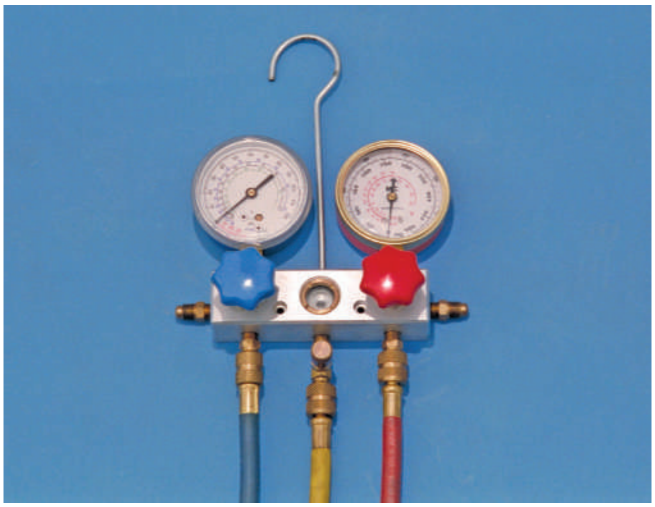


FIGURE 6–69 A manifold gauge set.

interchangeable, separate sets of hoses, gauges, and other equipment are required to service vehicles. All equipment used to service R-134a and R-12 systems must meet SAE standard J1991. The service hoses on the manifold gauge set must have manual or automatic backflow valves at the service port connector ends to prevent the refrigerant from being released into the atmosphere during connection and disconnection.

Manifold gauge sets for R-134 a can be identified by labels on the gauges and/or a light blue color on the face of the gauges. Also, R-134 a service hoses have a black stripe along their length and are clearly labeled. The low-pressure hose is blue with a black stripe. The high-pressure hose is red with a black stripe and the center service hose is yellow with a black stripe.

Electronic Leak Detector

An electronic leak detector **(Figure 6–70)** is safe and effective and can be used with all types of refrigerants. A hand-held battery-operated electronic leak detector has a test probe that is moved close to the areas of suspected leaks. Since refrigerant is heavier than air, the probe should be positioned below the test point. An alarm or a buzzer on the detector indicates the presence of a leak. On some models, a light flashes when refrigerant is detected.

Fluorescent Leak Tracer

To find a refrigerant leak using the fluorescent tracer system, a fluorescent dye is introduced into the air-conditioning system with a special infuser included with the detector equipment. The air conditioner is run for a few minutes, giving the tracer dye fluid time to circulate and penetrate. Wear protective goggles and scan the system with a black-light glow gun. Leaks in the system will shine under the black light as a luminous yellow-green **(Figure 6–71)**.

Courtesy of SPX Service Solutions.

FIGURE 6–70 An electronic leak detector.


Courtesy of Tracer Products.

FIGURE 6–71 With a fluorescent tracer system, refrigerant leaks will glow brightly when inspected with a UV/blue light as a luminous yellow-green.

Refrigerant Identifier

A refrigerant identifier **(Figure 6–72)** is used to identify the type of refrigerant present in a system. This test should be done before any service work. The tester is used to identify the purity and quality of the refrigerant sample taken from the system.

Sealant Detection Kit

Many refrigerants sold in small containers, such as one- and two-pound DIY cans, contain a sealant or stop-leak agent. Because the sealant can cause

FIGURE 6–72 A refrigerant identifier (analyzer).

FIGURE 6–73 A R-134a charging station.

severe damage to recovery and recharging stations, the system should be tested before attempting to recover any refrigerant.

Refrigerant Recycling/Charging Stations

A charging station **(Figure 6–73)** can remove, evacuate, and recharge an A/C system though most shops now use recovery, recycling, and recharging (RRR) machines that perform all three functions in one unit. These machines draw the old refrigerant out of the system, filter it, separate the oil, remove moisture and air, and store the refrigerant for future use.

All recycled refrigerant must be safely stored in DOT CFR Title 49 or UL-approved containers. Before recycled refrigerant can be used, it must be checked for noncondensable gases.

Thermometer

A digital readout or dial-type thermometer **(Figure 6–74)** is used to measure the air temperature at the vent outlets, which indicates the overall performance of the system. The thermometer can also be used to check the temperature of refrigerant lines, hoses, and components while diagnosing a system. While doing the latter, an electronic pyrometer works best.

FIGURE 6–74 A dial-type thermometer used to check A/C operation.

Compressor Tools

Although compressors are usually replaced when they are faulty, some compressor service procedures are standard practice. These procedures focus on the compressor clutch and shaft seal and require special tools. Clutch plate tools are required to gain access to the shaft seal. They are also needed to reinstall the clutch plate after service.

Typically to replace a shaft seal, you need an adjustable or fixed spanner wrench, clutch plate installer/remover, ceramic seal installer/remover, seal assembly installer/remover, seal seat installer/remover, shaft seal protector, snapring pliers, O-ring remover, and O-ring installer. Some of these tools are for a specific compressor; others have interchangeable parts to allow them to work on a variety of compressors.

Hose and Fitting Tools

An A/C system is a closed system, meaning outside air should never enter the system and the refrigerant in the system should never exit to outside air. To maintain a closed system, special fittings and hoses are used. Often, special tools, such as the spring-lock coupling tool set, are required when servicing the system's fittings and hoses. Without this tool, it is impossible to separate the connector and not damage it.

KEY TERMS

Ammeter
Dial bore gauge
Digital multimeter (DMM)
Dynamometer
Hydrometer
Insulation resistance tester
Lineman's gloves
Multimeter
Ohmmeter
Pyrometer
Scan tool
Testlight
Trace
Vacuum
VAT
Voltmeter
Waveform

SUMMARY

- Common diagnostic tools used to check an engine and its related systems include a compression gauge, cylinder leakage tester, oil pressure gauge, stethoscope, dial bore indicator, valve spring tester, cooling system pressure tester, coolant hydrometer, engine analyzers, fuel pressure gauge, injector balance tester, injector circuit test light, vacuum gauge, vacuum pump, vacuum leak detector, spark tester, logic probes, pyrometers, and exhaust analyzers.
- Common tools used to service an engine and its related systems include transaxle removal and installation equipment, ridge reamer, ring compressor, ring expander, ring groove cleaner, cylinder deglazer, cylinder hone, boring bar, cam bearing driver set, V-blocks, valve and valve seat resurfacing equipment, valve guide repair tools, valve spring compressor, torque angle gauge, oil priming tool, a coolant recovery and recycle system, fuel injector cleaners, fuel line tools, pinch-off pliers, timing light, and spark plug sockets.
- Some of the common diagnostic tools for electronic and electrical systems include a testlight, continuity tester, voltmeter, ohmmeter, ammeter, volt/ampere tester, DMM, lab scope, scan tools, and battery hydrometer.
- Common electrical and electronic system service tools include a computer memory saver, wire and terminal repair tools, headlight aimers, static straps, and sensor tools.
- The tools required to work on hybrid vehicles are the same as those used on a conventional vehicle with the addition of tools designed for high voltages, such as linemen's gloves, CAT III test equipment, and insulation resistance testers.
- Diagnostic tools for a vehicle's drivetrain include a drive shaft angle gauge and hydraulic pressure gauge set.
- Tools required to service the drivetrain include transaxle removal and installation equipment, transmission/transaxle holding fixtures, transmission jack, axle pullers, special tool sets, clutch alignment tool, clutch pilot bearing/bushing puller/installer, and universal joint tools.
- The various diagnostic tools used on a vehicle's running gear include a tire tread depth gauge, power-steering pressure gauge, wheel alignment equipment, brake disc micrometer, and drum micrometer.
- Some of the common tools used to service a vehicle's running gear include control arm bushing tools, tie-rod end and ball joint pullers, front bearing hub tool, pitman arm puller, tie-rod sleeve adjusting tool, steering column special tool set, shock absorber tools, spring/strut compressor tool, power-steering pump pulley special tool set, brake pedal depressor, tire changer, wheel balancer, wheel weight pliers, brake cleaning equipment and containment systems, holddown spring and return spring tools, boot drivers and pliers, caliper piston removal tools, drum brake adjusting tools, brake cylinder hones, tubing tools, brake shoe adjusting gauge, brake lathes, bleeder screw wrenches, and pressure bleeders.
- Common tools used to check a vehicle's heating and air-conditioning system include a manifold gauge set, a service port adapter set, an electronic leak detector, a fluorescent leak tracer, and a thermometer.
- Tools used to service air-conditioning systems include a refrigerant identifier, refrigerant charging station, refrigerant recovery and recycling system, compressor tools, and hose and fitting tools.

REVIEW QUESTIONS

Short Answer

1. Explain why testlights are not recommended for testing computer circuits.
2. Name the two basic types of compression gauges.
3. What tool is used to test engine manifold vacuum?
4. Describe two methods of trapping asbestos/brake dust.

True or False

1. *True or False?* A compression gauge will show the amount of air leaking through a cylinder as a percentage.
2. *True or False?* A lab scope is a visual voltmeter that shows voltage over a period of time.
3. *True or False?* A brake shoe adjusting gauge is an inside-outside measuring device used to initially adjust the expanse of brake shoes before the brake drum is installed.

Multiple Choice

1. Which of the following statements is *not* true?
   a. Exhaust analyzers allow a technician to look at the effectiveness of a vehicle's emission control systems.
   b. Most exhaust analyzers measure HC in parts per million or grams per mile.
   c. CO is measured as a percent of the total exhaust.
   d. Emission controls greatly alter O_2 and CO_2 emissions.
2. Technician A says that a brake drum micrometer has pointed anvils. Technician B says that a brake drum micrometer is a large inside micrometer that is read like any other micrometer. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. Technician A says that a pyrometer measures temperature. Technician B says that a thermometer measures temperature. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. When using a voltmeter, Technician A connects it in series with the circuit being tested. Technician B connects the red lead of the voltmeter to the more positive side of the circuit. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Technician A uses a digital volt/ohmmeter to test amperage. Technician B uses the same tool to test resistance. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. Technician A says that a charging station removes old refrigerant and recharges an A/C system. Technician B says that a charging station can remove, filter, and clean refrigerant. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. Which of the following statements about manifold gauge sets is *not* true?
   a. An adapter is required for using R-12 gauges on an R-134a system.
   b. A manifold gauge set is used when discharging, charging, and evacuating and for diagnosing trouble in an A/C system.
   c. The gauge manifold is designed to control refrigerant flow. When the manifold test set is connected into the system, pressure is registered on both gauges at all times.
   d. R-134a service hoses have a black stripe along their length, the low-pressure hose is blue, and the high-pressure hose is red.
8. When conducting an oil pressure test: Technician A says that lower than normal pressure can be caused by faulty piston oil rings. Technician B says that lower than normal oil pressure can be caused by excessive engine bearing clearances. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. Which of the following conditions can be revealed by fuel pressure readings?
   a. Faulty fuel pump
   b. Faulty fuel pressure regulator
   c. Restricted fuel delivery system
   d. All of the above
10. Technician A uses a high-impedance testlight on the high-voltage systems in hybrid vehicles. Technician B uses only CATIII test instruments to check high-voltage systems. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

11. Technician A says that a sulfated and plugged fuel injector must be replaced. Technician B says that a sulfated and plugged fuel injector can be cleaned. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
12. The tests conducted by a scan tool can also be done by some ___.
    a. fuel injector pulse testers
    b. exhaust analyzers
    c. engine analyzers
    d. digital volt/ohmmeters
13. When using a fuel injector pulse tester, Technician A says that little or no pressure drop indicates a plugged or defective injector. Technician B says that no pressure drop indicates an overly rich condition. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
14. To measure engine cranking current, a DMM (digital multimeter) can be used with a(n) :
    a. continuity tester
    b. inductive pickup
    c. carbon pile
    d. tachometer
15. While discussing a clutch alignment tool, Technician A says that the part of the tool that fits into the clutch plate must have a slightly larger OD (outside diameter) than the bore in the disc. Technician B says that the OD of the part of the tool that goes into the pilot must be slightly smaller than the ID (inside diameter) of the pilot bushing. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
16. Technician A says that ball joints may be pressed into the control arm. Technician B says that control arm bushings are often pressed into the control arm. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
17. Which of the following is *not* a suitable way to bleed an entire hydraulic brake system?
    a. Manual bleeding
    b. Bench bleeding
    c. Pressure bleeding
    d. Vacuum bleeding
18. Which is not a common use for a pressure transducer?
    a. Power-steering system pressure
    b. Oil pressure
    c. Engine vacuum
    d. Engine compression

CHAPTER 7

WORKING SAFELY IN THE SHOP

OBJECTIVES

- Understand the importance of safety and accident prevention in an automotive shop.
- Explain the basic principles of personal safety, including protective eyewear, clothing, gloves, shoes, and hearing protection.
- Explain the procedures and precautions for safely using tools and equipment.
- Explain the precautions that need to be followed to safely raise a vehicle on a lift.
- Explain what should be done to maintain a safe working area in a shop.
- Describe the unique safety considerations that must be adhered to when working on hybrid vehicles.
- Describe the purpose of the laws concerning hazardous wastes and materials, including the Right-To-Know laws.
- Describe your rights, as an employee and/or student, to have a safe place to work.

Working on automobiles can be dangerous. It can also be fun and very rewarding. To keep the fun and rewards rolling in, you need to prevent accidents by working safely. In an automotive repair shop, there is great potential for serious accidents, simply because of the nature of the business and the equipment used. When there is carelessness, the automotive repair industry can be one of the most dangerous occupations.

However, the chances of you being injured while working are close to zero if you learn to work safely and use common sense. Shop safety is the responsibility of everyone in the shop—you, your fellow students or employees, and your employer or instructor. Everyone must work together to protect the health and welfare of all who work in the shop. Shop accidents can cause serious injury, temporary or permanent disability, and death.

This chapter covers basic guidelines concerning personal, work area, tool and equipment, and hazardous material safety. In addition to what is in this chapter, special warnings are given throughout this book to alert you of situations where carelessness could result in personal injury. When working on cars, always follow the safety guidelines given in

service information, tool operation manuals, and other technical literature. They are there for your protection.

Personal Safety

To protect yourself from injuries, you need to wear personal protective equipment (PPE), dress appropriately, work professionally, and correctly handle tools and equipment. PPE are items such as safety glasses, uniforms, and safety boots or shoes that help protect you while working in the shop.

Eye Protection

Your eyes can become infected or permanently damaged by many things in a shop. Consider the following:

- Dirt and sharp bits of rust can easily fall into your eyes while you are working under a vehicle.
- Some procedures, such as grinding, release tiny particles of metal and dust, which are thrown off at very high speeds. These particles can easily get into your eyes, scratching or cutting them.
- Pressurized gases and liquids escaping a ruptured hose or loose hose fitting can spray into your eyes and cause blindness.

To be safe, wear suitable eye protection whenever you are working in the shop. In most shops, this is not an option—you **must** wear eye protection. There are many types of eye protection available **(Figure 7–1)**.

Safety glasses have lenses made of shatter-resistant safety glass, plastic or polycarbonate. They should also offer side protection. Regular prescription glasses do not offer sufficient protection and, should not be worn as a substitute for safety glasses. Prescription glasses can be made with polycarbonate lenses and can be worn as safety glass if they are rated ANSI Z87 and have side shields fixed to the frame.

FIGURE 7–1 Various types of eye protection: safety (splash) goggles, face shield, and safety glasses.

FIGURE 7–2 An eye wash station.

During some procedures you should wear additional eye protection. For example, when you are working around air-conditioning systems, you should wear splash goggles and, when using a bench grinder or cleaning parts with a pressurized spray, you should wear a face shield. The face shield will also protect the rest of your face.

Eye First Aid If chemicals such as battery acid, fuel, or solvents get into your eyes, flush them immediately and continuously with clean water. Have someone call a doctor and get medical help immediately. Many shops have eye wash stations or safety showers **(Figure 7–2)** that should be used whenever you or someone else has been sprayed or splashed with a chemical.

Clothing

Clothing that hangs out freely, such as shirttails, can create a safety hazard and cause serious injury. Nothing you wear should be allowed to dangle in the engine compartment or around equipment. Shirts should be tucked in and buttoned and long sleeves buttoned or carefully rolled up. Your clothing should be well fitted and comfortable but made with strong material. Some technicians prefer to wear coveralls or shop coats to protect their personal clothing. Your work clothes should offer you some protection but should not restrict your movement.

Keep your clothing clean. If you spill gasoline or oil on yourself, change that item of clothing immediately. Oil against your skin for a prolonged period can produce rashes or other allergic reactions. Gasoline can irritate cuts and sores.

Hair and Jewelry

Long hair and loose, hanging jewelry can create the same type of hazard as loose-fitting clothing. They can get caught in moving engine parts and machinery. If you have long hair, tie it back or tuck it under a cap.

Rings, necklaces, bracelets, and watches should not be worn while working. A ring can rip your finger off, a watch or bracelet can cut your wrist, and a necklace can choke you. This is especially true when working with or around electrical wires. The metals in most jewelry conduct electricity very well and can easily cause a short, through you, if it touches a bare wire.

Shoes

You should also protect your feet. Tennis and jogging shoes provide little protection if something falls on your foot. Boots or shoes made of leather, or a material that approaches the strength of leather, offer much better protection from falling objects. There are many designs of safety shoes and boots that also have steel plates built into the toe and shank to protect your feet. Many also have soles that are designed to resist slipping on wet surfaces. Foot injuries are not only quite painful but can also put you out of work for some time.

FIGURE 7–3 Polyurethane or vinyl gloves should be worn when handling strong and dangerous caustic chemicals.

Gloves

Good hand protection is often overlooked. A scrape, cut, or burn can seriously impair your ability to work for many days. Many students and technicians wear mechanics gloves to help protect their hands whenever they are working on a car. A well-fitted pair of heavy work gloves should be worn while grinding, welding, or when handling chemicals or high-temperature components. Polyurethane or vinyl gloves should be worn when handling strong and dangerous caustic chemicals **(Figure 7–3)**. These chemicals can easily burn your skin.

Many technicians wear thin, surgical-type latex **(Figure 7–4)** or nitrile gloves whenever they are working on vehicles. These offer little protection against cuts but do offer protection against disease and grease buildup under and around your fingernails. Latex gloves are more comfortable but weaken when they are exposed to gas, oil, and solvents. Nitrile gloves are not as comfortable but they are not affected by gas, oil, and solvents. Your choice of hand protection should be based on what you are doing.

FIGURE 7–4 Many technicians wear thin, surgical-type latex or nitrile gloves whenever they are working on vehicles.

Disease Prevention

When you are ill with something that may be contagious, see a doctor and do not go to work or school until the doctor says there is little chance of someone else contracting the illness from you. Doing this

will protect others, and if others do this you will be protected.

You should also be concerned with and protect yourself and others from bloodborne pathogens. **Bloodborne pathogens** are pathogenic microorganisms that are present in human blood and can cause disease. These pathogens include, but are not limited to, staph infections caused by the bacteria *Staphylococcus aureus*, hepatitis B virus (HBV), and human immunodeficiency virus (HIV). For everyone's protection, any injury that causes bleeding should be dealt with as a threat to others. You should avoid contact with the blood of another person. If you need to administer some form of first aid, make sure you wear hand protection before you do so. You should also wear gloves and other protection when handling the item that caused the cut. Most important, like all injuries, report the accident to your instructor or supervisor.

Ear Protection

Exposure to very loud noise levels for extended periods can lead to hearing loss. Air wrenches, engines running under a load, and vehicles running in enclosed areas can all generate harmful levels of noise. Simple earplugs or earphone-type protectors **(Figure 7–5)** should be worn in environments that are constantly noisy.

Respiratory Protection

Technicians often work with chemicals that have toxic fumes. Air or respiratory masks should be worn whenever you are exposed to toxic fumes **(Figure 7–6)**. Cleaning parts with solvents and painting are examples of when respiratory masks should be worn.

FIGURE 7–5 While working in a noisy environment, your ears can be protected with earmuffs or earplugs.

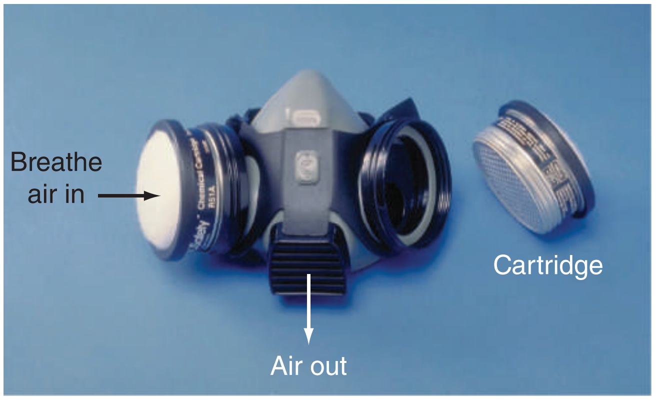


FIGURE 7–6 A respirator is used to prevent inhalation of toxic materials.

Masks should also be worn when handling parts that contain asbestos or when handling hazardous materials. The proper handling of these materials is covered in great detail later in this chapter.

Lifting and Carrying

Often technicians will need to move something that is heavy. Knowing how to lift these heavy things can save your career. When lifting any object, follow these steps:

1. Place your feet close to the object. Position your feet so you will be able to maintain a good balance.
2. Keep your back and elbows as straight as possible. Bend your knees until your hands reach the best place to get a strong grip on the object **(Figure 7–7)**.
3. If the part is in a cardboard box, make sure the box is in good condition. Old, damp, or

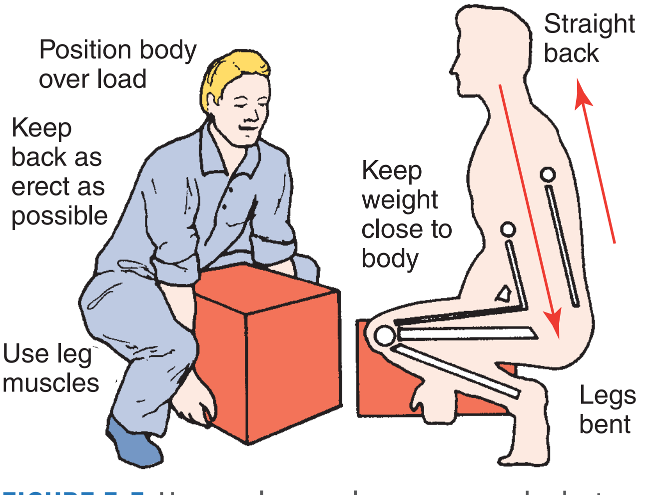


FIGURE 7–7 Use your leg muscles—never your back—to lift heavy objects.

Caution! Trying to "muscle" something with your arms or back can result in severe damage to your back and may end your career and limit what you do the rest of your life!

poorly sealed boxes will tear and the part will fall out.

4. Firmly grasp the object or container. Never try to change your grip as you move the load.
5. Keep the object close to your body, and lift it up by straightening your legs. Use your leg muscles, not your back muscles.
6. If you must change your direction of travel, never twist your body. Turn your whole body, including your feet.
7. When placing the object on a shelf or counter, do not bend forward. Place the edge of the load on the shelf and slide it forward. Be careful not to pinch your fingers.
8. When setting down a load, bend your knees and keep your back straight. Never bend forward. This strains the back muscles.
9. When lowering something heavy to the floor, set the object on blocks of wood to protect your fingers.

You should also use back-protection devices when you lift heavy objects. Always lift and work within your ability and ask others (or use a hoist) to help when you are not sure whether you can handle the size or weight of an object. Even small, compact parts can be surprisingly heavy or unbalanced. Think about how you are going to lift something before beginning.

Professional Behavior

Accidents can be prevented simply by the way you behave. The following list does not include everything you should or should not do; it merely gives some things to think about:

- Never smoke while working on a vehicle or while working in the shop.
- Playing around or "horseplay" is not fun when it sends someone to the hospital.
- To prevent serious burns, keep your skin away from hot metal parts such as the radiator, exhaust manifold, tailpipe, catalytic converter, and muffler.
- Always disconnect electric engine cooling fans when working around the radiator. Many of these will turn on without warning and can easily chop off a finger or hand. Make sure you reconnect the fan after you have completed your repairs.
- When working with a hydraulic press, make sure the pressure is applied in a safe manner. It is generally wise to stand to the side when operating the press.
- Properly store all parts and tools by putting them away in a place where people will not trip over them. This practice not only cuts down on injuries, it also reduces time wasted looking for a misplaced part or tool.
- Keep your work area clean and uncluttered. Make sure you clean up all spills before continuing to work.

Tool and Equipment Safety

An automotive technician must adhere to the following shop safety guidelines when using all tools and equipment.

Hand Tool Safety

Careless use of simple hand tools such as wrenches, screwdrivers, and hammers causes many shop accidents that could be prevented. Keep in mind the following tips when using hand tools:

- Keep all tools grease-free. Oily tools can slip out of your hand, causing broken fingers or at least cut or skinned knuckles.
- Inspect your tools for cracks, broken parts, or other dangerous conditions before you use them. Never use broken or damaged tools.
- Hand tools should only be used for the purpose they were designed for. Use the right tool for the job. Never use a wrench or pliers as a hammer, also never use screwdrivers as chisels.
- Make sure the tool is of professional quality.
- When using a wrench, always pull it, not push it, toward you. When using an adjustable wrench; pull the wrench so that the force of the pull is on the nonadjustable jaw.
- Always use the correct size of wrench.
- Use a box-end or socket wrench whenever possible.
- Do not use deep-well sockets when a regular size socket will work. The longer socket develops more twist torque and tends to slip off the fastener.
- When using an air impact wrench, always use impact sockets.

- Never use pliers to loosen or tighten a nut; use the correct wrench.
- Always be sure to strike an object with the full face of the hammerhead.
- Always wear safety glasses when using a hammer and/or chisel.
- Never strike two hammer heads together.
- Be careful when using sharp or pointed tools.
- Do not place sharp tools or other sharp objects into your pockets.
- If a tool is supposed to be sharp, make sure it is sharp. Dull tools can be more dangerous than sharp tools.
- Use knives, chisels, and scrapers in a motion that will keep the point or blade moving away from your body.
- Always hand a pointed or sharp tool to someone else with the handle toward the person to whom you are handing the tool.

Power Tool Safety

Many shops have areas specifically marked as special safety areas. **(Figure 7–8)** These safety areas or zones often contain equipment such as bench grinders, solvent tanks, welding equipment, and drill presses, which present special hazards in the shop. Working within or even near these areas often requires additional PPE over and above standard safety glasses, uniforms, and boots. For example, when using a bench grinder, a full face shield should be used to prevent debris from flying into your face. Be sure to identify what forms of PPE are necessary when working in and around these areas.

FIGURE 7-8 Some areas of the shop require additional safety precautions.

> **Caution!** Carelessness or mishandling of power tools can cause serious injury. Make sure you know how to operate a tool before using it.

Power tools are operated by an outside power source, such as electricity, compressed air, or hydraulic pressure. Always respect the tool and its power source. Carelessness can result in serious injury. Also, always wear safety glasses when using power tools. Never try to use a tool beyond its stated capacity.

Electrical Tools When using an electrically powered tool, make sure it is properly grounded. Check power cords for insulation cracks, as well as bare wires, before using it. Also, when using electrical power tools, never stand on a wet or damp floor. Before plugging in any electric tool, make sure its switch is in the *off* position. When you are finished using the tool, turn it off and unplug it. Never leave a running power tool unattended.

When using power equipment on a small part, never hold the part in your hand. Always mount the part in a bench vise or use vise grip pliers.

When using a bench or floor grinding wheel, check the machine and the grinding wheels for signs of damage before using them. If the wheels are damaged, they should be replaced before using the machine. Be sure to place all safety guards in position **(Figure 7–9)**. A safety guard is a protective cover over a moving part. Although the safety guards are designed to prevent injury, you should still wear safety glasses and/or a face shield while using the machine. Make sure there are no people or parts around the machine before starting it. Stand off to the side when starting the grinder, not right in front of

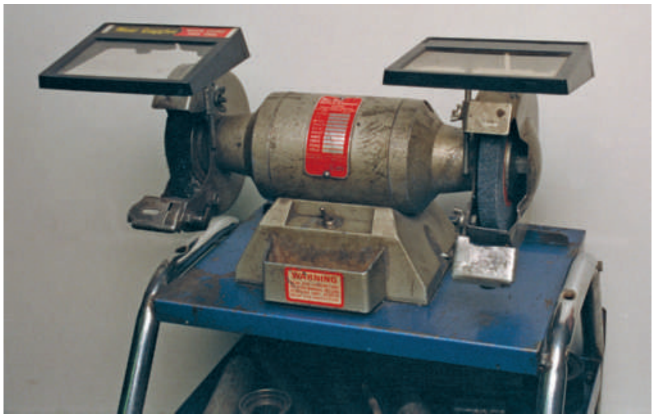


FIGURE 7-9 A bench with its safety shields in place.

it. Keep your hands and clothing away from the moving parts. Maintain a balanced stance while using the machine.

Compressed Air Tools Tools that use compressed air are called pneumatic tools. Compressed air is used to inflate tires, apply paint, and drive tools, such as air ratchets and impact wrenches. Pneumatic tools must always be operated at the pressure recommended by the manufacturer. Before using a pneumatic tool, check all hose connections for leaks and the air line for damage.

To use an air tool, connect the tool to the air hose coupler by sliding the locking sleeve back and inserting the tool's fitting into the hose coupler. Next, turn on the air supply valve and listen for any leaks. Do not use the air hose if there is a leak from the hose or fittings. Once finished with the tool, turn the air supply valve off and press the trigger on the tool to bleed off the pressure in the hose. Disconnect the tool and store the air hose properly.

When using an air nozzle, wear safety glasses and/or a face shield. Particles of dirt and pieces of metal, blown by the high-pressure air, can penetrate your skin or get into your eyes. Always hold an air nozzle securely when starting or shutting off the compressed air. A loose nozzle can whip suddenly and cause serious injury. Never point an air nozzle at anyone. Never use compressed air to blow dirt from your clothes or hair or use compressed air to clean the floor or workbench. Also, never spin bearings with compressed air. If the bearing is damaged, one of the steel balls or rollers might fly out and cause serious injury.

Lift Safety

Always be careful when raising a vehicle on a lift or a hoist. Adapters and hoist plates must be positioned correctly on lifts to prevent damage to the underbody of the vehicle. There are specific lift points. These points allow the weight of the vehicle to be evenly supported by the adapters or hoist plates. The correct lift points can be found in the vehicle's service information. **Figure 7–10** shows typical locations for unibody and frame cars. These diagrams are for illustration only. Also, always follow the recommended instructions for operating a particular lift.

Once the lift supports are properly positioned under the vehicle, raise the lift until the supports contact the vehicle. Then, check the supports to make sure they are in full contact with the vehicle. Shake the vehicle to make sure it is securely balanced on the lift, then raise the lift to the desired working height.

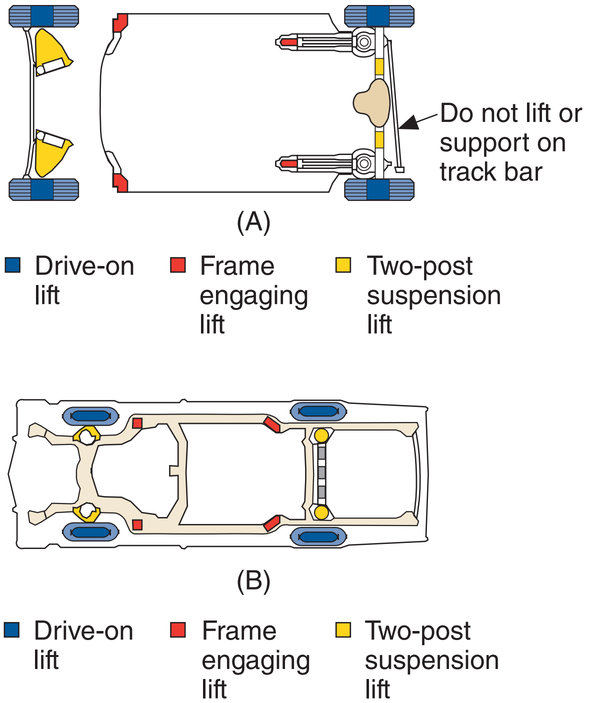


FIGURE 7–10 Typical lifting points: The correct ones for a vehicle are given in the service information for that vehicle.

Warning! Before working under a car, make sure the lift's locking device is engaged.

The Automotive Lift Institute (ALI) is an association concerned with the design, construction, installation, operation, maintenance, and repair of automotive lifts. Their primary concern is safety. Every lift approved by ALI has the label shown in **Figure 7–11**. It is a good idea to read through the safety tips included on that label before using a lift.

Jack and Jack Stand Safety

A vehicle can be raised by a hydraulic jack **(Figure 7–12)**. A handle on the jack is moved up and down to raise a vehicle and a valve is turned to release the hydraulic pressure in the jack to lower it. The jack has a lifting pad, which must be positioned under an area of the vehicle's frame or at one of the manufacturer's recommended lift points. Never place the pad under the floorpan or under steering and suspension parts, because they can be damaged by the weight of the vehicle. Always position the jack so that the wheels of the vehicle can roll as the vehicle is being raised.

Safety stands, also called **jack stands** **(Figure 7–13)**, are supports of various heights that

AUTOMOTIVE LIFT

SAFETY TIPS

Post these safety tips where they will be a constant reminder to your lift operator. For information specific to the lift, always refer to the lift manufacturer's manual.

1. Inspect your lift daily. Never operate if it malfunctions or if it has broken or damaged parts. Repairs should be made with original equipment parts.
2. Operating controls are designed to close when released. Do not block open or override them.
3. Never overload your lift. Manufacturer's rated capacity is shown on nameplate affixed to the lift.
4. Positioning of vehicle and operation of the lift should be done only by trained and authorized personnel.
5. Never raise vehicle with anyone inside it. Customers or by-standers should not be in the lift area during operation.
6. Always keep lift area free of obstructions, grease, oil, trash, and other debris.
7. Before driving vehicle over lift, position arms and supports to provide unobstructed clearance. Do not hit or run over lift arms, adapters, or axle supports. This could damage lift or vehicle.
8. Load vehicle on lift carefully. Position lift supports to contact at the vehicle manufacturer's recommended lifting points. Raise lift until supports contact vehicle. Check supports for secure contact with vehicle. Raise lift to desired working height. CAUTION: If you are working under vehicle, lift should be raised high enough for locking device to be engaged.
9. Note that with some vehicles, the removal (or installation) of components may cause a critical shift in the center of gravity and result in raised vehicle instability. Refer to the vehicle manufacturer's service manual for recommended procedures when vehicle components are removed.
10. Before lowering lift, be sure tool trays, stands, etc. are removed from under vehicle. Release locking devices before attempting to lower lift.
11. Before removing vehicle from lift area, position lift arms and supports to provide an unobstructed exit (See Item #7).

These "Safety Tips," along with "Lifting it Right," a general lift safety manual, are presented as an industry service by the Automotive Lift Institute. For more information on this material, write to: ALI, P.O. Box 1519, New York, NY 10101.

Look For This Label on all Automotive Service Lifts.

FOUNDED 1945

AUTOMOTIVE LIFT INSTITUTE ALI MEMBER ®

THIS AUTOMOTIVE LIFT WAS MANUFACTURED TO CONFORM TO THE REQUIREMENTS OF ANSI/ALI B153.1, A SAFETY STANDARD DEVELOPED COOPERATIVELY WITH THE INDUSTRY AND THOSE SUBSTANTIALLY CONCERNED WITH ITS SCOPE AND PROVISIONS. THE MANUFACTURER IS RESPONSIBLE FOR THE CONSTRUCTION OF THIS PRODUCT TO THIS STANDARD.

AUTOMOTIVE LIFT INSTITUTE, INC.

Courtesy of the Automotive Lift Institute

FIGURE 7–11 Automotive lift safety tips.

FIGURE 7–12 A typical hydraulic jack.

FIGURE 7–13 Jack stands should be used to support the vehicle after it has been raised by a jack.

sit on the floor. They are placed under a sturdy chassis member, such as the frame or axle housing, to support the vehicle. Once the safety stands are in position, the hydraulic pressure in the jack should be slowly released until the weight of the vehicle is on the stands. Like jacks, jack stands also have a capacity rating. Always use a jack stand of the correct rating.

Never move under a vehicle when it is supported by only a hydraulic jack. Rest the vehicle on the safety stands before moving under the vehicle.

The jack should be removed after the jack stands are set in place. This eliminates a hazard, such as a jack handle sticking out into a walkway. A jack handle that is bumped or kicked can cause a tripping accident or cause the vehicle to fall.

Chain Hoist and Crane Safety

Heavy parts of the automobile, such as engines, are removed by using chain hoists **(Figure 7–14)** or cranes. Another term for a chain hoist is chain fall. Cranes often are called cherry pickers.

FIGURE 7–14 A heavy-duty engine hoist.

To prevent serious injury, chain hoists and cranes must be properly attached to the parts being lifted. Always use bolts with enough strength to support the object being lifted. Place the chain hoist or crane directly over the assembly. Then, attach the lifting chain or cable to the hoist.

Cleaning Equipment Safety

Parts cleaning is a necessary step in most repair procedures. Cleaning automotive parts can be divided into three basic categories.

Chemical cleaning relies on chemical action to remove dirt, grease, scale, paint, or rust **(Figure 7–15)**. A combination of heat, agitation, mechanical scrubbing, or washing may be used to remove dirt. Chemical cleaning equipment includes small parts washers, hot/cold tanks, pressure washers, spray washers, and salt baths.

Thermal cleaning relies on heat, which bakes off or oxidizes the dirt. Thermal cleaning leaves an ash residue on the surface that must be removed by an additional cleaning process, such as airless shot blasting or spray washing.

FIGURE 7–15 An aqueous solvent-based parts washer.

Abrasive cleaning relies on physical abrasion to clean the surface. This includes everything from a wire brush to glass bead blasting, airless steel shot blasting, abrasive tumbling, and vibratory cleaning.

Vehicle Operation

When a customer brings a vehicle in for service, certain driving rules should be followed to ensure your safety and the safety of those around you. For example, before moving a car into the shop, buckle your seat belt. Make sure no one is near, the way is clear, and there are no tools or parts under the car before you start the engine.

Check the brakes before putting the vehicle in gear. Then, drive slowly and carefully in and around the shop. When approaching blind spots or driving through garage doors, sound the horn to let others know that a vehicle is approaching.

When road testing the car, obey all traffic laws. Drive only as far as is necessary to check the automobile and verify the customer's complaint. Never make excessively quick starts, turn corners too quickly, or drive faster than conditions allow.

If the engine must be kept running while you are working on the car, block the wheels to prevent the vehicle from moving. Place the transmission in park for automatic transmissions or in neutral for manual transmissions. Set the parking (emergency) brake. Never stand directly in front of or behind a running vehicle.

When parking a vehicle in the shop, always roll the windows down. This allows access inside if the doors accidentally lock.

Venting the Engine's Exhaust Whenever you need to have the engine running for diagnosis or service, the engine's exhaust must be vented to the outside. Carbon monoxide (CO) is present in the exhaust. CO is an odorless, tasteless, and colorless deadly gas. Inhaling CO can cause brain damage and, in severe cases, death. Early symptoms of CO poisoning include headaches, nausea, and fatigue.

Most shops have an exhaust ventilation system **(Figure 7–16)**. These systems collect the engine's exhaust and release it to the outside air. Before running an engine in the shop, connect a hose from the vehicle's tailpipe to the vent system. Make sure the vent system is turned on before running the engine. If the work area does not have an exhaust venting system, use a hose to direct the exhaust out of the building.

FIGURE 7–16 When running an engine in a shop, make sure the vehicle's exhaust is connected to the shop's exhaust ventilation system.

Electrical Safety

To prevent personal injury or damage to the vehicle, you should always take the necessary precautions before working on or around a vehicle's electrical system. You should disconnect the battery before disconnecting any electrical wire or component. This prevents the possibility of a fire or electrical shock. It also eliminates the possibility of an accidental short, which can ruin the car's electrical system. Disconnect the negative or ground cable first **(Figure 7–17)**, then disconnect the positive cable. Because electrical circuits require a ground to be complete, by removing the ground cable you eliminate the possibility of a circuit accidentally becoming completed. When reconnecting the battery, connect the positive cable first, then the negative.

FIGURE 7–17 Before doing any electrical work or working around the battery, disconnect the negative lead of the battery.

Also, when disconnecting electrical connectors, do not pull on the wires. When reconnecting the connectors, make sure they are securely connected.

Battery Precautions Because the vehicle's electrical power is stored in a battery or battery pack, special handling precautions must be followed when working with or near batteries. Here are some general precautions for batteries.

- Make sure you are wearing safety glasses (preferably a face shield) and protective clothing when working around and with batteries.
- Keep all flames, sparks, and excessive heat away from the battery at all times, especially when it is being charged.
- Never lay metal tools or other objects on the battery because a short circuit across the terminals can result.
- All batteries have an electrolyte, which is very corrosive. It can cause severe injuries if it comes in contact with your skin or eyes. If electrolyte gets on you, immediately wash with baking soda and water. If the acid gets in your eyes, immediately flush them with cool water for a minimum of 15 minutes and get immediate medical attention.
- Acid from a battery can damage a vehicle's paint and metal surfaces and harm shop equipment. Neutralize any electrolyte spills during servicing.
- The most dangerous battery is one that has been overcharged. It is hot and has been, or still may be, producing large amounts of hydrogen. Allow the battery to cool before working with or around it. Also never use or charge a battery that has frozen electrolyte.
- Always use a battery carrier or lifting strap to make moving and handling batteries easier and safer.
- Always charge a battery in well-ventilated areas.
- Never connect or disconnect charger leads when the charger is turned on. This generates a dangerous spark.
- Turn off all accessories before charging the battery and correct any parasitic drain problems.
- Make sure the charger's power switch is off when you are connecting or disconnecting the charger cables to the battery.
- Always double-check the polarity of the battery charger's connections before turning the charger on. Incorrect polarity can damage the battery or cause it to explode.
- Never attempt to use a charger as a boost to start the engine.

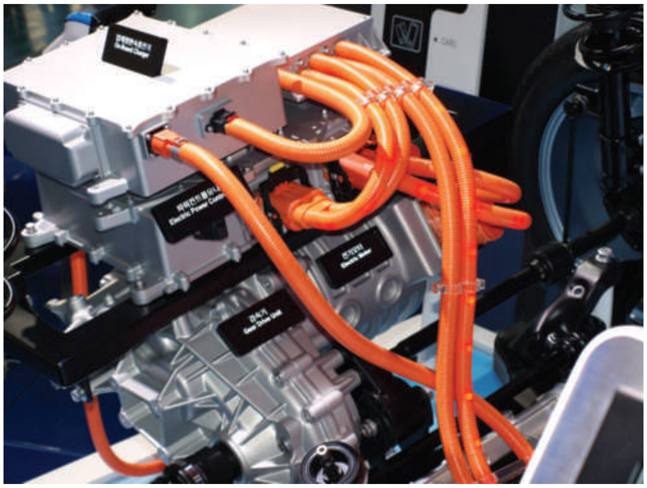


FIGURE 7–18 All high-voltage cables are colored orange and are enclosed in orange casing.

High-Voltage Systems Electric drive vehicles (battery-operated, hybrid, and fuel cell electric vehicles) have high-voltage electrical systems (from 42 volts to 650 volts). These high voltages can kill you! Fortunately, most high-voltage circuits are identifiable by size and color. The cables have thicker insulation and are typically colored orange **(Figure 7–18)**. The connectors are also orange. On most vehicles, the high-voltage cables are enclosed in an orange shielding or casing; again the orange indicates high voltage. In addition, the high-voltage battery pack and most high-voltage components have "High Voltage" caution labels **(Figure 7–19)**. Be careful not to touch these wires and parts. Here are some other safety precautions that should be adhered to when working on an electric drive vehicle:

- Always follow the safety guidelines given by the vehicle's manufacturer.
- Obtain the necessary training before working on these vehicles.
- Be sure to perform each repair operation correctly.
- Disable or disconnect the high-voltage system before performing services to those systems. Do this according to the procedures given by the manufacturer.
- Any time the engine is running in a hybrid vehicle, the generator is producing high voltage. Take care to prevent being shocked.
- Before doing any service to an electric drive vehicle, make sure the power to the electric motor is disconnected or disabled.
- Systems may have a high-voltage capacitor that must be discharged after the high-voltage system has been isolated. Make sure to wait the prescribed amount of time (normally about 10 minutes) before working on or around the high-voltage system.
- After removing a high-voltage cable, cover the terminal with vinyl electrical tape.
- Always use insulated tools **(Figure 7–20)**.

FIGURE 7–19 Most high-voltage components in a hybrid vehicle have "High Voltage" caution labels.

FIGURE 7–20 Examples of insulated tools that can be used when working on high-voltage systems.

- Use only the tools and test equipment specified by the manufacturer and follow the test procedures defined by the equipment manufacturer.
- Alert other technicians that you are working on the high-voltage systems with a warning sign such as “High-voltage work: Do not touch.”
- Wear insulating gloves when working on or around the high-voltage system. Make sure they have no tears, holes, or cracks and that they are dry. The integrity of the gloves should be checked before using them.
- Always install the correct type of circuit protection device into a high-voltage circuit.
- Many electric motors have a strong permanent magnet in them; do not handle these parts if you have a pacemaker.
- When an electric drive vehicle needs to be towed into the shop for repairs, make sure it is not towed on its drive wheels. Doing this will drive the generator(s), which can overcharge the batteries and cause them to explode. Always tow these vehicles with the drive wheels off the ground or move them on a flat bed.

Rotating Pulleys and Belts

Be careful around belts, pulleys, wheels, chains, or any other rotating part. When working around these, make sure your hands, shop towels, or loose clothing do not come in contact with the moving parts. Hands and fingers can be quickly pulled into a revolving belt or pulley even at engine idle speeds.

> **Warning!** Be careful when working around electric engine cooling fans. These fans can come on without warning, even when the engine is not running. Whenever you must work around these fans, disconnect the electrical connector to the fan motor before reaching into the area around the fan.

Work Area Safety

The floor of your work area and bench tops should be kept clean, dry, and orderly. Any oil, coolant, or grease on the floor can make it slippery. Slips can result in serious injuries. To clean up oil, use commercial oil absorbent. Also, keep all water off the floor. Water is slippery on smooth floors, and electricity flows well through water. Aisles and walkways should be kept clean and wide enough to easily move through. Make sure the work areas around machines are large enough to safely operate the machine.

Make sure all drain covers are snugly in place. Open drains or covers that are not flush to the floor can cause toe, ankle, and leg injuries.

Keep an up-to-date list of emergency telephone numbers clearly posted next to the telephone. These numbers should include a doctor, hospital, and fire and police departments. Also, the work area should have a first-aid kit for treating minor injuries and eye-flushing kits readily available. You should know where these items are kept.

Fire Hazards and Prevention

Gasoline is a highly flammable volatile liquid. Something that is flammable catches fire and burns easily. A volatile liquid is one that vaporizes very quickly. Flammable volatile liquids are potential fire bombs. Always keep gasoline, ethanol, or diesel fuel in an approved safety can **(Figure 7–21)**, and never use gasoline to clean your hands or tools.

The presence of gasoline is so common that its dangers are often forgotten. A slight spark or an increase in heat can cause a fire or explosion. Gasoline fumes are heavier than air. Therefore, when an open container of gasoline is sitting about, the fumes spill out over the sides of the container. These fumes are more flammable than liquid gasoline and can easily explode.

FIGURE 7–21 Flammable liquids should be stored in safety-approved containers.

Caution! Never siphon gasoline or diesel fuel with your mouth. These liquids are poisonous and can make you sick or fatally ill.

Never smoke around gasoline or in a shop filled with gasoline fumes. If the vehicle has a gasoline leak or you have caused a leak by disconnecting a fuel line, wipe it up immediately and stop the leak. Make sure that any grinding or welding that may be taking place in the area is stopped until the spill is totally cleaned up and the floor has been flushed with water. The rags used to wipe up the gasoline should be taken outside to dry, then stored in an approved dirty rag container. If vapors are present in the shop, have the doors open and turn on the ventilating system. It takes only a small amount of fuel mixed with air to cause combustion.

Ethanol Most commonly found as E85 (15 percent gasoline mixed with 85 percent ethanol), it is a very volatile liquid. Ethanol is a non-petroleum-based fuel and is used as an alternative fuel to gasoline. Ethanol is also used as an additive to increase the octane rating of gasoline. Handle and store E85 in the same way as gasoline.

Diesel Fuel Diesel fuel is not as volatile as gasoline but should be stored and handled in the same way. It is also not as refined as gasoline and normally contains many impurities, including active microscopic organisms that can be highly infectious. If diesel fuel happens to get on an open cut or sore, thoroughly wash it immediately.

Solvents Cleaning solvents are also not as volatile as gasoline, but they are still flammable. These should be stored and treated in the same way as gasoline. Handle all solvents (or any liquids) with care to avoid spillage. Keep all solvent containers closed, except when pouring. Proper ventilation is very important in areas where volatile solvents and chemicals are used. Solvent and other combustible materials must be stored in approved and designated storage cabinets or rooms **(Figure 7–22).**

Discard or clean all empty solvent containers. Solvent fumes in the bottom of these containers are very flammable. Never light matches or smoke near flammable solvents and chemicals, including battery acids.

Rags Oily or greasy rags can also be a source for fires. These rags should be stored in an approved container **(Figure 7–23)** and never thrown out with normal trash. When these oily, greasy, or paint-soaked rags are left lying about or are not stored

FIGURE 7–22 Store combustible materials in safety-approved cabinets.

Courtesy of the DuPont Company.

FIGURE 7–23 Dirty rags and towels should be kept in an approved container.

properly, they can cause spontaneous combustion. Spontaneous combustion results in a fire that starts by itself, that is, without a match.

Fire Extinguishers

You should know the location of all fire extinguishers **(Figure 7–24)** and fire alarms in the shop and how to use them before you need one. You should also be aware of the different types of fires and fire extinguishers **(Table 7–1)**. All extinguishers are marked with a symbol or letter signifying the class of fire for which they are intended. Using the wrong type of extinguisher may cause the fire to grow instead of being put out.

If a fire extinguisher is not handy, a blanket or fender cover may be used to smother the flames. Be careful when doing this because the heat of the fire may burn you and the blanket. If the fire is too great to smother, move everyone away from the fire and call the local fire department. A simple under-the-hood fire can cause the total destruction of the car and the building and can take some lives. You must be able to respond quickly and precisely to avoid a disaster.

In the event a fire becomes more than can be safely handled with a fire extinguisher, you and everyone else in the shop will need to evacuate the area. Every school and pubic building should have evacuation routes posted. These routes should clearly identify the nearest emergency exits.

FIGURE 7–24 Know the location and types of fire extinguishers that are available in the shop.

(Figure 7–25) During the first days of class or at the start of a new job, make sure you locate the evacuation routes and understand exactly where you are to go in the event of an emergency.

Using a Fire Extinguisher Remember, never open doors or windows during a fire unless it is absolutely necessary; the extra draft will only make the fire worse. Make sure the fire department is contacted before or during your attempt to extinguish a fire. To extinguish a fire, stand 6 to 10 feet from the fire. Before releasing the agent from the extinguisher,

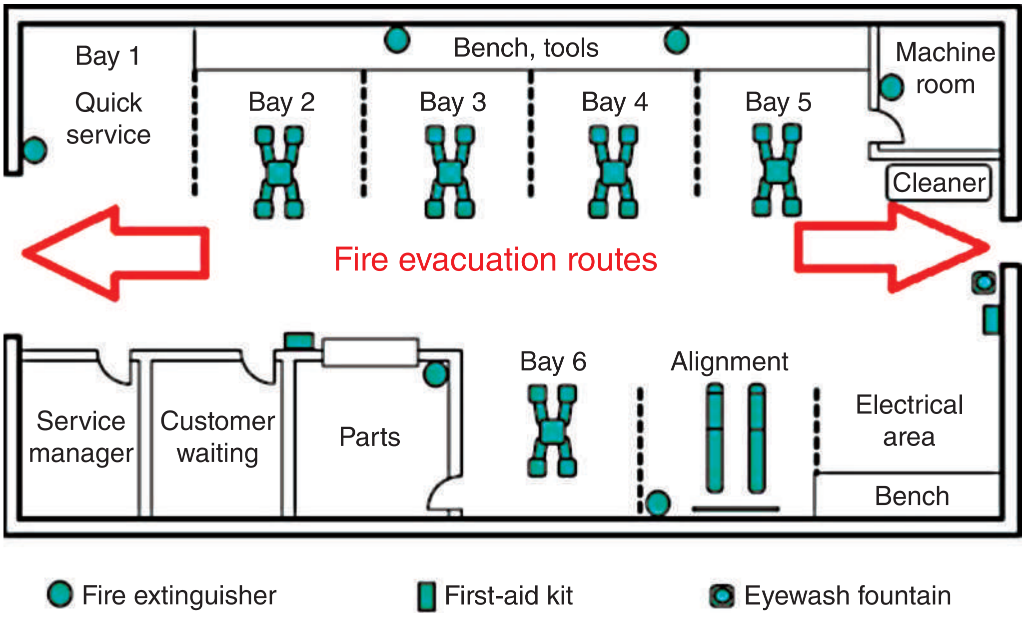


FIGURE 7–25 Identify evacuation routes before you actually need them.

TABLE 7–1 GUIDE TO EXTINGUISHER SELECTION

	Class of Fire	Typical Fuel Involved	Type of Extinguisher
Class A Fires (green)	**For Ordinary Combustibles** Put out a class A fire by lowering its temperature or by coating the burning combustibles.	Wood Paper Cloth Rubber Plastics Rubbish Upholstery	Water*[1] Foam* Multipurpose dry chemical[4]
Class B Fires (red)	**For Flammable Liquids** Put out a class B fire by smothering it. Use an extinguisher that gives a blanketing, flame-interrupting effect; cover whole flaming liquid surface.	Gasoline Oil Grease Paint Lighter fluid	Foam* Carbon dioxide[5] Halogenated agent[6] Standard dry chemical[2] Purple K dry chemical[3] Multipurpose dry chemical[4]
Class C Fires (blue)	**For Electrical Equipment** Put out a class C fire by shutting off power as quickly as possible and by always using a nonconducting extinguishing agent to prevent electric shock.	Motors Appliances Wiring Fuse boxes Switchboards	Carbon dioxide[5] Halogenated agent[6] Standard dry chemical[2] Purple K dry chemical[3] Multipurpose dry chemical[4]
Class D Fires (yellow)	**For Combustible Metals** Put out a class D fire of metal chips, turnings, or shavings by smothering or coating with a specially designed extinguishing agent.	Aluminum Magnesium Potassium Sodium Titanium Zirconium	Dry powder extinguishers and agents only

**Cartridge-operated water, foam, and soda-acid types of extinguishers are no longer manufactured. These extinguishers should be removed from service when they become due for their next hydrostatic pressure test.*

Notes:

(1) Freezes in low temperatures unless treated with antifreeze solution, usually weighs more than 20 pounds (9 kg), and is heavier than any other extinguisher mentioned.

(2) Also called ordinary or regular dry chemical (sodium bicarbonate).

(3) Has the greatest initial fire-stopping power of the extinguishers mentioned for class B fires. Be sure to clean residue immediately after using the extinguisher so sprayed surfaces will not be damaged (potassium bicarbonate).

(4) The only extinguishers that fight A, B, and C classes of fires. However, they should not be used on fires in liquefied fat or oil of appreciable depth. Be sure to clean residue immediately after using the extinguisher so sprayed surfaces will not be damaged (ammonium phosphates).

(5) Use with caution in unventilated, confined spaces.

(6) May cause injury to the operator if the extinguishing agent (a gas) or the gases produced when the agent is applied to a fire is inhaled.

hold the extinguisher firmly in an upright position. Aim the nozzle at the base and use a side-to-side motion, sweeping the entire width of the fire **(Figure 7–26)**. To help remember how to use an extinguisher, remember the word “PASS.” Also, stay low to avoid inhaling the smoke. If the area gets too hot or too smoky, get out. Never go back into a burning building for anything.

FIGURE 7-26 Aim the nozzle at the base of the fire and sweep the entire width of the fire.

Pull the pin from the handle of the extinguisher.

Aim the extinguisher's nozzle at the base of the fire.

Squeeze the handle.

Sweep the entire width of the fire with the contents of the extinguisher.

Manufacturers' Warnings and Government Regulations

A typical shop contains many potential health hazards for those working in it. These hazards can cause injury, sickness, health impairments, discomfort, and even death. These hazards can be classified as:

Chemical hazards—caused by high concentrations of vapors, gases, or dust

Hazardous wastes—those substances that are the result of a service

Physical hazards—include excessive noise, vibration, pressures, and temperatures

Ergonomic hazards—conditions that impede normal body position and motion

Many government agencies have the responsibility to ensure safe work environments for all workers. Federal agencies include the **Occupational Safety and Health Administration (OSHA)**, Mine Safety and Health Administration (MSHA), and National Institute for Occupational Safety and Health (NIOSH). These agencies, as well as state and local governments, have instituted regulations that must be understood and followed. Everyone in a shop has the responsibility to adhere to these regulations.

OSHA

In 1970, OSHA was formed to "assure safe and healthful working conditions for workers by authorizing enforcement of the standards developed under the Act and by assisting and encouraging the States in their efforts to assure safe and healthful working conditions by providing research, information, education, and training in the field of occupational safety and health."

The established safety standards are consistent across the country. It is the employer's responsibility to provide a place of employment free from all recognized hazards. All automotive industry safety and health issues are controlled by OSHA.

Right-To-Know Law

OSHA also regulates the use of many potentially hazardous materials. The Environmental Protection Agency (EPA) regulates their disposal. Servicing and maintaining a vehicle involves the handling and managing of a wide variety of materials and wastes. Some of these wastes can be toxic to fish, wildlife, and humans when improperly managed. It is the shop's legal responsibility to manage the wastes properly and to prevent the pollution of our natural resources.

An important part of a safe work environment is the employee's knowledge of potential hazards. All employees are protected by **Right-To-Know Laws** concerning all potentially hazardous materials. OSHA's Hazard Communication Standard was originally intended for chemical companies and manufacturers that require employees to handle potentially hazardous materials. Since then federal courts decided that these regulations should apply to all companies, including auto repair shops.

The general intent of Right-To-Know Laws is for employers to provide their employees with a safe working place. All employees must be trained about their rights, the nature of the hazardous chemicals in their workplace, and the contents of the labels on the chemicals. All information about each chemical must be posted on **safety data sheets (SDS)**, formerly known as material safety data sheets (MSDS) and must be accessible. The manufacturer of the chemical provides these sheets **(Figure 7–27)**. They detail the chemical composition and precautionary information for all products that can present a health or safety hazard.

A SDS lists the product's ingredients, potential health hazards, physical description, explosion and

HEXANE

MSDS Safety Information

Ingredients

Name: HEXANE (N_HEXANE)

% Wt: >97

OSHA PEL: 500 PPM

ACGIH TLV: 50 PPM

EPA Rpt Qty: 1 LB

DOT Rpt Qty: 1 LB

Health Hazards Data

LD50 LC50 Mixture: LD50:(ORAL,RAT) 28.7 KG/MG

Route Of Entry Inds _ Inhalation: YES

Skin: YES

Ingestion: YES

Carcinogenicity Inds _ NTP: NO

IARC: NO

OSHA: NO

Effects of Exposure: ACUTE:INHALATION AND INGESTION ARE HARMFUL AND MAY BE FATAL. INHALATION AND INGESTION MAY CAUSE HEADACHE, NAUSEA, VOMITING, DIZZINESS, IRRITATION OF RESPIRATORY TRACT, GASTROINTESTINAL IRRITATION AND UNCONSCIOUSNESS. CONTACT W/SKIN AND EYES MAY CAUSE IRRITATION. PROLONGED SKIN MAY RESULT IN DERMATITIS (EFTS OF OVEREXP)

Signs And Symptoms Of Overexposure: HLTH HAZ:CHRONIC:MAY INCLUDE CENTRAL NERVOUS SYSTEM DEPRESSION.

Medical Cond Aggravated By Exposure: NONE IDENTIFIED.

First Aid: CALL A PHYSICIAN. INGEST:DO NOT INDUCE VOMITING. INHAL:REMOVE TO FRESH AIR. IF NOT BREATHING, GIVE ARTIFICIAL RESPIRATION. IF BREATHING IS DIFFICULT, GIVE OXYGEN. EYES:IMMED FLUSH W/PLENTY OF WATER FOR AT LEAST 15 MINS. SKIN:IMMED FLUSH W/PLENTY OF WATER FOR AT LEAST 15 MINS WHILE REMOVING CONTAMD CLTHG & SHOES. WASH CLOTHING BEFORE REUSE.

Handling and Disposal

Spill Release Procedures: WEAR NIOSH/MSHA SCBA & FULL PROT CLTHG. SHUT OFF IGNIT SOURCES:NO FLAMES, SMKNG/FLAMES IN AREA. STOP LEAK IF YOU CAN DO SO W/OUT HARM. USE WATER SPRAY TO REDUCE VAPS. TAKE UP W/SAND OR OTHER NON-COMBUST MATL & PLACE INTO CNTNR FOR LATER (SU PDAT)

Neutralizing Agent: NONE SPECIFIED BY MANUFACTURER.

Waste Disposal Methods: DISPOSE IN ACCORDANCE WITH ALL APPLICABLE FEDERAL, STATE AND LOCAL ENVIRONMENTAL REGULATIONS. EPA HAZARDOUS WASTE NUMBER:D001 (IGNITABLE WASTE).

Handling And Storage Precautions: BOND AND GROUND CONTAINERS WHEN TRANSFERRING LIQUID. KEEP CONTAINER TIGHTLY CLOSED.

Other Precautions: USE GENERAL OR LOCAL EXHAUST VENTILATION TO MEET TLV REQUIREMENTS. STORAGE COLOR CODE RED (FLAMMABLE).

Fire and Explosion Hazard Information

Flash Point Method: CC

Flash Point Text: _9F,_23C

Lower Limits: 1.2%

Upper Limits: 77.7%

Extinguishing Media: USE ALCOHOL FOAM, DRY CHEMICAL OR CARBON DIOXIDE. (WATER MAY BE INEFFECTIVE).

Fire Fighting Procedures: USE NIOSH/MSHA APPROVED SCBA & FULL PROTECTIVE EQUIPMENT (FP N).

Unusual Fire/Explosion Hazard: VAP MAY FORM ALONG SURFS TO DIST IGNIT SOURCES & FLASH BACK. CONT W/STRONG OXIDIZERS MAY CAUSE FIRE. TOX GASES PRDCED MAY INCL:CARBON MONOXIDE, CARBON DIOXIDE.

FIGURE 7–27 Material safety data sheets are an important part of employee training and should be readily accessible.

fire data, reactivity and stability data, and protection data including first aid and proper handling.

All hazardous materials must be properly labeled, indicating what health, fire, or reactivity hazard they pose and what protective equipment is necessary when handling each. Also, a list of all hazardous materials used in the shop must be posted for employees to see.

Shops must also keep records of all related training, records of accidents or spill incidents, satisfaction of employee requests for specific chemical information, and a general right-to-know compliance procedure manual utilized within the shop.

Hazardous Wastes

> **Warning!** When handling any hazardous waste material, be sure to wear the proper safety equipment recommended by the SDS. Follow all required procedures. This includes the use of approved respirator equipment.

Many repair and service procedures generate **hazardous wastes**, such as dirty solvents. Something is classified as a hazardous waste by the EPA if it is on its list of known harmful materials. A complete EPA list of hazardous wastes can be found in the Code of Federal Regulations. It should be noted that a material is only considered a hazardous waste when the shop is ready to dispose of it.

Regulations on the generation and handling of hazardous waste have led to the development of equipment found in shops. Examples of these are thermal cleaning units, close-loop steam cleaners, waste oil furnaces, oil filter crushers, refrigerant recycling machines, engine coolant recycling machines, and highly absorbent cloths.

> **Warning!** The shop is ultimately responsible for the safe disposal of hazardous waste, even after it leaves the shop. Only licensed waste removal companies should dispose of the waste. In addition to hauling the waste away, they will also take care of all the paperwork, deal with the various government agencies, and advise the shop on how to recover the disposal costs. If there is a hazardous waste spill, contact the National Response Center (1-800-424-8802) immediately. Failure to do so can result in a $10,000 fine or a year in jail, or both.

Always keep hazardous waste separate from other wastes. Make sure they are properly labeled and sealed in the recommended containers. The storage area should be covered and may need to be fenced and locked if vandalism could be a problem.

Guidelines for Handling Shop Wastes

Some of the common hazardous wastes, along with what you should do with them follows:

Oil Recycle oil. Set up equipment, such as a drip table or screen table with a used-oil collection bucket, to collect oil that drips off parts. Place drip pans underneath vehicles that are leaking fluids. Do not mix other wastes with used oil, except as allowed by

FIGURE 7–28 A single oil-filter crusher.

your recycler. Used oil generated by a shop (and/or oil received from household do-it-yourself generators) may be burned on site in a commercial space heater. Also, used oil may be burned for energy recovery. Contact state and local authorities to determine requirements and to obtain necessary permits.

Oil Filters Drain for at least 24 hours, crush **(Figure 7–28)**, and recycle used oil filters.

Batteries Recycle batteries by sending them to a reclaimer or back to the distributor. Keeping shipping receipts can demonstrate that you have recycled. Store batteries in a watertight, acid-resistant container. Inspect batteries for cracks and leaks when they come in. Treat a dropped battery as if it were cracked. Acid residue is hazardous because it is corrosive and may contain lead and other toxins. Neutralize spilled acid by covering it with baking soda or lime, and dispose of all hazardous material.

Metal Residue from Machining Collect metal filings from machining metal parts and recycle them, if possible. Prevent metal filings from falling into a sewer drain.

Refrigerants Recover and/or recycle refrigerants during the servicing of air-conditioning systems. You should never knowingly vent refrigerants into the atmosphere. Recovery and/or recycling must be performed by an EPA-certified technician using certified equipment and following specified procedures.

Solvents Replace hazardous chemicals with less toxic alternatives that have equal performance. For example, substitute water-based cleaning solvents for petroleum-based solvent degreasers. To reduce the amount of solvent used when cleaning parts, use a two-stage process: dirty solvent followed by fresh solvent. Hire a hazardous waste management service to clean and recycle solvents. Store solvents in closed containers to prevent evaporation. Evaporation of solvents contributes to ozone depletion and smog formation. In addition, the residue from evaporation must be treated as a hazardous waste.

Containers Cap, label, cover, and properly store all liquid containers and small tanks within a diked area and on a paved impermeable surface to prevent spills from running into surface or ground water.

Other Solids Store materials such as scrap metal, old machine parts, and worn tires under a roof or tarpaulin to protect them from the elements and to prevent potential contaminated runoff. Consider recycling tires by retreading them.

Liquid Recycling Collect and recycle coolants from radiators. Store transmission fluids, brake fluids, and solvents containing chlorinated hydrocarbons separately, and recycle or dispose of them properly.

Shop Towels/Rags Keep waste towels in a closed container marked "contaminated shop towels only." To reduce costs and liabilities associated with disposal of used towels, investigate using a laundry service that is able to treat the wastewater generated from cleaning the towels.

Asbestos has been identified as a health hazard. *Asbestos* is a term used to describe a number of naturally occurring fibrous materials. It is a carcinogen that causes a number of diseases including cancer. Asbestos-caused cancer, or mesothelioma, is a form of lung cancer. When breathed in, the asbestos fibers cause scarring of the lungs and/or damage to the lung's air passages. The injuries and scars become an effective holding place for the asbestos. Obviously, you want to avoid breathing in asbestos dust and fibers. Be careful when working with asbestos materials, such as brake pads, clutch discs, and some engine gaskets. All asbestos waste must be disposed of in accordance with OSHA and EPA regulations.

For more on work environment safety, contact the U.S. EPA Office of Compliance at http://es.inel.gov.

KEY TERMS

- Abrasive cleaning
- Asbestos
- Bloodborne pathogens
- Chemical cleaning
- Hazardous waste
- Jack stands
- Safety data sheets (SDS)
- Occupational Safety and Health Administration (OSHA)
- Right-To-Know Laws
- Safety data sheets
- Safety stands
- Thermal cleaning

SUMMARY

- Dressing safely for work is very important. Wear snug-fitting clothing, eye and ear protection, protective gloves, steel-toed shoes, and caps to cover long hair.
- When choosing eye protection, make sure it has safety glass and offers side protection.
- A respirator should be worn whenever you are working around toxic fumes or excessive dust.
- When shop noise exceeds safe levels, protect your ears by wearing earplugs or earmuffs.
- Safety while using any tool is essential, and even more so when using power tools. Before plugging in a power tool, make sure the power switch is off. Disconnect the power before servicing the tool.
- Always observe all relevant safety rules when operating a vehicle lift or hoist. Jacks, jack stands, chain hoists, and cranes can also cause injury if not operated safely.
- Use care while moving a vehicle in the shop. Carelessness and playing around can lead to a damaged vehicle and serious injury.
- Carbon monoxide (CO) gas is a poisonous gas present in engine exhaust fumes. Exhaust must be properly vented from the shop using tailpipe hoses or other reliable methods.
- Adequate ventilation is also necessary when working with any volatile solvent or material.
- Gasoline, Ethanol, and diesel fuel are highly flammable and should be kept in approved safety cans.
- Never light matches near any combustible materials.
- It is important to know when to use each of the various types of fire extinguishers. When fighting a fire, aim the nozzle at the base and use a side-to-side sweeping motion.
- Right-To-Know Laws came into effect in 1983 and are designed to protect employees who must handle hazardous materials and wastes on the job.
- Material safety data sheets (MSDS) contain important chemical information and must be furnished to all employees annually. New employees should be exposed to the sheets as part of their job orientation.
- All hazardous and asbestos waste should be disposed of according to OSHA and EPA regulations.

REVIEW QUESTIONS

Short Answer

1. What is the correct way to dispose of used oil filters?
2. Where in the shop should a list of emergency telephone numbers be posted?
3. Describe the correct process for lifting a heavy object.
4. What are bloodborne pathogens and why should technicians be concerned about them?
5. List at least five things you should remember when using hand tools.
6. List at least five precautions that must be adhered to while working with or around a vehicle's battery.
7. Describe the correct procedure for connecting and disconnecting an air hose from an air tool.
8. Where can complete EPA lists of hazardous wastes be found?
9. There are many ways to clean parts while they are being serviced. These methods can be grouped into three separate categories. What are they?
10. List at least five precautions that must be adhered to while working on a vehicle with a high-voltage system.
11. What is the correct procedure for using a fire extinguisher to put out a fire?

Multiple Choice

1. Which of the following offer(s) the least protection for your eyes?
   a. Face shield
   b. Safety glasses
   c. Splash goggles
   d. Prescription glasses

2. Which of the following statements about latex and nitrile gloves is *not* true?
   a. The gloves offer protection against cuts.
   b. The gloves offer protection against disease and grease buildup under and around your fingernails.
   c. Latex gloves are more comfortable but weaken when they are exposed to gas, oil, and solvents.
   d. Nitrile gloves are not as comfortable but they are not affected by gas, oil, and solvents.
3. Which of the following statements about safety glasses is true?
   a. They should offer side protection.
   b. The lenses should be made of a shatterproof material.
   c. Some service operations require that additional eye protection be worn with safety glasses.
   d. All of the above statements are true.
4. Gasoline is ___.
   a. highly volatile
   b. highly flammable
   c. dangerous, especially in vapor form
   d. All of the above
5. Technician A says that it is recommended that you wear shoes with nonslip soles in the shop. Technician B says that steel-toed shoes offer the best foot protection. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. Technician A says that used engine coolant should be collected and recycled. Technician B says that all oil-based waste materials can be collected in the same container if an approved waste disposal company is hired to rid the shop of the oil. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. Federal Right-To-Know Laws concern ___.
   a. auto emission standards
   b. hazards associated with chemicals used in the workplace
   c. employee benefits
   d. hiring practices
8. Which of the following is/are important when working in an automotive shop?
   a. Using the proper tool for the job
   b. Avoiding loose-fitting clothes
   c. Wearing steel-toed shoes
   d. All of the above
9. Technician A says that the flammability of a substance is a statement of how easily the substance vaporizes or explodes. Technician B says that the volatility of a substance is a statement of how well the substance supports combustion. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. Which of the following is *not* recommended for use when trying to extinguish flammable liquid fires?
    a. Foam
    b. Carbon dioxide
    c. Water
    d. Dry chemical
11. Technician A ties his long hair behind his head while working in the shop. Technician B covers her long hair with a cap. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
12. Technician A uses compressed air to blow dirt from his clothes and hair. Technician B uses compressed air to clean off the top of a workbench. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
13. Heavy protective gloves should be worn when ___.
    a. welding
    b. grinding metal
    c. working with caustic cleaning solutions
    d. All of the above
14. Proper disposal of oil filters includes ___.
    a. recycling used filters
    b. burning them in the waste oil heater
    c. crushing them
    d. Both A and C

PREVENTIVE MAINTENANCE AND BASIC SERVICES

CHAPTER 8

OBJECTIVES

- Describe the information that should be included on a repair order.
- Explain how the vehicle and its systems can be defined by deciphering its VIN.
- Explain the importance of preventive maintenance, and list at least six examples of typical preventive maintenance services.
- Understand the differences between the types of fluids required for preventive maintenance and know how to select the correct one for a particular vehicle.
- Explain how the design of a vehicle determines what preventive maintenance procedures must be followed.

Preventive maintenance services are those services performed not to correct problems but rather to prevent them. These and other basic services are covered in this chapter. All of these services may be performed by technicians in many different types of service facilities—dealerships, independents, and specialty shops **(Figure 8–1)**. Regardless of what type of shop, the first thing a tech needs to worry about is the repair order.

Repair Orders

A **repair order (RO)** is written for every vehicle brought into the shop. ROs may also be called service or work orders. ROs contain information about the customer, the vehicle, the customer's concern or request, an estimate of the cost for the services, and the time the services should be completed. ROs are legal documents that are used for many other purposes, such as payroll and general record keeping **(Figure 8–2)**. Legally, an RO protects the shop and the customer.

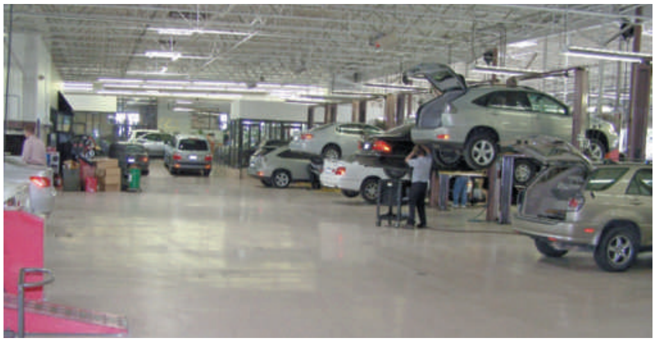


FIGURE 8-1 Service facilities run smoothly when there is good communication between the customer and the technician.

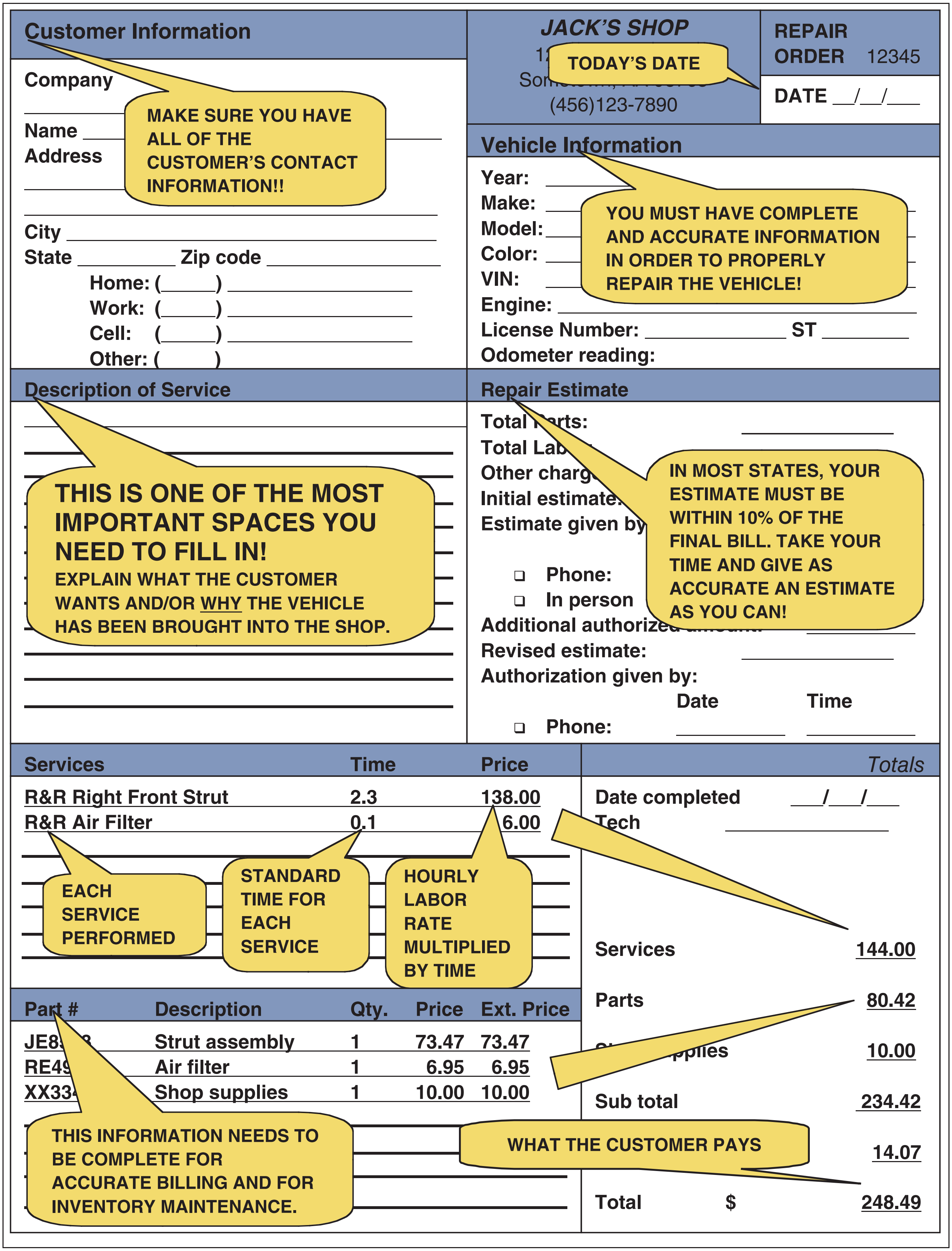


FIGURE 8–2 A completed repair order.

Although every shop may enter different information onto the original RO, most ROs contain the following information:

- Complete customer information
- Complete vehicle identification
- Service history of the vehicle
- The customer's concern
- Preliminary diagnosis of the problem
- Estimate of the amount of time and costs required for the service
- Time the services should be completed
- Name or other identification of the technician assigned to perform the services
- Actual services performed with their cost
- Parts replaced during the services and their cost
- Recommendations for future services

An RO is signed by the customer, who in doing so authorizes the services and accepts the terms noted on the RO. The customer also agrees to pay for the services when they are completed. Many states require a customer signature to begin repair work and for a change in the original estimate. If a signature is not required for changes in the original estimate, all phone conversations concerning the estimate should be noted on the RO.

In most cases when a customer signs the RO, he or she acknowledges the shop's right to impose a mechanic's lien. This lien basically says that the shop may gain possession of the vehicle if the customer does not pay for the agreed-upon services and the vehicle remains at the shop for a period of 90 or more days. This clause ensures that the shop will receive some compensation for the work performed, whether or not the customer pays the bill.

Service records are kept by the shop to maintain the vehicle's service history and for legal purposes. Evidence of repairs and recommended repairs is very important for settling potential legal disputes with the vehicle's owner in the future.

Computerized Shop Management Systems

Most service facilities use computerized shop management software **(Figure 8–3)**.

The information for the completion of an RO is input into a computer. The software also helps in the estimation of repair costs. The software also takes information from the RO and saves it in various files. These files are used for many purposes, such as schedule reminders, bookkeeping, vehicle/owner history, and tracking employee productivity. Notes can also be added to the RO (these do not appear on the RO). These personal notes can be used to remind the shop of commitments made to the customer, any special information about the customer and/or the vehicle, and any abnormal events that took place during the customer's last visit to the shop.

When the customer arrives at the shop, the computer can quickly recall all pertinent information about the vehicle. Typically, all the service writer needs to do is input the vehicle's license number, the vehicle's identification number, or the owner's name. If the customer has been to the shop before, all information will be available to the service writer. Also, most shop management software relies on numerical codes to denote what services have been and will be performed. These codes serve as shortcuts so the service writer does not need to key in the description of each service. The codes are designated by the software company or the vehicle's manufacturer. At a dealership, these link directly to the warranty reimbursement file.

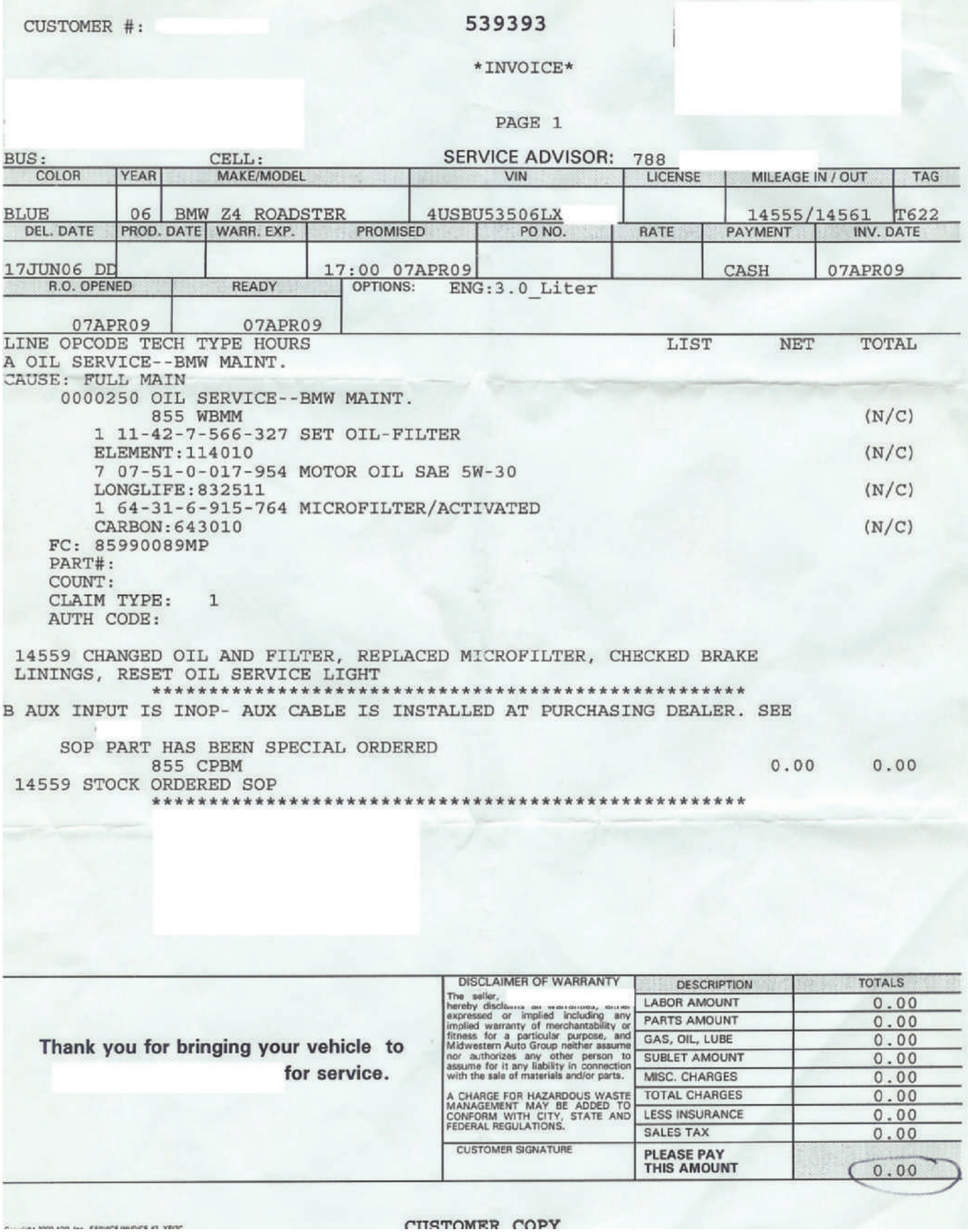
Parts Replacement

Very often when a service is performed, parts are replaced. This appears on the RO as "R&R," which stands for "remove and replace." In a dealership, nearly all of the replacement parts are original equipment manufacturer (OEM) parts obtained through the parts department. Some replacement parts installed by a dealership and nearly all parts installed by other service facilities are from the aftermarket. Other replacement parts may be rebuilt or remanufactured units. Normally, remanufactured parts are totally tested, disassembled, cleaned, and machined, and all of the weak or dysfunctional parts replaced. If this process is completed correctly, the remanufactured part will be as reliable as an original equipment (OE) part.

If the replaced part has no core value, the shop disposes of the part. However, many shops offer the part to the customer as proof that the part was removed and a new one installed. In many states, the shop is required by law to either return the old parts or allow the customer to inspect them. Always place the part in plastic or another container before putting it inside the vehicle. This will prevent any dirt on the part from getting on anything inside the vehicle.

Sublet Repairs

Service facilities typically do not perform all possible services. Often another business will be contracted to perform a service or part of a service. This is referred to as subletting. **Sublet repairs** are sent to



CUSTOMER #: 539393

INVOICE

PAGE 1

BUS: CELL: SERVICE ADVISOR: 788

COLOR	YEAR	MAKE/MODEL	VIN	LICENSE	MILEAGE IN / OUT	TAG
BLUE	06	BMW Z4 ROADSTER	4USBU53506LX		14555/14561	T622

DEL. DATE	PROD. DATE	WARR. EXP.	PROMISED	PO NO.	RATE	PAYMENT	INV. DATE
17JUN06 DD			17:00 07APR09			CASH	07APR09

R.O. OPENED	READY	OPTIONS:
07APR09	07APR09	ENG:3.0_Liter

LINE OPCODE TECH TYPE HOURS	LIST	NET	TOTAL
A OIL SERVICE--BMW MAINT.			
CAUSE: FULL MAIN			
0000250 OIL SERVICE--BMW MAINT.			
855 WBMM			(N/C)
1 11-42-7-566-327 SET OIL-FILTER			
ELEMENT:114010			(N/C)
7 07-51-0-017-954 MOTOR OIL SAE 5W-30			
LONGLIFE:832511			(N/C)
1 64-31-6-915-764 MICROFILTER/ACTIVATED			
CARBON:643010			(N/C)
FC: 85990089MP			
PART#:			
COUNT:			
CLAIM TYPE: 1			
AUTH CODE:			
14559 CHANGED OIL AND FILTER, REPLACED MICROFILTER, CHECKED BRAKE LININGS, RESET OIL SERVICE LIGHT			
**			
B AUX INPUT IS INOP- AUX CABLE IS INSTALLED AT PURCHASING DEALER. SEE			
SOP PART HAS BEEN SPECIAL ORDERED			
855 CPBM		0.00	0.00
14559 STOCK ORDERED SOP			
**			

Thank you for bringing your vehicle to for service.

DISCLAIMER OF WARRANTY

The seller, hereby disclaims all warranties, either expressed or implied including any implied warranty of merchantability or fitness for a particular purpose, and Midwestern Auto Group neither assume nor authorizes any other person to assume for it any liability in connection with the sale of materials and/or parts.

A CHARGE FOR HAZARDOUS WASTE MANAGEMENT MAY BE ADDED TO CONFORM WITH CITY, STATE AND FEDERAL REGULATIONS.

CUSTOMER SIGNATURE

DESCRIPTION	TOTALS
LABOR AMOUNT	0.00
PARTS AMOUNT	0.00
GAS, OIL, LUBE	0.00
SUBLET AMOUNT	0.00
MISC. CHARGES	0.00
TOTAL CHARGES	0.00
LESS INSURANCE	0.00
SALES TAX	0.00
PLEASE PAY THIS AMOUNT	0.00

CUSTOMER COPY

FIGURE 8–3 Most shops use computer-based shop management systems.

When estimating the cost of a repair or service:

- Make sure you have the correct contact information for the customer.
- Make sure you have the correct information about the vehicle.
- Always use the correct labor and parts guide or database for that specific vehicle.
- Locate the exact service for that specific vehicle in the guide or database.
- Using the guidelines provided in the guide or database, choose the proper time allocation listed for the service.
- Multiply the allocated time by the shop's hourly labor rate.
- If any sublet repairs are anticipated, list this service as a sublet repair and add the cost to the labor costs.
- Using the information given in the guide or database, identify the parts that will be replaced for that service.
- Locate the cost of the parts in the guide or database or in the catalogs used by the shop.
- Repeat the process for all other services required or requested by the customer.
- Multiply the time allocations by the shop's hourly flat rate.
- Add all of the labor costs together; this sum is the labor estimate for those services.
- Add the cost of all the parts together; this sum is the estimate for the parts required for the services.
- Add the total labor and parts costs together. If the shop charges a standard fee for shop supplies, add it to the labor and parts total. This sum is the cost estimate to present to the customer.

FIGURE 8-4 Guidelines for estimating the cost of repairs.

shops that specialize in certain repairs, such as radiator repairs. The cost of the subletting is added to the costs of the services performed by the service facility. Often the customer is billed slightly more than the actual cost of the sublet repair.

When Estimating the Cost of a Repair or Service:

- Make sure you have the correct contact information for the customer and the correct information about the vehicle.
- Always use the correct labor and parts guide or database for that specific vehicle.
- Locate the exact service for that specific vehicle in the guide or database.
- Using the guidelines, choose the proper time allocation listed for the service.
- Multiply the allocated time by the shop's hourly labor rate.
- If any sublet repairs are anticipated, list this service as a sublet repair and add the cost to the labor costs.
- Using the information given, identify the parts that will be replaced for that service.
- Locate the cost of the parts that will be replaced.
- Repeat the process for all other services required or requested by the customer.
- Add all of the labor costs together; this sum is the labor estimate for those services.
- Add the cost of all the parts together; this sum is the estimate for the parts required for the services.
- Add the total labor and parts costs together. If the shop charges a standard fee for shop supplies, add it to the labor and parts total. This sum is the cost estimate to present to the customer.

The customer is protected against being charged more than the estimate given on the RO, unless he or she later authorizes a higher amount. Some states allow shops to be within 10 percent of the estimate, whereas others hold the shop to the amount that was estimated. **Figure 8–4** lists some things to follow when estimating the cost of services and repairs.

Vehicle Identification

Before any service is done to a vehicle, it is important to know exactly what type of vehicle you are working on. The best way to do this is to refer to the **vehicle's identification number (VIN)**. The VIN is on a plate behind the lower corner of the driver's side of the windshield as well as other locations on the vehicle. The VIN is made up of seventeen characters and contains all pertinent information about the vehicle. The use of the seventeen number and letter code became

FIGURE 8–5 A vehicle identification plate.

mandatory in 1981 and is used by all manufacturers of vehicles both domestic and foreign. Most new vehicles have a scan code below the VIN **(Figure 8–5)**.

Each character of a VIN has a particular purpose. The first character identifies the country where the vehicle was manufactured; for example:

- 1 or 4 – U.S.A.
- 2 – Canada
- 3 – Mexico
- J – Japan
- K – Korea
- S – England
- W – Germany

The second character identifies the manufacturer; for example:

- A – Audi
- B – BMW
- C – Chrysler
- D – Mercedes-Benz
- F – Ford
- G – General Motors
- H – Honda
- N – Nissan
- T – Toyota

The third character identifies the vehicle type or manufacturing division (passenger car, truck, bus, etc). The fourth through eighth characters identify the features of the vehicle, such as the body style, vehicle model, and engine type.

The ninth character is used to identify the accuracy of the VIN and is a check digit. The tenth character identifies the model year; for example:

- D – 2013
- E – 2014
- F – 2015
- G – 2016
- H – 2017
- J – 2018
- K – 2019
- L – 2020
- M – 2021
- N – 2022
- P – 2023
- R – 2024
- S – 2025
- T – 2026
- V – 2027

The eleventh character identifies the plant where the vehicle was assembled, and the twelfth to seventeenth characters identify the production sequence of the vehicle as it rolled off the manufacturer's assembly line.

Preventive Maintenance

Preventive maintenance (PM) involves performing certain services to a vehicle on a regularly scheduled basis before there is any sign of trouble. Regular inspection and routine maintenance can prevent major breakdowns and expensive repairs. It also keeps cars and trucks running efficiently and safely.

Once the vehicle's warranty or maintenance term expires, repairs will have to be made and paid for by the customer. A 2012 study found that the average age of passenger cars in the United States is over 11 years old. The numbers of vehicles on the road, average vehicle age, and length of ownership have been increasing for years. To keep older

vehicles running properly, the PM program is vitally important.

A survey of 2,375 vehicles conducted during National Car Care Month found that more than 90 percent of the cars lacked some form of service. The cars were inspected for exhaust emissions, fluid levels, tire pressure, and other safety features. The results indicated that 34 percent of the cars had restricted air filters; 27 percent had worn belts; 25 percent had clogged PCV filters; 14 percent had worn hoses; and 20 percent had bad batteries, battery cables, or terminals.

During the fluid and cooling system inspection, 39 percent failed due to bad or contaminated transmission or power-steering fluid, 36 percent had worn-out or dirty engine oil, 28 percent had inadequate cooling system protection, and 8 percent had a faulty radiator cap.

In the safety category, 50 percent failed due to worn or improperly inflated tires, 32 percent had inoperative headlights or brake lights, and 14 percent had worn wipers.

Maintenance Schedules and Reminders

A typical PM schedule recommends particular service at mileage or time intervals. Driving habits and conditions should also be used to determine the frequency of PM service intervals. For example, vehicles that frequently are driven for short distances in city traffic often require more frequent oil changes due to the more rapid accumulation of condensation and unburned fuel in the oil. Most manufacturers also specify more frequent service intervals for vehicles that are used to tow a trailer or those that operate in extremely dusty or unusual conditions.

It is important that your customer understands the differences between what the vehicle manufacturer considers normal and severe service. In many cases, if a vehicle is driven in any of the conditions listed in the severe service category, the maintenance intervals increase to twice as often as for normal service. Because operating conditions and manufacturer's maintenance recommendations vary, many shops suggest using the manufacturer's PM schedule as the minimum requirement. The shop may then tailor the vehicle's PM schedule based on the actual operating conditions.

Many vehicles now use maintenance reminder systems. These systems often show a message, such as the engine oil life percentage, in a driver information center. Other vehicles show codes for the next required service **(Figure 8–6)**. To determine what services are specified by the code, check the vehicle's service manual or the service information.

FIGURE 8-6 A maintenance indicator and service identifier.

Safety Inspections

Several states require annual or biennial vehicle safety inspections. The intent of these inspections is to improve road safety. Research shows that states with annual safety inspection programs have 20 percent fewer accidents than states without these inspections. The inspections consist of a series of checks of various systems and areas of a vehicle. Common checks are shown in **Figure 8–7**. The exact systems and subsystems that are inspected vary. The inspections may be part of the vehicle registration process. Often automobile dealers are required to complete a safety inspection on all used vehicles before they are sold and report the results to the customer.

Basic Services

Often while performing PM on a vehicle, a technician notices the need for a minor repair. Both PM and those basic minor services are covered in the rest of this chapter.

CUSTOMER CARE

Whenever you do any service to a vehicle, use fender covers **(Figure 8–8)** and do not leave fingerprints on the exterior or interior of the car. Use floor, seat, and steering wheel covers to protect the interior. If oil or grease gets on the car, clean it off.

INSPECT WINDSHIELD AND OTHER GLASS FOR:

Cloudiness, distortion, or other obstruction to vision.
Cracked, scratched, or broken glass.
Window tinting.
Operation of front door glass.

INSPECT WINDSHIELD WIPER/WASHER FOR:

Operating condition.
Condition of blade.

INSPECT WINDSHIELD DEFROSTER FOR:

Operating condition.

INSPECT MIRRORS FOR:

Rigidity of mounting.
Condition of reflecting surface.
View of road to rear.

INSPECT HORN FOR:

Electrical connections, mounting, and horn button.
Emits a sound audible for a minimum of 200 feet.

INSPECT DRIVER'S SEAT FOR:

Anchorage.
Location.
Condition.

INSPECT SEAT BELTS FOR:

Condition.

INSPECT HEADLIGHTS FOR:

Approved type, aim, and output.
Condition of wiring and switch.
Operation of beam indicator.

INSPECT OTHER LIGHTS FOR:

Operation of all lamps, lens color, and condition of lens.
Aim of fog and driving lamps.

INSPECT SIGNAL DEVICE FOR:

Correct operation of indicators (visual or audible).
Illumination of all lamps, lens color, and condition of lens.

INSPECT FRONT DOORS FOR:

Handle or opening device permits the opening of the door from the outside and inside of the vehicle.
Latching system that holds door in its proper closed position.

INSPECT HOOD FOR:

Operating condition of hood latch.

INSPECT FLUIDS FOR:

Levels that are below the proper level.

INSPECT BELTS AND HOSES FOR:

Belt tension, wear, or absence.
Hose damage.

INSPECT POLLUTION CONTROL SYSTEM FOR:

Presence of emissions system-evidence that no essential parts have been removed, rendered inoperative, or disconnected.

INSPECT BATTERY FOR:

Proper anchorage.
Loose or damaged connections.

INSPECT FUEL SYSTEM FOR:

Any part that is not securely fastened.
Liquid fuel leakage.
Fuel tank filler cap for presence.

INSPECT EXHAUST SYSTEM FOR:

Damaged exhaust-manifold, gaskets, pipes, mufflers, connections, etc.
Leakage of gases at any point from motor to point discharged from system.

INSPECT STEERING AND SUSPENSION FOR:

Play in steering wheel.
Wear in bushings, kingpins, ball joints, wheel bearings, and tie-rod ends.
Looseness of gear box on frame, condition of drag link, and steering arm.
Wheel alignment and axle alignment.
Broken spring leaves and worn shackles.
Shock absorbers.
Broken frame.
Broken or missing engine mounts.
Lift blocks.

INSPECT FLOOR PAN FOR:

Holes that allow exhaust gases to enter occupant compartment.
Conditions that create a hazard to the occupants.

INSPECT BRAKES FOR:

Worn, damaged, or missing parts.
Worn, contaminated, or defective linings or drums.
Leaks in system and proper fluid level.
Worn, contaminated, or defective disc pads or discs.
Excessive pedal play.

INSPECT PARKING BRAKE FOR:

Proper adjustment.

INSPECT TIRES, WHEELS, AND RIMS FOR:

Proper inflation.
Loose or missing lug nuts.
Condition of tires, including tread depth.
Mixing radials and bias ply tires.
Wheels that are cracked or damaged so as to cause unsafe operation.

FIGURE 8-7 A safety inspection may include these items.

Service Bulletin and Recall Check

When a vehicle is brought in for service, many shops will check for applicable technical service bulletins (TSBs) and recalls. Any items that apply can be addressed with the customer. A search for TSBs often can save your time and trouble by providing you with information about a concern, an updated part or repair procedure before you spend time trying to figure out a concern on your own. Also, it is

FIGURE 8–8 Fender covers should be used when working under the hood.

possible that the owner of the vehicle is not aware that a recall applies to his or her car. Alerting them can help build trust and goodwill between the customer and the shop.

Engine Oil

Engine oil is a clean or refined form of **crude oil**. Crude oil, when taken out of the ground, is dirty and does not work well as a lubricant for engines. Crude oil must be refined to meet industry standards. Engine oil (often called motor oil) is just one of the many products that come from crude oil. Engine oil is specially formulated to:

- Flow easily through the engine
- Provide lubrication without foaming
- Reduce friction and wear
- Prevent the formation of rust and corrosion
- Cool the engine parts it flows over
- Keep internal engine parts clean
- Maintain compatibility with seals to prevent leaks
- Provide improved fuel economy by reducing friction
- Not cause damage to catalytic converters and oxygen sensors

Engine oil is derived from a base stock. There are four groups of base stocks used in automotive engine oils, Group I to Group IV, from lowest quality to highest. Most modern engines require a Group III or IV base stock oil to meet the requirements for wear, emissions, and viscosity.

Engine oil contains many additives, each intended to improve the effectiveness of the oil. The American Petroleum Institute (API) classifies engine oil as S-class for gasoline or "spark" ignition engines or C-class or F-class for diesel or "compression" ignition engines. The various types of oil within each class are further rated according to their ability to meet the engine manufacturers' warranty specifications **(Table 8–1)**. Engine oils can be classified as **energy-conserving** (fuel-saving) **oils**. These are designed to reduce friction, which in turn reduces fuel consumption. Friction modifiers and other additives are used to achieve this.

In addition to the API rating, oil **viscosity** is important in selecting engine oil. The ability of oil to resist flowing is its viscosity. The thicker the oil, the higher its viscosity rating. Viscosity is affected by temperature; hot oil flows faster than cold oil. Oil flow is important to the life of an engine. Because an engine operates under a wide range of temperatures, selecting the correct viscosity is very important.

Because of changes in engine technology such as variable valve timing, placing piston rings closer to the top of the piston, and the adoption of hybrid powertrains, using the correct viscosity oil is more critical than ever. Using the incorrect weight oil can cause excessive oil consumption, increased fuel consumption, VVT system faults, and other concerns.

TABLE 8–1 ENGINE OIL SERVICE RATINGS

Rating	Comments
SA	Straight mineral oil (no additives), not suitable for use in any engine
SB	Non-detergent oil with additives to control wear and oil oxidation
SC	Obsolete since 1964
SD	Obsolete since 1968
SE	Obsolete since 1972
SF	Obsolete since 1980
SG	Obsolete since 1988
SH	Obsolete since 1993
SJ	Obsolete since 1997
SL	Started in 2001
SM	Started in 2005
SN	Started in 2011
FA-4	Started in 2017 for high-speed diesel engines using fuel with up to 15 ppm sulfur content
CK-4	Started in 2017 for high-speed diesel engines using fuel with up to 500 ppm sulfur content

The Society of Automotive Engineers (SAE) has established an oil viscosity classification system that is accepted throughout the industry. This system is a numeric rating in which the higher viscosity, or heavier weight, oils receive the higher numbers. For example, oil classified as SAE 50 weight oil is heavier and flows slower than SAE 10 weight oil.

Modern engine oils are **multiviscosity oils**. These oils carry a combined classification such as 5W-30. This rating says the oil has the viscosity of both a 5- and a 30-weight oil. The "W" after the 5 notes that the oil's viscosity was tested at 0 °F (–18 °C). This is commonly referred to as the "winter grade." Therefore, the 5W means the oil has a viscosity of 5 when cold. The 30 rating is the hot rating. This rating was the result of testing the oil's viscosity at 212 °F (100 °C). To formulate multiviscosity oils, polymers are blended into the oil. Polymers expand when heated. With the polymers, the oil maintains its viscosity to the point where it is equal to 30-weight oil. The SAE classification and the API rating are displayed on the container of oil **(Figure 8–9)**.

ILSAC Oil Ratings The International Lubrication Standardization and Approval Committee (ILSAC), formed by both domestic and Japanese vehicle manufacturers, has developed an oil rating that combines SAE viscosity ratings and the API service rating. If engine oil meets the standards, a "sunburst" symbol is displayed on the container **(Figure 8–10)**. ILSAC standards require an oil to meet specific standards for low and high temperature operation, deposit control, sludge control, and others.

The current ILSAC standard, introduced in 2010, is GF-5. Oils that meet GF-5 standards have improved high temperature deposit protection and are designed for the added heat and stresses of turbocharged and flex-fuel engines. The next standard, GF-6, is currently in development and will be formulated to offer increased high temperature, high shear (HTHS) performance and possibly offering viscosity ratings less than 0W20 to help meet fuel economy standards.

FIGURE 8–9 The SAE classification and the API rating are displayed in this way on a container of oil.

FIGURE 8–10 The API certification mark, commonly referred to as "the sunburst."

SHOP TALK

Many engines have very specific requirements. Always install the type of oil specified by the manufacturer. Never assume that a particular type of oil can be used in an engine.

ACEA Oil Ratings

ACEA stands for the Association of Constructors of European Automobiles. There are ACEA oil ratings for both gasoline and diesel engines. Requirements include meeting standards for (SAPS) sulfated ash, phosphorus, sulfur, and high-temperature high-shear. The 2016 ACEA A/B ratings are for gasoline and light-duty diesel engines. The C class oils, C1–C5, are for both newer gasoline and diesel engines with exhaust aftertreatment systems and are based on HTHS viscosity requirements.

Manufacturers' Oil Ratings

The vehicle manufacturers themselves also have specific oil ratings. These ratings are a result of changes in engine technology, seal and gasket technology, and emission standards. One of the newest oil ratings is General Motors' Dexos standard. This new oil standard is required for all late-model GM engines.

As engine designs increase the demands of motor oil, more manufacturers will require that oil be made from superior base stocks or switch to synthetic oils.

Synthetic Oils

Synthetic oils are made through a chemical, not natural, process, and are derived from Group IV

base stocks. The introduction of synthetic oils dates back to World War II. Synthetic oils have many advantages over mineral oils, including better fuel economy and engine efficiency by reducing friction; they have low viscosity in low temperatures and a higher viscosity in warm temperatures, and they tend to have a longer useful life. Synthetic oils cost more than mineral oils, which is the biggest drawback for using them. Engine oils that are blends of mineral oils and synthetics to keep the cost down are available but offer many of the advantages of synthetic oil.

Maintenance Perhaps the PM service that is best known to the public is changing the engine's oil and filter. Because oil is the lifeblood of an engine, it is critical that the oil and filter are changed on a regular basis. Photo Sequence 3 shows the steps involved in changing the engine oil and oil filter. Whenever doing this, make sure the oil is the correct rating for the vehicle. Oil requirements are found in the vehicle's owner's manual **(Figure 8–11)** and in the service information. Regardless of who performs the oil changes, it is very important that the correct oil be used. Using an oil that does not meet the engine's specifications can cause immediate faults with VVT and cylinder deactivation systems. Over time, the wrong oil can lead to rapid wear of timing chain components, seal failure, and sludge formation.

Recommended Fluids and Lubricants	
Usage	**Fluid/Lubricant**
Engine Oil	Use only engine oil licensed to the dexos 1 specification, or equivalent, of the proper SAE viscosity grade. ACDelco dexos 1 Synthetic Blend is recommended. *See Engine Oil on page 10–9.*
Engine Coolant	50/50 mixture of clean, drinkable water and use only DEX-COOL Coolant. See Engine Coolant on page 10–16.
Hydraulic Brake System	DOT 3 Hydraulic Brake Fluid (GM Part No. 19299818, in Canada 19299819).
Hydraulic Power Steering System	DEXRON®-VI Automatic Transmission Fluid.
Windshield Washer	Automotive windshield washer fluid that meets regional freeze protection requirements.
Automatic Transmission	DEXRON®-VI Automatic Transmission Fluid.
Transfer Case (All-Wheel Drive)	Transfer Case Fluid (GM Part No. 19256084, in Canada 19256085).
Chassis Lubrication	Chassis Lubricant (GM Part No. 12377985, in Canada 88901242) or lubricant meeting requirements of NLGI #2, Category LB or GC-LB.
Key Lock Cylinders	Multi-Purpose Lubricant, Superlube (GM Part No.12346241, in Canada 10953474).

FIGURE 8–11 Most late-model vehicles have specific requirements for engine oil and other fluids.

FIGURE 8–12 Check the engine's oil level with the dipstick.

In between oil and filter changes, the level of the oil should be periodically checked. When doing this, make sure the vehicle is parked on level ground. Locate and remove the oil dipstick. With a clean rag, wipe the oil from the dipstick and reinsert it all the way in its tube. Remove it again and check the level of the oil **(Figure 8–12)**. If the level is at the "full" mark, the level is okay. If the level is at the "add" mark, this means the level is about 1 quart low. Regardless of the level, examine the oil for evidence of dirt. If the oil is contaminated, it must be changed.

Oil Filter The oil pumped through the system passes through an oil filter. This filter is normally changed along with the oil. There are many shapes and sizes of filters and each may require a special tool to remove and install one **(Figure 8–13)**. Always use a filter that meets the OE filtration specifications. An inexpensive filter that does not meet specifications may not provide adequate filtering of the oil. Also, many OE filters have anti-drainback valve, which prevents oil from draining out of the filter and back into the oil pan as the vehicle sits. This can cause engine noise on start-up and lead to rapid wear on engine parts.

FIGURE 8–13 A variety of oil filter tools.

PHOTO SEQUENCE 3

Changing the Oil and Oil Filter

P3-1 Always make sure the vehicle is positioned safely on a lift or supported by jack stands before working under it. Before raising the vehicle, allow the engine to run awhile. After it is warm, turn off the engine.

P3-2 The tools and other items needed to change the engine's oil and oil filter are rags, a funnel, an oil filter wrench, safety glasses, and a wrench for the drain plug.

P3-3 Place the oil drain pan under the drain plug before beginning to drain the oil.

P3-4 Loosen the drain plug with the appropriate wrench. After the drain plug is loosened, quickly remove it so the oil can freely drain from the oil pan.

P3-5 Make sure the drain pan is positioned so it can catch all of the oil.

P3-6 While the oil is draining, use an oil filter wrench to loosen and remove the oil filter.

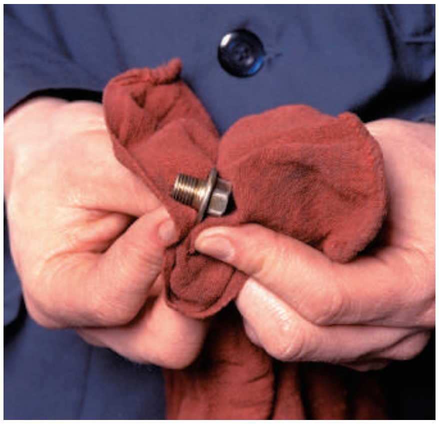
P3-7 Make sure the oil filter seal came off with the filter. Then place the filter into the drain pan so it can drain. After it has completely drained, discard the filter according to local regulations.

P3-8 Wipe off the oil filter sealing area on the engine block. Then apply a coat of clean engine oil onto the new filter's seal.

P3-9 Install the new filter and hand-tighten it. Oil filters should be tightened according to the directions given on the filter.

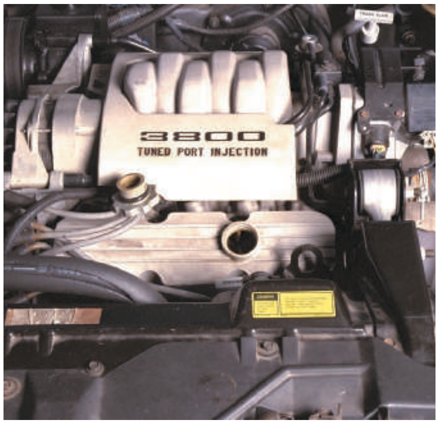
PHOTO SEQUENCE 3

Changing the Oil and Oil Filter *(continued)*



P3-10 Prior to installing the drain plug, wipe off its threads and sealing surface with a clean rag.

P3-11 Tighten the drain plug according to the manufacturer's recommendations. Overtightening can cause thread damage, whereas undertightening can cause an oil leak.



P3-12 With the oil filter and drain plug installed, lower the vehicle and remove the oil filter cap.

P3-13 Carefully pour the oil into the engine. The use of a funnel usually keeps oil from spilling on the engine.

P3-14 After the recommended amount of oil has been put in the engine, check the oil level.

P3-15 Start the engine and allow it to reach normal operating temperature. While the engine is running, check the engine for oil leaks, especially around the oil filter and drain plug. If there is a leak, shut down the engine and correct the problem.

P3-16 After the engine has been turned off, recheck the oil level and correct it as necessary.

SHOP TALK

Most late-model vehicles have a maintenance reminder lamp in the instrument panel. This lamp comes on when maintenance is due and will stay on until it is turned off by a technician. The method for doing this varies with the manufacturer; always check the service information for the correct procedure.

Cooling System

Whenever you change an engine's oil, you should also do a visual inspection of the different systems under the hood, including the cooling system. Inspect all cooling system hoses for signs of leakage and/or damage. Replace all hoses that are swollen, cracked, or show signs of leakage. The radiator should also be checked for signs of leaks; if any are evident the radiator should be repaired or replaced. Also, check the front of the radiator for any buildup of dirt and bugs **(Figure 8–14)**. This can restrict airflow through the radiator and should be removed by thorough cleaning.

The level and condition of the engine's coolant should also be checked. Check the coolant's level at the coolant recovery tank **(Figure 8–15)**. It should be between the "low" and "full" lines. If the level is too low, more coolant should be added through the cap of the tank, not the radiator. Bring the level up to the "full" line. Always use the correct type of coolant when topping off or replacing it. Look at the color of the coolant when checking the level. It should not look rusty, crusty, or cloudy. If the coolant looks contaminated, the cooling system should be flushed and new coolant put into the system.

FIGURE 8–14 A buildup of dirt and bugs can restrict airflow through the radiator.

FIGURE 8–15 The level of coolant in the cooling system should be checked at the coolant recovery tank.

Coolant Engine **coolant** is a mixture of water and antifreeze. Water alone has a boiling point of 212 °F (100 °C) and a freezing point of 32 °F (0 °C) at sea level.

SHOP TALK

Recycle all used antifreeze/coolant or take it to an authorized collection point. Do not dump old coolant into a sewage drain, the ground, or any body of water.

Caution! Never remove the radiator cap when the coolant is hot. Because the system is pressurized, the coolant can be hotter than boiling water and will cause severe burns. Wait until the top radiator hose is not too hot to touch. Then press down on the cap and slowly turn it until it hits the first stop. Now slowly let go of the cap. If there is any built-up pressure in the system, it will be released when the cap is let up. After all pressure has been exhausted, turn the radiator cap to remove it.

A mixture of 70 percent antifreeze and 30 percent water will raise the boiling point of the mixture to 276 °F (136 °C) under 15 psi of pressure and lower the freezing point to –84 °F (–64 °C). Normally, the recommended mixture is a 50/50 solution of water and antifreeze.

The antifreeze concentration must always be a minimum of 44 percent all year and in all climates. If the percentage is lower than 44 percent, engine parts may be eroded by cavitation, and cooling system components may be severely damaged by corrosion.

Five types of coolant are commonly available:

- **Ethylene glycol**—This was once the most commonly used antifreeze. It uses inorganic acid technology (IAT), is green in color, and provides good protection regardless of climate but it is poisonous. IAT coolant is not compatible with newer long-life coolants.
- **Propylene glycol**—This type has the same basic characteristics as ethylene glycol-based coolant but is not sweet tasting and is less harmful to animals and children. Propylene glycol-based coolants are not used as factory-fill coolants and should not be mixed with ethylene glycol.
- **Phosphate-free**—This is ethylene glycol-based coolant with zero phosphates, which makes it more environmentally friendly. Phosphate-free coolant is recommended by some auto manufacturers.
- **Organic acid technology (OAT)**—This coolant is also environmentally friendly and contains zero phosphates or silicones. This orange coolant is often referred to by a brand name "DEX-COOL" and is used in all late-model GM vehicles **(Figure 8–16)**.
- **Hybrid organic acid technology (HOAT)**—This is similar to OAT coolant but has additives that make the coolant less abrasive to water pumps. This type of coolant is used by Ford and Chrysler and is not compatible with IAT or OAT coolants.
- **Manufacturer specific coolants**—Many manufacturers require a specific coolant for their vehicles. These coolants may be phosphate free, silicate free, borate free or all of the above. Factory coolants are usually sold premixed 50/50 coolant and pure water.

Caution! Never leave ethylene glycol or propylene glycol coolant out and lying around. Both children and animals will drink it because of its sweet taste. The coolant is poisonous and can cause death.

FIGURE 8–16 Ethylene glycol is the most commonly used antifreeze/coolant and is green in color. OAT coolant is orange and is often referred to by the brand name "DEX-COOL."

When inspecting and servicing the coolant, it is important to note that color alone does not really determine what coolant is appropriate for the vehicle. Several colors of orange, pink, yellow, and blue are used in modern vehicles and each vehicle manufacturer has specific coolant use specifications. Before pouring in any coolant, first check the service information to determine exactly which coolant is required.

Coolant Condition A coolant hydrometer is used to check the amount of antifreeze in the coolant. This tester contains a pickup hose, coolant reservoir, and squeeze bulb. The pickup hose is placed in the radiator coolant. When the squeeze bulb is squeezed and released, coolant is drawn into the reservoir. As coolant enters the reservoir, a pivoted float moves upward with the coolant level. A pointer on the float indicates the freezing point of the coolant on a scale located on the reservoir housing.

A refractometer **(Figure 8–17)** offers a precise way to check coolant condition. Most refractometers can also measure the specific gravity of battery

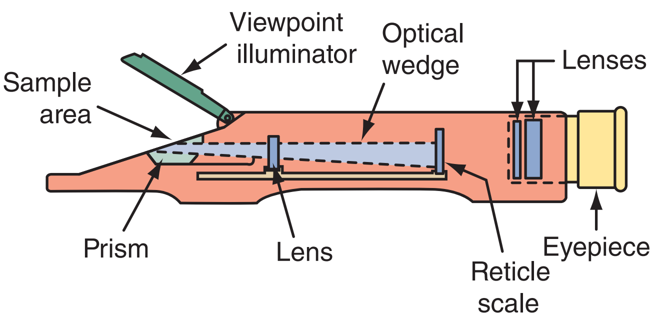


FIGURE 8–17 A refractometer that tests coolant condition and battery electrolyte.

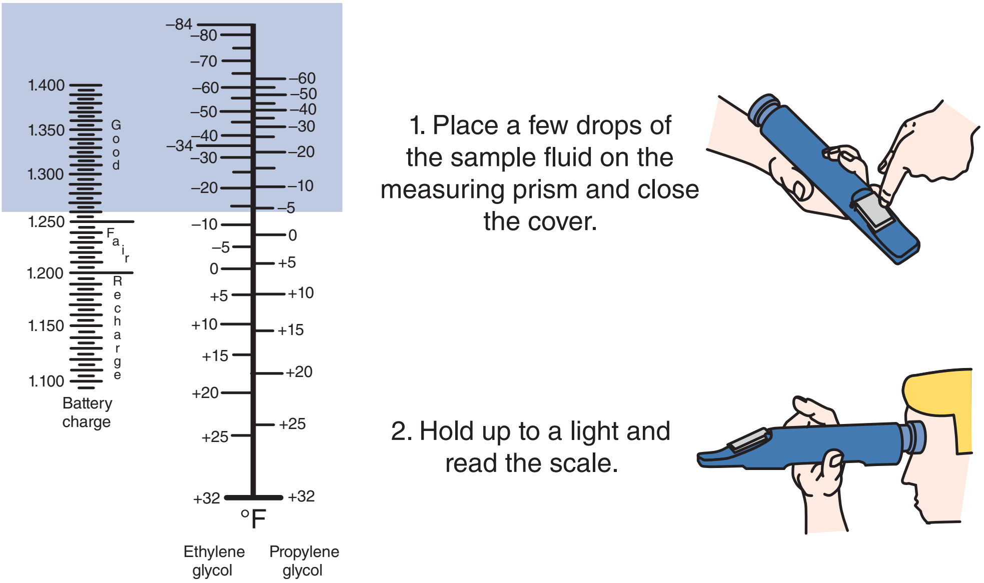


FIGURE 8–18 Measuring antifreeze and battery electrolyte levels with a refractometer.

electrolyte and may test the condition of brake fluid. A sample of the fluid is placed in the sample area of the meter and as light passes through the sample, a line is cast on the meter's scale. The line shows the concentration of the antifreeze in the coolant **(Figure 8–18)**.

Litmus strips are also used to evaluate coolant. The test strips are immersed into a sample of coolant. After about 1 to 5 minutes the strip will change color. The color of the strip is then compared to a scale on the container of strips. Matching the colors will indicate the freeze protection level and the acidity of the coolant **(Figure 8–19)**.

Drive Belts

V-belts and **V-ribbed belts (serpentine belts)** are used to drive water pumps, power-steering pumps, air-conditioning compressors, generators, and emission control pumps. Heat has adverse effects on drive belts and this can cause the belts to harden and crack. Excessive heat normally comes from slippage. Slippage can be caused by improper belt tension or oily conditions. When there is slippage, the support bearing of the component driven by the belt can be damaged.

The angled sides of V-belts contact the inside of the pulleys' grooves **(Figure 8–20)**. This point of contact is where motion is transferred. As a V-belt wears, it begins to ride deeper in the groove. This reduces its tension and promotes slippage. Because this is a normal occurrence, periodic adjustment of belt tension is necessary.

Drive belts can be used to drive a single part or a combination of parts. An engine can have three or more V-belts.

FIGURE 8–19 Matching the color of a test strip to the scale on its container will indicate the freeze protection level and the acidity of the coolant.

V-Belt Inspection Even the best V-belts last only an average of 4 years. That time can be shortened by things that can be found by inspecting the belts. Check the condition of all of the drive belts on the engine. Carefully look to see if they have worn or glazed edges, tears, splits, and signs of oil soaking **(Figure 8–21)**. If these conditions exist, the belt should be replaced. Also inspect the grooves of the pulleys for rust, oil, wear, and other damage. If a pulley is damaged, it should be replaced. Rust, dirt, and oil should be cleaned off the pulley before installing a new belt.

Misalignment of the pulleys reduces the belt's service life and brings about rapid pulley wear, which causes thrown belts and noise. Undesirable side or

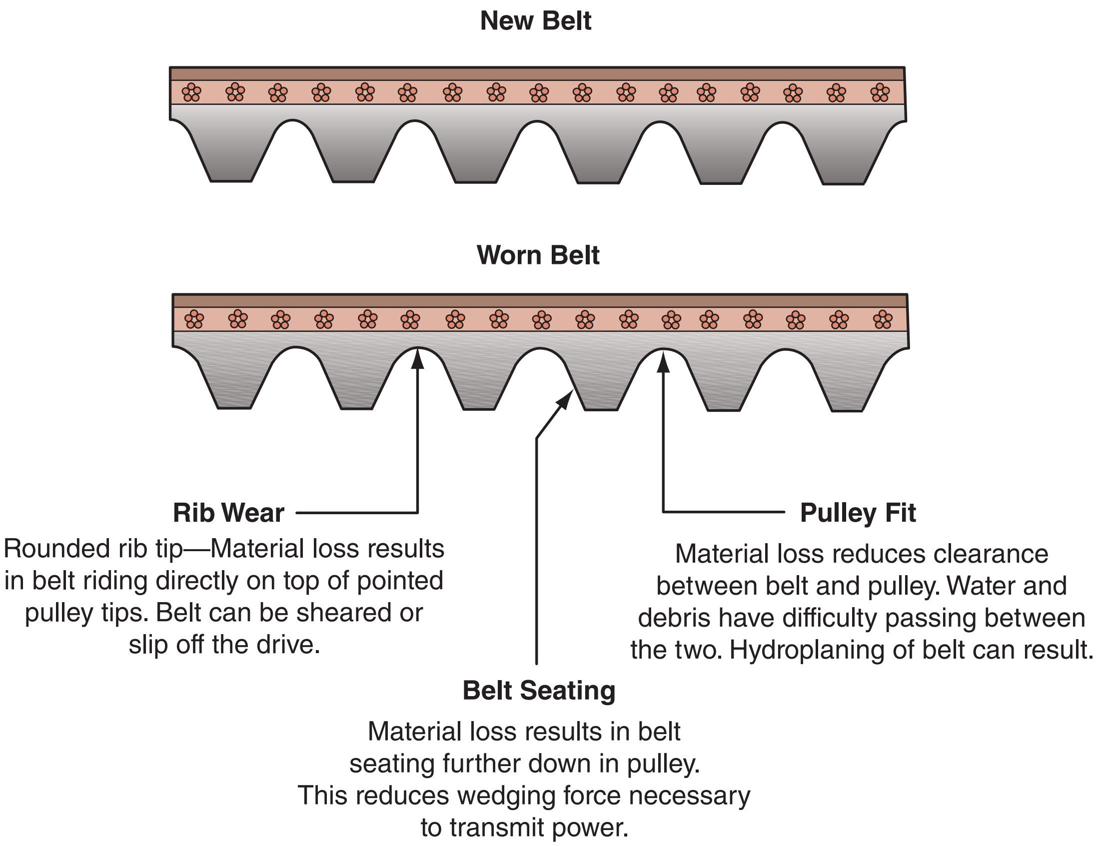


FIGURE 8-20 The sides of a V-belt contact the grooves of the pulleys.

end thrust loads can also be imposed on pulley or pump shaft bearings. Check alignment with a straightedge. Pulleys should be in alignment within 1/16 inch (1.59mm) per foot of the distance across the face of the pulleys.

A quick check of a belt's tension can be made by locating the longest span of the belt between two pulleys. With the engine off, press on the belt midway through that distance. If the belt moves more than ½ inch per foot of free span, the belt should be

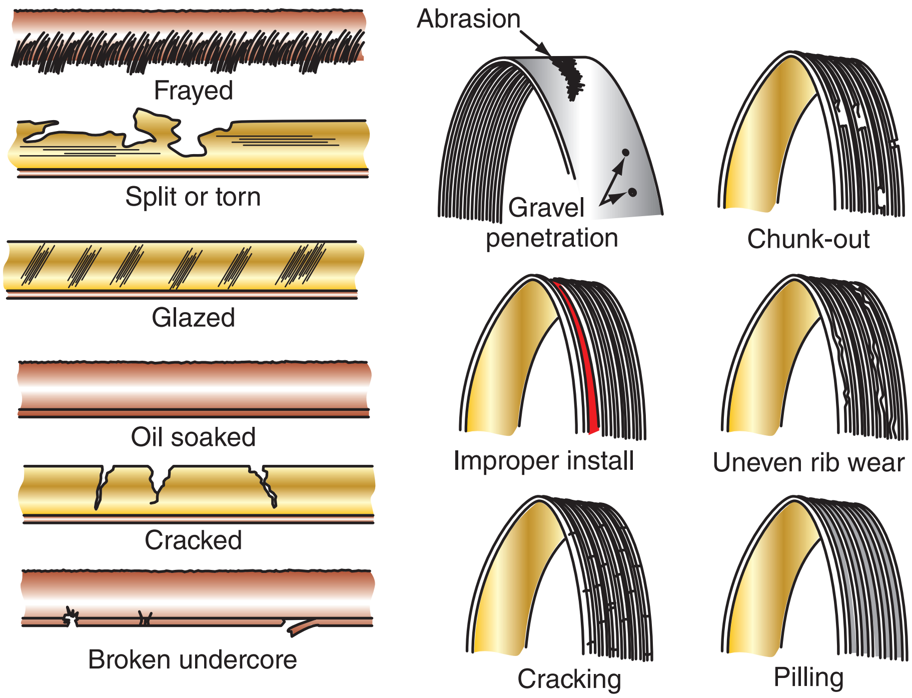


FIGURE 8-21 Drive belts should be inspected.

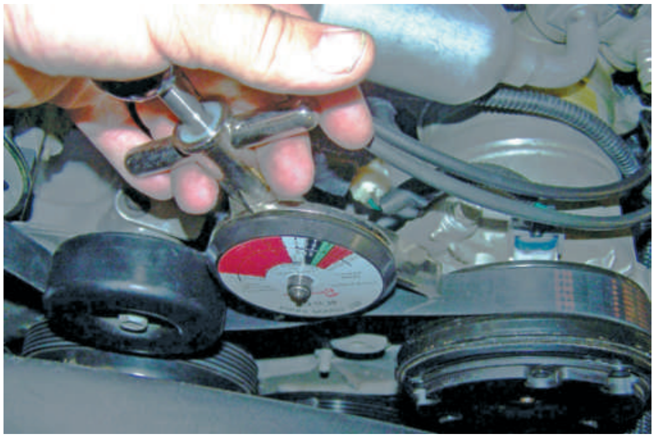


FIGURE 8–22 Check the tension of a drive belt with a belt tension gauge.

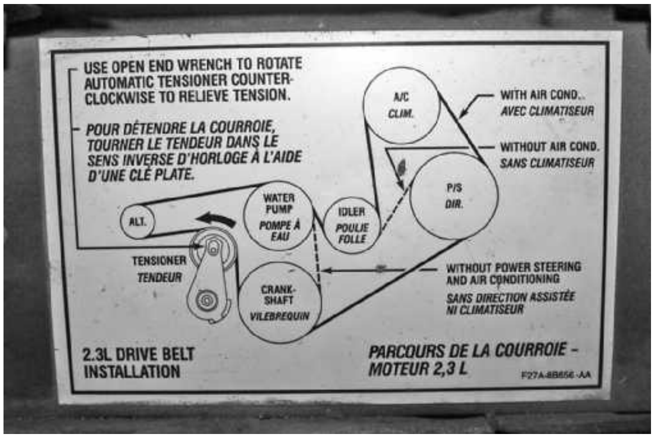


FIGURE 8–23 The routing of a typical serpentine drive belt.

adjusted. Keep in mind that different belts require different tensions. The belt's tension should be checked with a belt tension gauge **(Figure 8–22)**.

> **USING SERVICE INFORMATION**
> Proper belt-tightening procedures are given in the specification section of the service information.

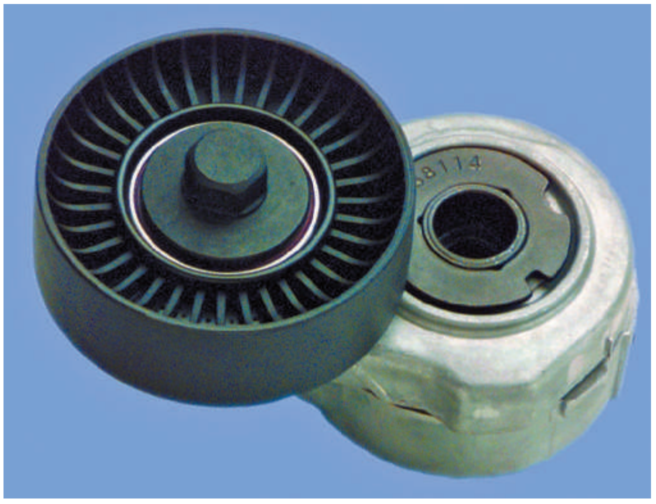
The exact procedure for adjusting belt tension depends on what the belt is driving. Normally, the mounting bracket for the component driven by the belt and/or its tension-adjusting bolt is loosened. The mounting brackets on generators, power-steering pumps, and air compressors are designed to be adjustable. Some brackets have a hole or slot to allow the use of a pry bar. Other brackets have a ½-inch square opening in which a breaker bar can be installed to move the component and tighten the belt. Other engines have an adjusting bolt, sometimes called a jackscrew, that can be tightened to correct the belt tension. Loosen the mounting bolts and hold the component in the position that provides for the correct tension. Be careful not to damage the part you are prying against. Then tighten the mounting bolts or tension adjusting bolt to keep the tension on the belt. Once tightened, recheck the belt tension with the tension gauge.

V-Ribbed Belts Most late-model vehicles use a V-ribbed or multi-ribbed belt to drive all or most accessories. Multi-rib belts are long and follow a complex path that weaves around the various pulleys **(Figure 8–23)** and are also called serpentine belts. Proper tension is critical due to the complex routing. Serpentine belts are typically flat on the outside and have a series of continuous ribs on the inside. These ribs fit into matching grooves in the pulleys. Both the ribbed side and the flat side of the belt can be used to transfer power. Over time, the belts will stretch and lose their tension. To compensate for this and to keep a proper amount of belt tension, serpentine belt systems have an automatic belt tensioner pulley. This pulley is a spring-loaded pulley **(Figure 8–24)** that exerts a predetermined amount of pressure on the belt to keep it at the desired tension.

V-ribbed belts are exposed to dirt, rocks, salt, and water; these along with pulley shape and slight misalignments result in rib surface wear. Belts are designed to have a clearance between itself and the pulley. When rib material is lost, that clearance is lost, and eliminates a way for dirt and water to pass through the system.

A belt that has stretched in length can cause slippage and the bottoming out of the belt tensioner, which can damage the tensioner, generate noise, and fail to properly drive accessory pulleys.

V-ribbed belts can be made of neoprene (polychloroprene) or EPDM (ethylene propylene diene monomer) rubber. Both of these are types of



Courtesy of Gates Corporation.

FIGURE 8–24 A belt tensioner for a serpentine belt.

FIGURE 8–25 A damaged V-ribbed belt.

synthetic rubber and each has their own advantages and disadvantages.

V-Ribbed Belt Inspection The procedures for inspecting these belts are similar but vary with the belt's construction. Although neoprene belts are dependable for up to 60,000 miles, through use they begin to develop cracks, uneven rib wear, edge and backside wear, glazing, and noise **(Figure 8–25)**. If any of these are evident, during an inspection of the belt, the belt should be replaced.

EPDM belts resist cracking, therefore a look for cracks may not be the best way to check these belts. It is better to check these belts for a loss of material. A loss as little as 5 percent can cause a loss of tension and/or belt slip, which will affect the operation of components and lead to their failure **(Figure 8–26)**.

If a belt does not have the proper tension, it may squeal or chirp, it may roll off a pulley, or it may slip. Excessive tension may put unwanted forces on the pulleys and the shafts they are attached to, leading to noise, belt breakage, glazing, and damage to the bearings and bushings in the driven components.

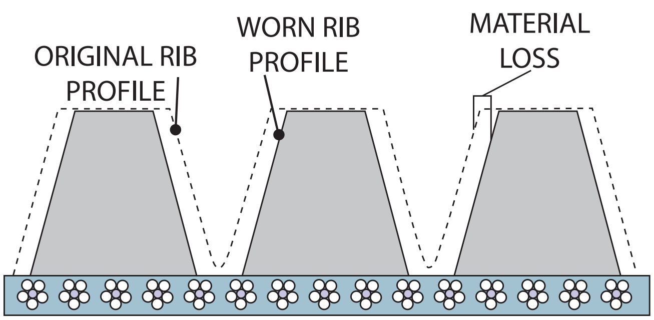


FIGURE 8–26 As multirib belts wear, the distance between the grooves increases.

Improper tension is normally caused by belt stretch or a faulty tensioner. Do not assume that the belt tensioner is working properly. Measure the belt tension when performing a belt inspection and after a new belt is installed. In many cases, the tensioner should be replaced when the drive belt is replaced to maintain correct tension on the pulleys.

Belt Replacement If a drive belt is damaged, it should be replaced. If there is more than one drive belt, all should be replaced even if only one is bad. Always use an exact replacement belt. The size of a new belt is typically given, along with the part number, on the belt container **(Figure 8–27)**. You can verify that the new belt is a replacement for the old one by physically comparing the two. This, however, does not account for any belt stretch that may have occurred. Therefore, only use this comparison as verification. The best way to select the correct replacement belt is with a parts catalog and/or by matching the numbers on the old belt to the numbers on the new belt.

To replace a V-belt on some engines, it may be necessary to remove the fan, fan pulley, and other accessory drive belts to gain access to belts needing replacement. Also, before removing the old drive belt, disconnect the electric cooling fan at the radiator, if the vehicle has one. Remove the old belt by loosening the components that have adjusting slots for belt tension. Then slip the old belt off. Check the condition and alignment of the pulleys. Correct any problems before installing the new belt. Place the new belt around the pulleys. Once in place, loosely tighten the bolts that were loosened during belt removal. Then adjust the tension of the belt and retighten all mounting hardware.

Photo Sequence 4 shows the correct procedure for inspecting, removing, replacing, and adjusting a V-ribbed belt. Before removing a serpentine belt, locate a belt routing diagram in a service manual or

FIGURE 8–27 The size and part number of a new belt are given on the belt container. The size can be verified by physically comparing the old with the new belt.

SHOP TALK

It is never advisable to pry a belt onto a pulley. Obtain enough slack so the belt can be slipped on without damaging either the V-belts or a pulley. Some power-steering pumps have a ½-inch drive socket to aid in adjusting belts to the proper tension without prying against any accessory.

on an underhood decal. Compare the diagram with the routing of the old belt. If the actual routing is different from the diagram, draw the existing routing on a piece of paper.

After installation of a new belt, the engine should be run for 10 to 15 minutes to allow belts to seat and reach their initial stretch condition. Modern steel-strengthened V-belts do not stretch much after the initial run-in, but it is often recommended that the tension of the belt be rechecked after 5,000 miles (8,000 km).

Stretch Fit Belts

Many newer cars and light trucks have stretch fit belts that require no tensioner. This type of belt is typically used to drive one accessory, such as the A/C compressor. The belt is installed using a special tool that attaches to the drive pulley. Rotating the pulley gently stretches the belt over the pulleys and into the grooves. Once installed, there is no provision for adjusting belt tension. The old belt is removed by cutting it off **(Figure 8–28)**.

Air Filters

If an air filter is doing its job, it will get dirty. Most air filters are made of pleated paper to increase the filtering area. As a filter gets dirty, the amount of air that can flow through it is reduced. This is not a problem until less air than what the engine needs can get through the filter. Without the proper amount of air, the engine will not be able to produce the power it should; nor will it be as fuel efficient as it should be.

Courtesy of Gates Corporation.

FIGURE 8–28 Installing a stretch fit belt requires special tools so the belt is not damaged.

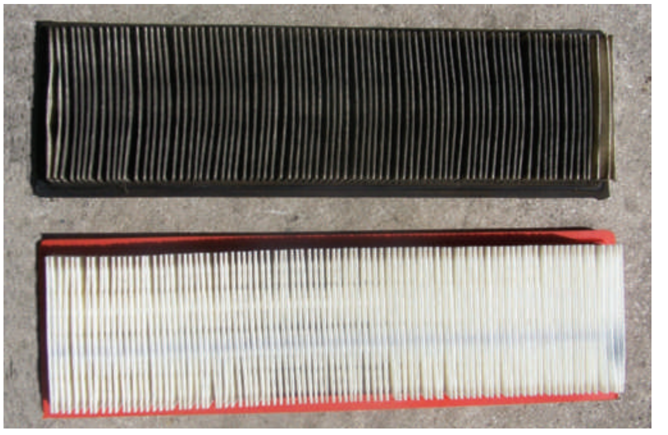


FIGURE 8–29 A dirty and a clean air filter.

Included in the PM plan for all vehicles is the replacement of the air filter. This mileage or time interval is based on normal operation. If the vehicle is used, or has been used, in heavy dust, the life of the filter is shorter. Always use a replacement filter that is the same size and shape as the original. An air filter should also be periodically checked for excessive dirt or blockage **(Figure 8–29)**.

When replacing the filter element, carefully remove all dirt from the inside of the housing. Large pieces of dirt and stones accumulate here. It would be disastrous if that dirt got into the cylinders. Also make sure that the air cleaner housing is properly aligned and closed around the filter to ensure good airflow of clean air. If the filter does not seal well in the housing, dirt and dust can be pulled into the air-stream to the cylinders. The shape and size of the air filter element depends on its housing; the filter must be the correct size for the housing or dirt will be drawn into the engine.

Battery The battery is the main source of electrical energy for the vehicle. It is very important that it is inspected and checked on a regular basis.

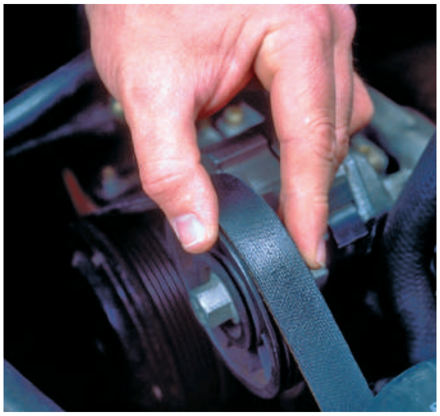
SHOP TALK

It should be noted that disconnecting the battery on late-model cars removes some memory from the engine's computer and the car's accessories. Besides losing the correct time on its clock or the programmed stations on the radio, the car might run roughly, the airbag light may turn on, and transmission shifting may be affected.

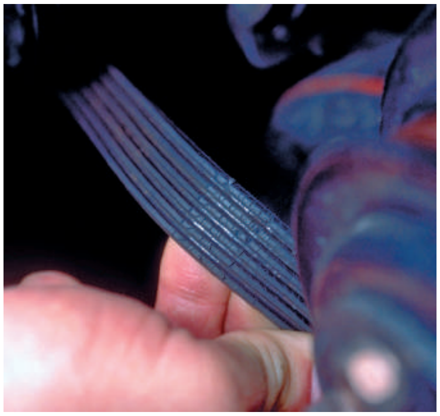
PHOTO SEQUENCE 4

Typical Procedure for Inspecting, Removing, Replacing, and Adjusting a Drive Belt

P4-1 Inspect the belt by looking at both sides.



P4-2 Look for signs of glazing.



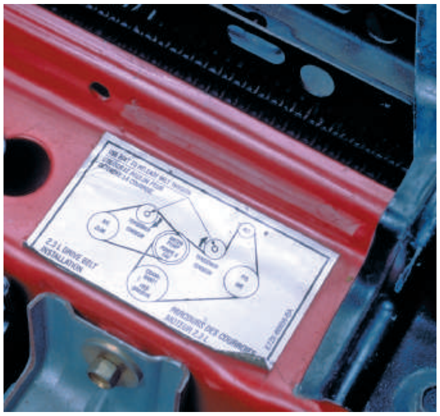
P4-3 Look for signs of tearing or cracking.

P4-4 To replace a worn belt, locate the tensioner or generator pulley.

P4-5 Loosen the hold-down fastener for the tensioner or generator pulley.

P4-6 Pry the tensioner or generator pulley inward to release the belt tension and remove the belt.

P4-7 Match the old belt up for size with the new replacement belt.

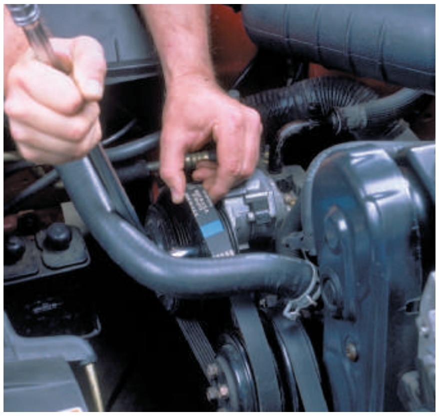


P4-8 Observe the belt routing diagram in the engine compartment.

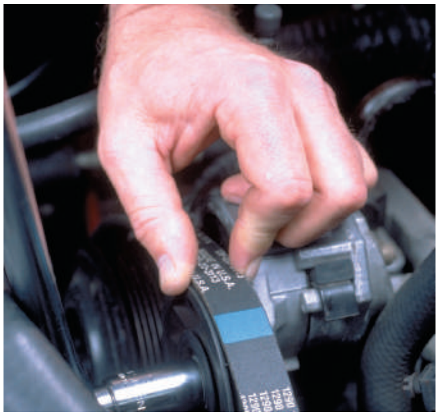
PHOTO SEQUENCE 4

Typical Procedure for Inspecting, Removing, Replacing, and Adjusting a Drive Belt *(continued)*

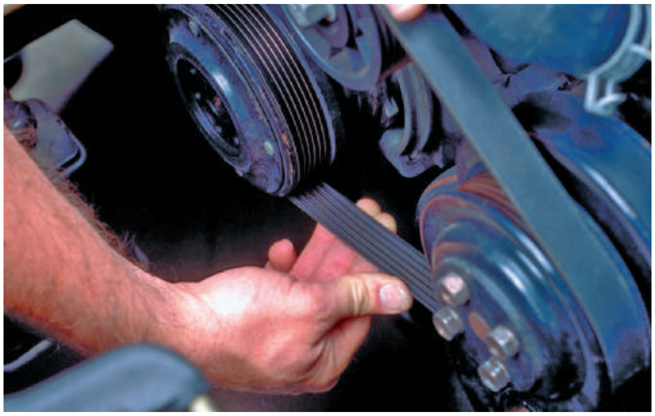
P4-9 Install the new belt over each of the drive pulleys. Often the manufacturer recommends a sequence for feeding the belt around the pulleys.



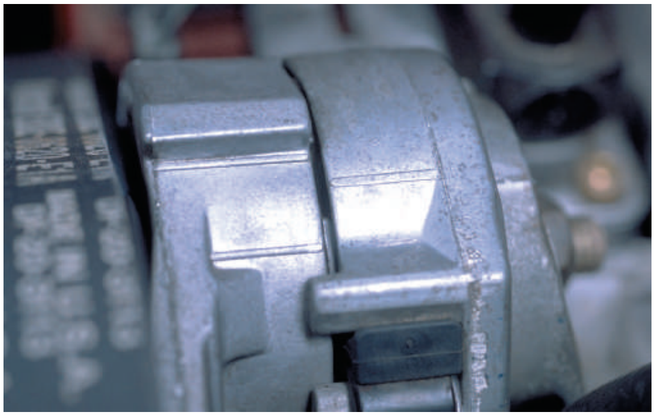
P4-10 Pry out the tensioner or generator pulley to put tension on the belt.



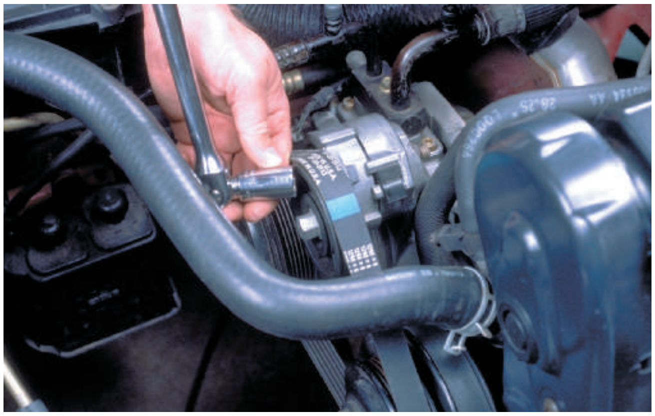
P4-11 Install the belt squarely in the grooves of each pulley.



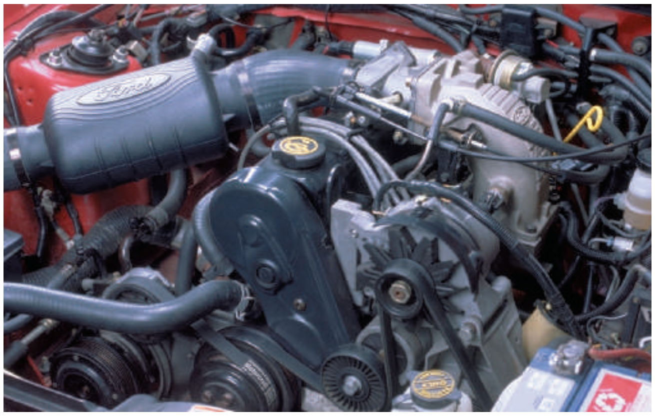
P4-12 Measure the belt deflection in its longest span. If a belt tension gauge is available, use it and compare the tension.



P4-13 Pry the tensioner or generator pulley to adjust the belt to specifications.



P4-14 Tighten the tensioner or generator pulley fastener.



P4-15 Start the engine and check the belt for proper operation.

PROCEDURE

1. Visually inspect the battery cover and case for dirt and grease.
2. Check the electrolyte level (if possible).
3. Inspect the battery for cracks, loose terminal posts, and other signs of damage.
4. Check for missing cell plug covers and caps.
5. Inspect all cables for broken or corroded wires, frayed insulation, or loose or damaged connectors.
6. Check the battery terminals, cable connectors, metal parts, holddowns, and trays for corrosion damage or buildup—a bad connection can cause reduced current flow.
7. Check the heat shield for proper installation on vehicles so equipped.

FIGURE 8-31 Automatic transmission fluid (ATF).

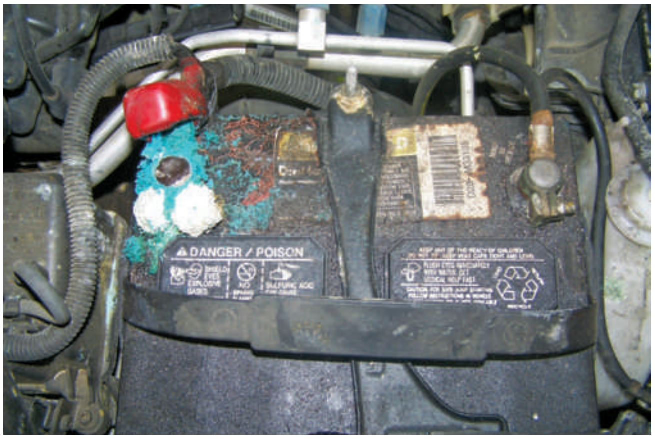


FIGURE 8-30 A really dirty battery.

If the battery or any of the associated parts are dirty **(Figure 8–30)** or corroded, they should be removed and cleaned. Photo Sequence 5 shows the correct procedure for cleaning a battery, a battery tray, and battery cables.

Transmission Fluid

The oil **(Figure 8–31)** used in automatic transmissions is called automatic transmission fluid (ATF). This special fluid is dyed red so that it is not easily confused with engine oil. Before checking the fluid, make sure to check and follow the fluid inspection procedures. These typically include operating the vehicle until the fluid is at operating temperature, which can be 180 °F (82.2 °C) or more, transmission in Park and the vehicle on a flat surface. Then set the parking brake and allow the engine to idle. Usually it is recommended that the ATF level be checked when the transmission is placed into Park; however, some may require some other gear. Make sure you follow those requirements. Locate the fluid dipstick (normally located to the rear of the engine) and pull it out of its tube. Check the level of the fluid on the dipstick **(Figure 8–32)**. If the level is low, add only enough to bring the level to full. Make sure you only use the fluid recommended by the manufacturer.

If the transmission does not have a dipstick, refer to the service information for the steps to check the fluid level. Some vehicles require a special tool

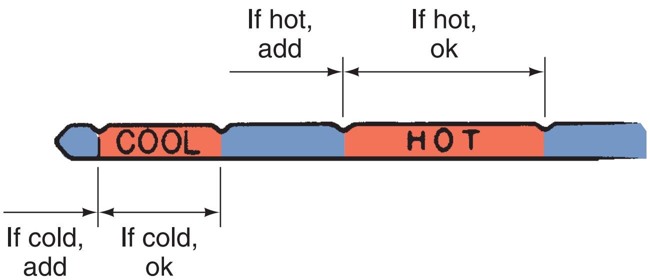


FIGURE 8-32 Automatic transmission fluid should be checked regularly. Normally the level is checked when the engine is warm. The normal cold level is well below the normal hot level.

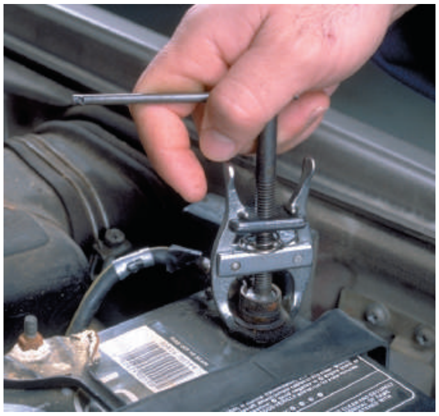
SHOP TALK

When removing or installing a battery, always use the built-in battery strap or a battery lifting tool to lift the battery in or out of its tray.

PHOTO SEQUENCE 5

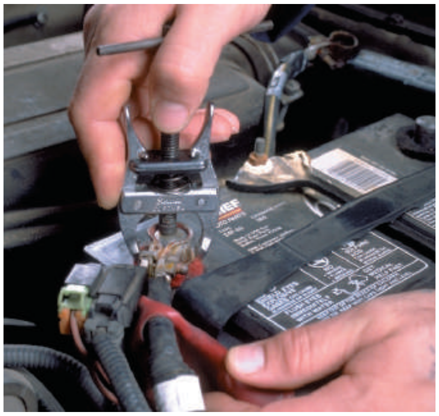
Typical Procedure for Cleaning a Battery Case, Tray, and Cables

P5-1 Loosen the battery negative terminal clamp.



P5-2 Use a terminal clamp puller to remove the negative cable.

P5-3 Loosen the battery positive terminal clamp.



P5-4 Use a terminal clamp puller to remove the positive clamp.

P5-5 Remove the battery hold-down hardware and any heat shields.

P5-6 Remove the battery from the tray.

P5-7 Mix a solution of baking soda and water.

P5-8 Brush the baking soda solution over the battery case, but do not allow the solution to enter the cells of the battery.

P5-9 Flush the baking soda off with water.

PHOTO SEQUENCE 5

Typical Procedure for Cleaning a Battery Case, Tray, and Cables *(continued)*

P5-10 Use a scraper and wire brush to remove corrosion from the hold-down hardware.

P5-11 Brush the baking soda solution over the hold-down hardware and then flush with water.

P5-12 Allow the hardware to dry. Then paint it with corrosion-proof paint.

P5-13 Use a terminal cleaner brush to clean the battery cables.

P5-14 Use a terminal cleaner brush to clean the battery posts.

P5-15 Install the battery back into the tray. Also install the hold-down hardware.

P5-16 Install the positive battery cable. Then install the negative cable.

SHOP TALK

Many late-model vehicles do not have a transmission dipstick and require special procedures to check the fluid. Refer to the vehicle's service information to find out how to check the fluid.

(a special dipstick) to accurately check fluid level, while others require removing a check plug and noting how much fluid drips from the opening. Failure to follow the manufacturer's procedures can result in incorrect fluid-level readings.

The condition of the fluid should be checked while checking the fluid level. The normal color of ATF is pink or red. If the fluid has a dark brownish or blackish color and/or a burned odor, the fluid has been overheated. A milky color indicates that engine coolant has been leaking into the transmission's cooler in the radiator.

After checking the ATF level and color, wipe the dipstick on absorbent white paper and look at the stain left by the fluid. Dark particles are normally band and/or clutch material, whereas silvery metal particles are normally caused by the wearing of the transmission's metal parts. If the dipstick cannot be wiped clean, it is probably covered with varnish, which results from fluid oxidation. Varnish will cause the transmission's valves to stick, causing improper shifting speeds. Varnish or other heavy deposits indicate the need to change the transmission's fluid and filter.

The exact fluid that should be used in an automatic transmission depends on the transmission design and the year the transmission was built. It is very important that the correct type of ATF be used. Each manufacturer has a fluid specification that must be followed. Always refer to the service or owner's manual for the correct type of fluid to use. Some transmission dipsticks are also marked with the type of ATF required.

Some transmissions require the use of unique fluids. CVTs require a fluid that is much different from that used in automatic transmissions. Always use the fluid recommended by the manufacturer. The use of the wrong fluid may cause the transmission to operate improperly and/or damage the transmission.

Manual Transmissions Manual transmissions, transaxles, and drive axle units require the use of specific lubricants or oils, and the levels should be checked according to the recommended time frames. Some manufacturers recommend that the fluids be periodically changed. Most repair shops have an air-operated

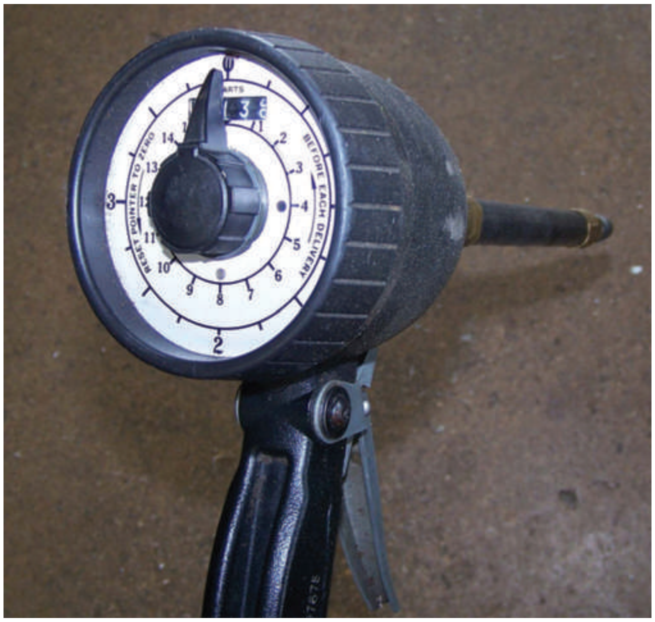


FIGURE 8–33 The dispenser handle for an air pump used to fill transmissions and drive axles with lubricant.

dispenser for these fluids **(Figure 8–33)**; others rely on a hand-operated pump.

Power-Steering Fluid

Normally the power-steering fluid level is checked with the engine warm but turned off. If the fluid is cold, it will read lower than normal. The filler cap on the power-steering pump normally has a dipstick. Unscrew the cap and check the level **(Figure 8–34)**. Add fluid as necessary. Sometimes the fluid used in these systems is ATF; check the service information for the proper fluid type before adding fluid.

FIGURE 8–34 The filler cap on a power-steering pump normally has a dipstick to check the fluid level.

Brake Fluid

Brake fluid levels are checked at the master cylinder. Older master cylinders were made of cast iron or aluminum and had a metal bail that snaps over the master cylinder cover to hold it in place. Normally the bail can be moved in only one direction. Once moved out of the way, the master cylinder cover can be removed. Once removed, the fluid levels can be checked.

Newer master cylinders have a metal or plastic reservoir mounted above the cylinder. The reservoir will have one or two caps. To check the fluid level in a metal reservoir, the cap must be removed. Most often the caps are screwed on. The caps on some plastic reservoirs have snaps to hold them. Unsnap the cap to check the fluid. It is important to clean the area around the caps before removing them. This prevents dirt from falling into the reservoir. A rubber diaphragm attached to the inside of the caps is designed to stop dirt, moisture, and air from entering into the reservoir. Make sure the diaphragm is not damaged.

Most new plastic reservoirs are translucent and allow the fluid level to be observed from the outside **(Figure 8–35)**. Do not open the master cylinder reservoir unnecessarily as this allows air and moisture to contact the brake fluid.

While checking the fluid level, look at the color of the fluid. Brake fluid tends to absorb moisture and its color gives clues as to the moisture content of the fluid. Dark- or brown-colored fluid indicates contamination and the system may need to be flushed and the fluid replaced.

When it is necessary to add brake fluid, make sure the fluid is the correct type and is fresh and clean. There are basically four types of brake fluids: DOT 3, DOT 4, DOT 5, and DOT 5.1 **(Figure 8–36)**.

DOT 3, DOT 4, and DOT 5.1 fluids are polyalkylene-glycol-ether mixtures, called "**polyglycol**" for short.

FIGURE 8–35 Translucent brake fluid reservoirs allow the fluid level to be observed from the outside.

FIGURE 8–36 The three types of brake fluid: DOT 3 is the most commonly used.

The color of both DOT 3 and DOT 4 fluid ranges from clear to light amber. DOT 5 fluids are all silicone based because only silicone fluid—so far—can meet the DOT 5 specifications. Although the other three fluid grades are compatible, they do not combine well if mixed together in a system. Therefore, it is best to use the fluid type recommended by the manufacturer and never mix fluid types in a system.

Clutch Fluid On some vehicles with a manual transmission, there is another smaller master cylinder close to the brake master cylinder. This is the clutch master cylinder. Its fluid level needs to be checked, which is done in the same way as brake fluid. In most cases, the clutch master cylinder uses the same type of fluid as the brake master cylinder. However, check this out before adding any fluid.

Diesel Exhaust Fluid

Newer diesel engine vehicles use a special diesel exhaust fluid (DEF) made of 33 percent urea and 67 percent pure deionized water. This mixture is stored in a tank and is injected into the diesel exhaust after-treatment system to reduce NO_x emissions. How often the tank needs to be filled depends on the vehicle's operating conditions, but customers should expect to refill the tank about every 5,000 miles. If the tank runs out, the on-board computer system will limit engine and vehicle speed until the tank is refilled and the system operation returns to normal. Fluid tanks are filled either under the hood or through a filler neck near the diesel fuel cap.

Store DEF in its original container and keep it sealed. Once open, DEF has a shelf life of about a year and it needs to remain pure. If left open, contaminants can dilute it and greatly affect the quality of the fluid. Contaminated fluid could damage the

diesel catalyst system. DEF is not considered hazardous but is mildly corrosive and will stain paint if not cleaned up when spilled.

Windshield Wipers

Check the condition of the windshield wipers. Wiper blades can become dull, torn, or brittle. If they are, they should be replaced. Also, check the condition of the wiper arms. Look for signs of distortion or damage. Also, check the spring on the arm. This spring is designed to keep the wiper blade fairly tight against the windshield. If the spring is weak or damaged, the blade will not do a respectable job cleaning the glass.

Most wiper blade assemblies have replaceable blades or inserts. To replace the blades, grab hold of the assembly and pivot it away from the windshield. Once the arm is moved to its maximum position, it should stay there until it is pivoted back to the windshield. Doing this will allow you to easily replace the wiper blades without damaging the vehicle's paint or glass.

There are three basic types of wiper blade inserts **(Figure 8–37)**. Look carefully at the old blade to determine which one to install. Remove the old insert and install the new one. After installation, pull on the insert to make sure it is properly secured. If the insert comes loose while the wipers are moving across the windshield, the wiper arm could scratch the glass.

Most often wiper blades are replaced as an assembly. There are several methods used to secure the blades to the wiper arm **(Figure 8–38)**. Most replacement blades come with the necessary adapters to secure the blade to the arm.

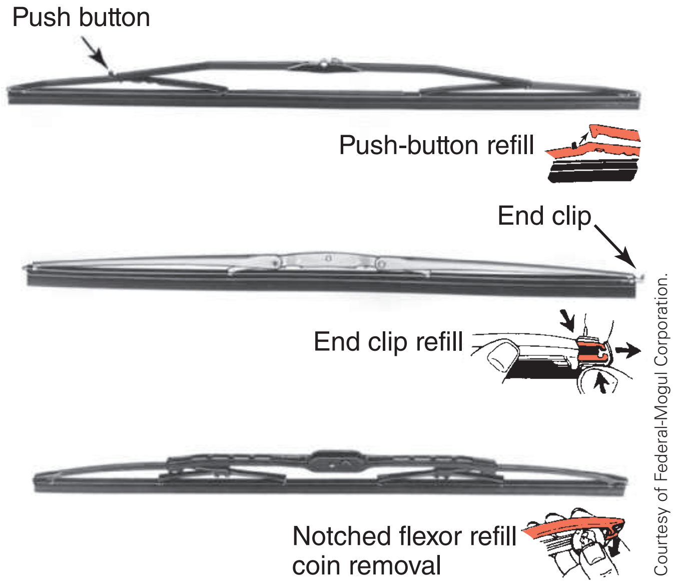


FIGURE 8–37 Examples of the different ways that wiper blade inserts are secured to the blade assembly.

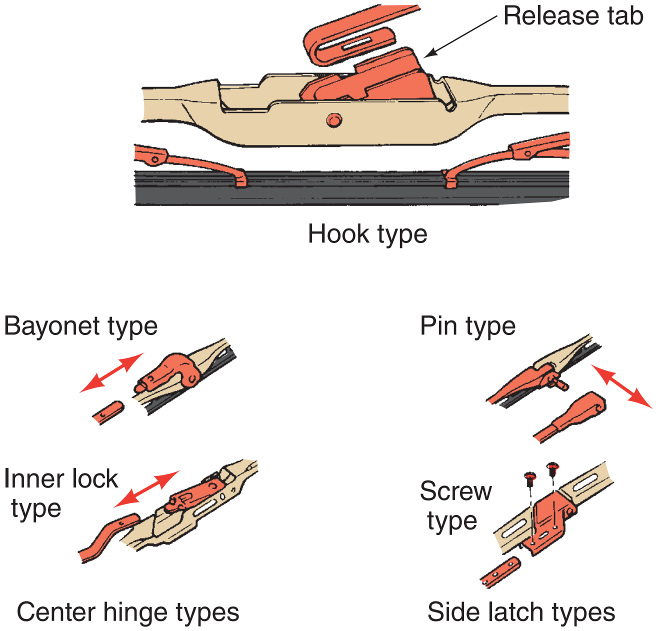


FIGURE 8–38 Examples of the different ways that wiper blades are secured to the wiper arm.

Wiper arms are either mounted onto a threaded shaft and held in place by a nut, or they are pressed over a splined shaft. Some shaft-mounted arms are held in place by a clip that must be released before the arm can be pulled off. When installing wiper arms, make sure they are positioned so the blades do not hit the frame of the windshield while they are operating. When checking the placement and operation of the wipers, wet the windshield before turning on the wipers. The water will serve as a lubricant for the wipers.

Windshield Washer Fluid The last fluid level to check is the windshield washer fluid **(Figure 8–39)**. Visually check the level and add as necessary. Always use windshield washer fluid and never add water to the washer fluid, especially in cold weather.

FIGURE 8–39 Check the level of the windshield washer fluid at the reservoir.

Water can freeze and crack the tank or clog the washer hoses and nozzles.

Tires

The vehicle's tires should be checked for damage and wear. Tires should have at least 1⁄16-inch of tread remaining. Any less and the tire should be replaced. Tires have "tread wear indicators" molded into them. When the wear bar shows across the width of the tread, the tire is excessively worn. A tire wear gauge gives an accurate measurement of the tread depth **(Figure 8–40)**. Also, check the tires for bulges, nails, tears, and other damage. All of these indicate the tire should be replaced.

Inflation Check the inflation of the tires. To do this, use a tire pressure gauge **(Figure 8–41)**. Press the gauge firmly onto the tire's valve stem. The air pressure in the tire will push the scale out of the tool. The highest number shown on the scale is the air pressure of the tire. Compare this reading with the specifications for the tire.

FIGURE 8–40 A tire tread depth gauge.

FIGURE 8–41 Check the tires and wheels for damage and proper inflation.

The correct tire pressure is listed in the vehicle's owner's manual or on a decal (placard) stuck on the driver's doorjamb **(Figure 8–42)**. The air pressure rating on the tire is not the amount of pressure the tire should have. Rather this rating is the maximum pressure the tire should ever have when it is cold.

Vehicles built since 2010 are fitted with tire pressure monitoring systems (TPMS). These systems either have an air pressure sensor inside of each wheel or use wheel speed sensor data to determine tire pressure. When the pressure is below or above a specified range, the vehicle's computer causes a warning light on the dash to illuminate. This alerts the driver of a problem. For vehicles that have pressure sensors, the sensors can be, and should be, checked, as part of regular maintenance.

Whenever tire work is performed, the TPMS should be reset. Vehicles without sensors often have a tire pressure monitoring (TPM) relearn button that is pressed and held to place the system into learn mode

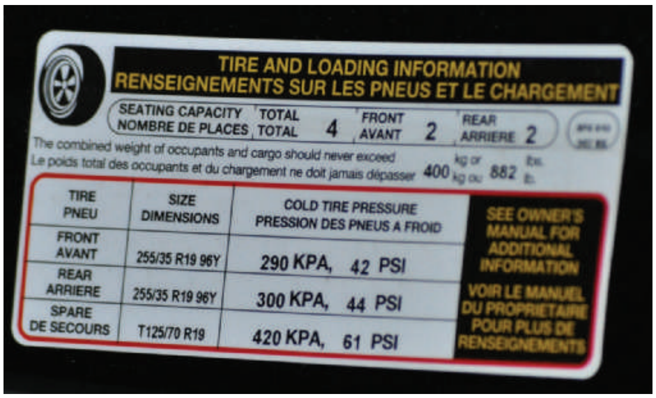


FIGURE 8–42 The tire placard gives the recommended cold tire pressure for that vehicle.

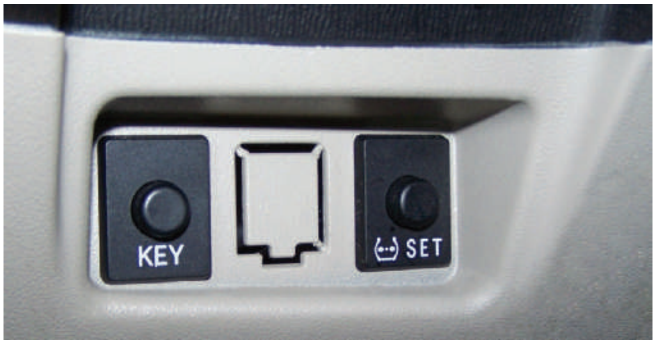


FIGURE 8–43 Some vehicles have a TPM reset or relearn button.

(Figure 8–43). When the vehicle is driven, the system will determine tire pressure based on ABS wheel speed sensor inputs. TPMS with sensors should be relearned anytime tire work, such as a tire rotation, is performed. This ensures that the current location of the sensors is programed into the TPM module and the readings, if displayed on the instrument panel, are correct.

Tire Rotation To equalize tire wear, most car and tire manufacturers recommend that the tires be rotated. Front and rear tires perform different jobs and can wear differently, depending on driving habits and the type of vehicle. In a RWD vehicle, for instance, the front tires usually wear along the outer edges, primarily because of the scuffing and slippage encountered in cornering. The rear tires wear in the center because of acceleration thrusts. To equalize wear, it is recommended that tires be rotated as illustrated in **(Figure 8–44)**. Radial tires should be initially rotated at 7,500 miles and then at least every 15,000 miles thereafter. It is important that directional tires are kept rotating in the direction they are designed for. This means the tires may need to be dismounted from the wheel, flipped, and reinstalled on the rim before being put on the other side of the car.

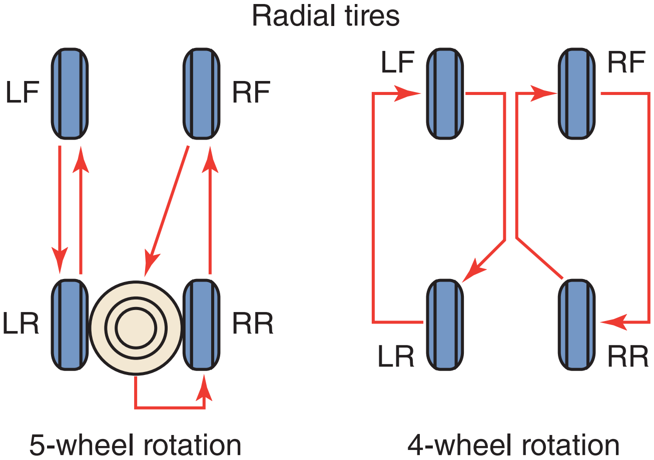


FIGURE 8–44 Rotation sequence for radial tires.

FIGURE 8–45 Wheel lugs should be tightened to the specified torque.

Lug Nut Torque Obviously, to rotate the tires you must remove the tire/wheel assemblies and then reinstall them. Before reinstalling a tire/wheel assembly on a vehicle, make sure the wheel studs are clean and not damaged, then clean the axle/rotor flange and wheel bore with a wire brush or steel wool. If rust and corrosion are an issue, coat the axle pilot flange with disc brake caliper slide grease or an equivalent. Place the wheel on the hub. Install the lug nuts, and tighten them alternately to draw the wheel evenly against the hub. They should be tightened to a specified torque **(Figure 8–45)** and sequence to avoid distortion. Many tire technicians snug up the lug nuts, then when the car is lowered to the floor, they use a torque wrench for the final tightening.

Warning! Overtorquing of the lug nuts is a common cause of disc brake rotor distortion. Also, an overtorqued lug distorts the threads of the lug and could lead to failure.

Some technicians use a torque absorbing adapter, also called a torque stick **(Figure 8–46)**, to tighten the lug nuts. Follow the torque stick manufacturer's instructions for setting and checking torque accuracy to ensure the lugs are not over- or undertorqued. Make sure to use the correct stick for the required torque. Then check the actual torque of the lug nuts with a torque wrench.

Chassis Lubrication

A PM procedure that is becoming less common because of changing technology is chassis lubrication. However, all technicians should know how to do this. During the lubrication procedure, grease is forced between two surfaces that move or rub against each other. The grease reduces the friction produced by the

FIGURE 8–46 Torque sticks are color coded to indicate their torque setting.

movement of the parts. During a chassis lube, grease is forced into a pivot point or joint through a grease fitting. Grease fittings are found on steering and suspension parts, which need lubrication to prevent wear and noise caused by their action during vehicle operation.

Grease fittings are called **zerk fittings** and are threaded into the part that should be lubricated. A fitting at the end of a manual or pneumatic grease gun fits over the zerk to inject the lubricant. Older vehicles have zerk fittings in many locations, whereas newer vehicles use permanently lubricated joints. Some of these joints have threaded plugs that can be removed to lubricate the joint. A special adapter is threaded onto the grease gun and into the plug's bore to lubricate the joint. After grease has been injected into the joint, the plug should be reinstalled or a zerk fitting installed. On some vehicles, rubber or plastic plugs are installed at the factory; they should never be reused.

Carefully look at the joints to see if the joint boots are sealed or not. Some joints, such as tie-rod ends and ball joints, are sealed with rubber boots. If the boots are good, wipe any old grease or dirt from the zerk fittings to prevent injecting it into the joint. Next, push the grease gun's nozzle straight onto a zerk fitting and pump grease slowly into the joint **(Figure 8–47)**. If the joint has a sealed boot, put just enough grease into the joint to cause the boot to slightly expand. If the boot is not sealed, put in enough grease to push the old grease out. Then wipe off the old grease and any excess grease. Repeat this at all lubrication points.

Check the driveshaft U-joints on both RWD and 4WD trucks and SUVs for grease fittings. Even newer vehicles have grease fittings in the U-joints that require periodic lubrication **(Figure 8–48)**.

FIGURE 8–47 A grease gun forces lubrication into a joint through a zerk fitting.

FIGURE 8–48 A lubrication decal on a late-model full size truck.

Greases Greases are made from oil blended with thickening agents. There are a few synthetic greases available that meet the same standards as petroleum greases. The thickening agent increases the viscosity of the grease. Greases are categorized by a National Lubricating Grease Institute (NLGI) number and by the thickeners and additives that are in the grease. Some greases are also labeled with an "EP," which means they have extreme pressure additives. The number assigned by the NLGI is based on test results and the specifications set by the American Society for Testing Materials (ASTM).

The ASTM specifies the consistency of grease using a penetration test. During this test, the grease is heated and placed below the tip of a test cone. The cone is dropped into the grease. The distance the cone is able to penetrate the grease is measured. The cone will penetrate deeper into soft grease. The NLGI number represents the amount of penetration **(Figure 8–49)**. The higher the NLGI number, the thicker the grease is. NLGI #2 is typically specified for wheel bearings and chassis lubrication.

NLGI grade	Worked penetration after 60 strokes at 77 °F (25 °C)	Appearance
000	44.5–47.5 mm	fluid
00	4.00–4.30 mm	fluid
0	3.55–3.85 mm	very soft
1	3.10–3.40 mm	soft
2	2.65–2.95 mm	moderately soft
3	2.20–2.50 mm	semifluid
4	1.75–2.05 mm	semihard
5	1.30–1.60 mm	hard
6	0.85–1.15 mm	very hard

FIGURE 8–49 The table shows the NLGI grades and the worked penetration ranges.

The NLGI also specifies grease by its use and has established two categories for automotive use. Chassis lubricants are identified with the prefix "L," and wheel bearing lubricants have a prefix of "G." Greases are further defined within those groups by their overall performance. Chassis greases are classified as either LA or LB, and there are three classifications for wheel bearing greases (GA, GB, and GC). Many types of greases are labeled as both GC and LB and are acceptable for both. These are often referred to as multipurpose greases **(Figure 8–50)**. The NLGI certification mark is included on the grease's container **(Figure 8–51)**.

Hybrid Vehicles

Hybrid vehicles are maintained and serviced in the same way as conventional vehicles, except for the hybrid components. The latter includes the high-voltage battery pack and circuits, which must be respected when doing any service on the vehicles. Other services to hybrid vehicles are normal services that must be completed in a different way.

For the most part, service to the hybrid system is not something that is done by technicians, unless they are certified to do so by the automobile manufacturer. Keep in mind that a hybrid has nearly all of the basic systems as a conventional vehicle and these are diagnosed and serviced in the same way. Through an understanding of how the hybrid vehicle operates, you can safely service them.

One of the things to pay attention to is the stop-start feature. You need to know when the engine will normally shut down and restart. Without this knowledge, or the knowledge of how to prevent this, the engine may start on its own when you are working under the hood. Needless to say, this can create a safety hazard. There is a possibility that your hands or something else can be trapped in the rotating belts or hit by a cooling fan. Unless the system is totally shut down, the engine may start at any time when its control system senses that the battery needs to be recharged.

In addition, there is a possibility that the system will decide to power the vehicle by electric only. When it does this, there is no noise, just a sudden movement of the vehicle. This can scare you and can be dangerous. To prevent both of these, always remove the key from the ignition. Make sure the "READY" lamp in the instrument cluster is off; this lets you know

Class	Purpose
GA	Mild duty—wheel bearings
GB	Mild to moderate duty—wheel bearings
GC	Mild to severe duty—wheel bearings
LA	Mild duty—chassis parts and universal joints
LB	Mild to severe duty—chassis parts and universal joints

FIGURE 8–50 ASTM grease designation guide.

NATIONAL LUBRICATING GREASE INSTITUTE
NLGI
AUTOMOTIVE WHEEL BEARING LUBRICANT
GC

NATIONAL LUBRICATING GREASE INSTITUTE
NLGI
AUTOMOTIVE WHEEL BEARING & CHASSIS LUBRICANT
GC-LB

NATIONAL LUBRICATING GREASE INSTITUTE
NLGI
AUTOMOTIVE CHASSIS LUBRICANT
LB

FIGURE 8–51 NLGI identification symbols.

FIGURE 8–52 An example of some of the warning lights in a hybrid vehicle.

the system is also off **(Figure 8–52)**. Hybrids from Toyota and Hyundai use a "READY" light but other manufacturers use other indicators to let you know the vehicle is powered up and ready to be driven. Make sure you know how to tell when the vehicle is completely powered down before beginning any work.

Maintenance

Maintenance of a hybrid vehicle is much the same as a conventional one. Care needs to be taken to avoid anything orange while carrying out the maintenance procedures.

The computer-controlled systems are extremely complex and are very sensitive to voltage changes. This is why the manufacturers recommend a thorough inspection of the auxiliary battery and connections every 6 months.

The engines used in hybrids are modified versions of engines found in other models. Other than fluid checks and changes, there is little maintenance required on these engines. However, there is less freedom in deciding the types of fluids that can be used and the parts that can replace the original equipment. Hybrids are not very forgiving. Always use the exact replacement parts and the specified fluids.

Typically, the engine oil used in a hybrid is very light, for example 0W-20 oil. If heavier oil is used, the computer may see this as a problem and prevent the engine from starting. The heavier oil may cause an increase in the current required to crank the engine. If the computer senses very high current draw while attempting to crank the engine, it will open the circuit in response.

Special attention is necessary for the cooling systems in hybrid vehicles. Most hybrids have two cooling systems, one for the engine and one for the hybrid drive systems and/or battery packs. These cooling systems do not intermix and different coolants are used in each. If servicing a hybrid vehicle's cooling system, first make sure you are working on the correct cooling system. Cooling the hybrid system is important and checking the coolant's condition and level is an additional PM check. The cooling system used in some hybrids features electric pumps and storage tanks **(Figure 8–53)**. The tanks store heated coolant and can cause injury if you are not aware of how to check them.

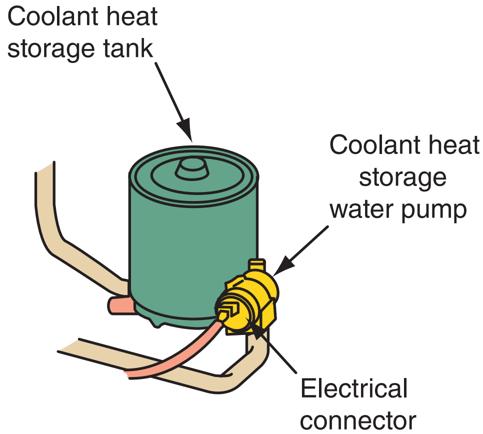


FIGURE 8–53 The hot coolant storage tank for Toyota hybrids.

Many hybrids use passenger compartment air for the high-voltage battery cooling system. These air supply systems often contain air filters that may also need to be serviced at regular intervals. There is a filter in the ductwork from the outside of the vehicle to the battery box. This filter needs to be periodically changed. If the filter becomes plugged, the temperature of the battery will rise to dangerous levels. In fact, if the computer senses high temperatures it may shut down the system.

A normal part of PM is checking power steering and brake fluids. The power-steering systems used by the manufacturers vary; some have a belt-driven pump, some have an electrically driven pump, and others have a pure electric and mechanical steering gear. Each variety requires different care; therefore, always check the service information for the specific model before doing anything to these systems. Also, keep in mind that some hybrids use the power-steering pump as the power booster for the brake system.

Hybrids are all about fuel economy and reduced emissions. Everything that would affect these should be checked on a regular basis. Items such as tires, brakes, and wheel alignment can have a negative effect, and owners of hybrids will notice the difference. These owners are constantly aware of their fuel mileage due to the displays on the instrument panel.

Additional PM Checks

The following PM checks are tasks that should be performed at these suggested time intervals to help ensure safe and dependable vehicle operation.

Time: While operating the vehicle

- Pay attention to and note any changes in the sound of the exhaust or any smell of exhaust fumes in the vehicle.
- Check for vibrations in the steering wheel. Notice any increased steering effort or looseness in the steering wheel.
- Notice if the vehicle constantly turns slightly or pulls to one side of the road.
- When stopping, listen and check for strange sounds, pulling to one side, increased brake pedal travel, or hard-to-push brake pedal.
- If any slipping or changes in the operation of the transmission occur, check the transmission fluid level.
- Check for fluid leaks under the vehicle. (Water dripping from the air-conditioning system after use is normal.)
- Check the automatic transmission's park function.
- Check the parking brake.

Time: At least monthly

- Check the operation of all exterior lights, including the brake lights, turn signals, and hazard warning flashers.

Time: At least twice a year

- Check the pressure in the spare tire.
- Check headlight alignment.
- Check the muffler, exhaust pipes, and clamps.
- Inspect the lap/shoulder belts for wear.
- Check the radiator, heater, and air-conditioning hoses for leaks or damage.

Time: At least once a year

- Lubricate all hinges and all outside key locks.
- Lubricate the rubber weather strips for the doors.
- Clean the body's water drain holes.
- Lubricate the transmission controls and linkage.

KEY TERMS

Coolant
Crude oil
Energy-conserving oil
Multiviscosity oil
Polyglycol
Repair order (RO)
Serpentine belt
Sublet repair
V-belts
Vehicle identification number (VIN)
Viscosity
V-ribbed belts
Zerk fitting

SUMMARY

- A repair order (RO) is a legal document used for many purposes.
- An RO includes a cost estimate for the repairs. By law, this estimate must be quite accurate.
- Preventive maintenance (PM) involves regularly scheduled vehicle service to keep it operating efficiently and safely. Technicians should stress the importance of PM to their customers.
- Engine oil is a clean or refined form of crude oil. It contains many additives, each intended to improve the effectiveness of the oil.
- The American Petroleum Institute (API) classifies engine oil according to its ability to meet the engine manufacturers' warranty specifications.
- The Society of Automotive Engineers (SAE) has established an oil viscosity classification system that has a numeric rating in which the higher viscosity, or heavier weight oils, receives the higher numbers.
- Changing the engine's oil and filter should be done on a regular basis.
- Whenever the engine's oil is changed, a thorough inspection of the cooling systems should be done.
- Normally, the recommended mixture for engine coolant is a 50/50 solution of water and antifreeze.
- V-belts and V-ribbed (serpentine) belts are used to drive water pumps, power-steering pumps, air-conditioning compressors, generators, and emission control pumps.
- If a belt does not have the proper tension, it may produce squealing and chirping noises; allow the belt to roll off a pulley; or slip, which reduces the power that drives a component.
- Excessive belt tension may put unwanted forces on the pulleys and the shafts they are attached to, leading to noise, belt breakage, glazing, and damage to the bearings and bushings in water pumps, generators, and power-steering pumps.
- The air filter should be periodically checked for excessive dirt or blockage and a replacement filter should be the same size and shape as the original.
- The battery is the main source of electrical energy for the vehicle. It is very important that it is checked on a regular basis.
- If the battery or any of the associated parts are dirty or corroded, remove the battery and clean them.
- The condition of the automatic transmission fluid (ATF) should be checked while checking the fluid level.
- Normally the fluid used in power-steering systems is ATF. Check the service information for the proper fluid type before adding fluid.

- Check the level of the brake fluid and make sure the fluid is the correct type and is fresh and clean.
- There are basically four types of brake fluids: DOT 3, DOT 4, DOT 5, and DOT 5.1. Most automakers specify DOT 3 fluid for their vehicles.
- Check the windshield wipers for signs of dullness, tears, and hardness. Also check the spring on the wiper arm.
- The vehicle's tires should be checked for damage and wear as well as for proper inflation.
- To equalize tire wear, most car and tire manufacturers recommend that the tires be rotated after a specified mileage interval.
- Several parts of a vehicle may need periodic lubrication; always use the correct type of grease when doing this.
- Some PM procedures are unique to hybrid vehicles; always follow the recommendations of the manufacturer.
- When servicing a hybrid vehicle, always respect its high-voltage system.

REVIEW QUESTIONS

Short Answer

1. Describe the information found in a VIN.
2. List five different types of oil rating systems.
3. Why should you wipe off the outside of a zerk fitting before injecting grease into it?
4. List at least five things that should be checked while inspecting a vehicle's battery.
5. How does a technician determine the proper inflation for a vehicle's tires?
6. Explain the purpose of a repair order and describe the type of information it should contain.

True or False

1. *True or False?* Legally, an RO protects the shop and the customer.
2. *True or False?* If brake fluid is discolored, the system must be flushed and the fluid replaced.
3. *True or False?* ATF labeled as "Multivehicle ATF" can safely be used in all automatic transmissions.
4. *True or False?* An oil with the classification of 5W-30 has the viscosity of both a 5- and 30-weight oil. The 5W means the oil has a viscosity of 5 when warm and a 30 rating when it is cold.

Multiple Choice

1. Technician A stresses the need to follow the manufacturer's recommendations for preventive maintenance to his customers. Technician B says that the proper PM service intervals depends on the customer's driving habits and typical driving conditions. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. Technician A says that the recommended tire inflation pressure is located on the tire sidewall. Technician B says that maximum tire cold inflation pressure is located on the sidewall. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. When working on a hybrid electric vehicle, which of the following statements does *not* reflect things you should be aware of?
   a. The engine will normally shut down and restart when as needed when stopped.
   b. The engine may start at any time when its control system senses that the battery needs to be recharged.
   c. The system may decide to power the vehicle, while it is parked, even if the engine is OFF.
   d. Make sure the "READY" lamp in the instrument cluster is off; this lets you know the system is off.
4. While examining the color of an engine's coolant: Technician A says that because it is orange, the cooling system should be flushed and new coolant put into the system. Technician B says that if the coolant looks rusty, the cooling system should be flushed and new coolant put into the system. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. While checking the condition of a vehicle's ATF: Technician A says that if the fluid has a burnt color or odor, the fluid has been overheated. Technician B says that a milky color indicates that engine coolant has been leaking into the transmission's cooler in the radiator. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

6. Technician A says that if a drive belt does not have the proper tension, it may produce squealing and chirping noises. Technician B says belt tension should be checked even if the engine has an automatic belt tensioner. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. Technician A says that to accurately check brake fluid level, the master cylinder cap must be removed. Technician B says not to remove the master cylinder cap unless absolutely necessary to stop air from entering the reservoir. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. Which of the following statements about drive belt slippage is *not* true?
   a. Excessive heat normally comes from slippage.
   b. As a V-belt slips, it begins to ride deeper in the pulley groove.
   c. Slippage can be caused by improper belt tension or oily conditions.
   d. When there is slippage, heat travels through the drive pulley and down the shaft to the support bearing of the component it is driving.
9. Which of the following statements about an oil's viscosity is *not* true?
   a. The ability of oil to resist flow is its viscosity.
   b. Viscosity is affected by temperature; hot oil flows faster than cold oil. Oil flow is important to the life of an engine.
   c. In the API system of oil viscosity classification, the lighter oils receive a higher number.
   d. Heavyweight oils are best suited for use in high-temperature regions. Low-weight oils work best in low temperature operations.
10. While discussing a vehicle's maintenance program: Technician A says most vehicles can safely follow the "normal" service schedule in the vehicle's owner's manual. Technician B says common driving conditions often require a vehicle to use the "severe" maintenance schedule. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
11. Which of the following is *not* a true statement about a mechanic's lien?
    a. This lien states that the shop may gain possession of the vehicle if the customer does not pay for the agreed-upon services.
    b. The right to impose a mechanic's lien can be exercised by a shop within 30 days after the services have been completed.
    c. In most cases, the shop's right to impose a lien on the vehicle being serviced must be acknowledged by the customer prior to beginning any services to the vehicle.
    d. This clause ensures that the shop will receive some compensation for the work performed, whether or not the customer pays the bill.
12. While discussing the effects of overtorquing wheel lugs: Technician A says that this can cause the threads of the lugs and/or studs to distort. Technician B says that this can cause disc brake rotor distortion. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
13. The most commonly used brake fluid in domestic vehicles is:
    a. DOT 2
    b. DOT 3
    c. DOT 4
    d. DOT 5
14. Which of the following greases are best suited for lubricating automotive wheel bearings?
    a. LA
    b. LB
    c. GA
    d. GC
15. While discussing the special preventive maintenance items for a hybrid vehicle: Technician A says that special coolants are required in most hybrids because the coolant not only cools the engine, but also the inverter assembly. Technician B says that the battery cooling system may have a filter in the ductwork from the outside of the vehicle to the battery box and that this filter needs to be periodically changed. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

ENGINES

SECTION 2

CHAPTER 9

AUTOMOTIVE ENGINE DESIGNS AND DIAGNOSIS

OBJECTIVES

- Describe the various ways in which engines can be classified.
- Explain what takes place during each stroke of the four-stroke cycle.
- Define important engine measurements and performance characteristics, including bore and stroke, displacement, compression ratio, engine efficiency, torque, and horsepower.
- Outline the basics of diesel, stratified, Atkinson, and Miller-cycle engine operation.
- Explain how to evaluate the condition of an engine.
- List and describe abnormal engine noises.

Introduction to Engines

The engine **(Figure 9–1)** provides the power to drive the vehicle's wheels. All automobile engines, both gasoline and diesel, are classified as internal-combustion engines because the combustion or burning that creates energy takes place inside the engine.

The biggest part of the engine is the cylinder block **(Figure 9–2)**. The cylinder block is a large casting of metal drilled with holes to allow for the passage of lubricants and coolant through the block and provide spaces for parts to move. The main bores in the block are the cylinders, which are fitted with pistons. The block houses or holds the major engine parts.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE		REPAIR ORDER		
Year: 2000	**Make:** Honda	**Model:** Civic	**Mileage:** 164,285	**RO:** 5512
Concern:	Customer complains the engine has a rough idle and does not have as much power as it used to but seems to smooth out at highway speeds.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

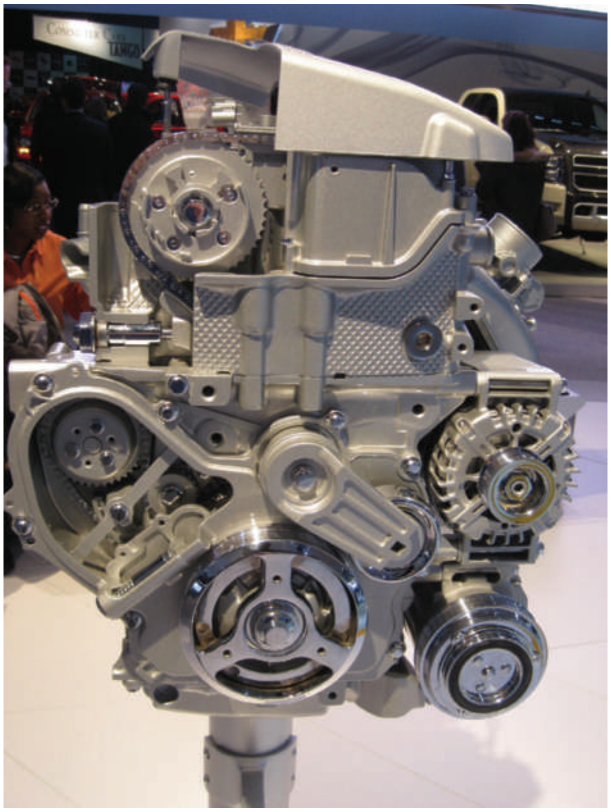
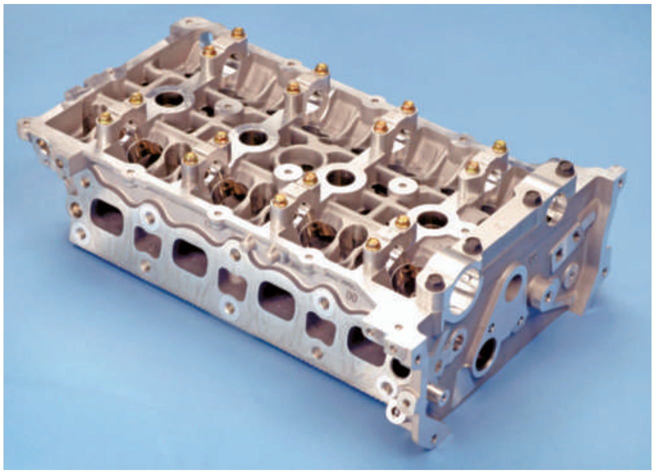


FIGURE 9–1 Today's engines are complex, efficient machines.

The cylinder head fits on top of the cylinder block to close off and seal the top of the cylinders **(Figure 9–3)**. The cylinder head contains all or most of the combustion chamber. The combustion chamber is the area where the air-fuel mixture is compressed and burned. The cylinder head also contains ports through which the air-fuel mixture enters and burned gases exit the cylinders and bores for the spark plugs.

The valve train opens and closes the intake and exhaust ports. Movable valves open and close the ports. A camshaft controls the movement of the valves. Springs are used to help close the valves.

FIGURE 9–2 A cylinder block for an eight-cylinder engine.



Courtesy of Chrysler LLC

FIGURE 9–3 A cylinder head for a late-model inline four-cylinder engine.

The up-and-down motion of the pistons must be converted to a rotary motion before it can drive the wheels of a vehicle. To do this, the pistons are connected to a crankshaft by connecting rods **(Figure 9–4)**. The upper end of the connecting rod

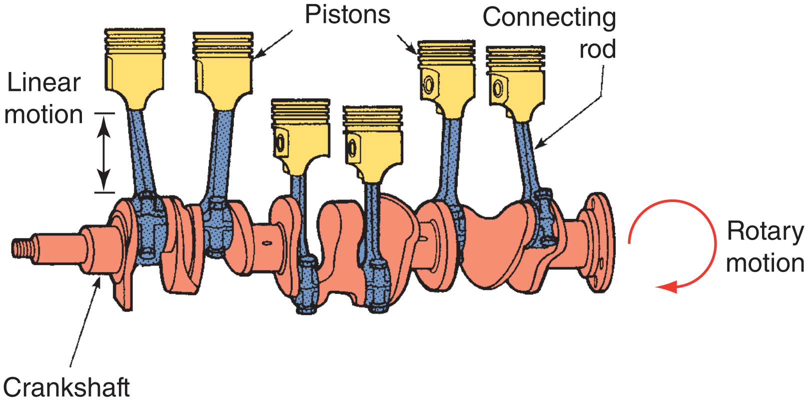


FIGURE 9–4 The linear (reciprocating) motion of the pistons is converted to rotary motion by the crankshaft.

moves with the piston. The lower end is attached to the crankshaft and moves in a circle. The end of the crankshaft is connected to the flywheel or flexplate. Through the flywheel, the power from the engine is indirectly sent to the drive wheels.

Engine Construction

Modern engines are designed to meet the performance and fuel efficiency demands of the public. Most are made of lightweight, noniron materials (for example, aluminum, magnesium, fiber-reinforced plastics); and with fewer and smaller fasteners to hold things together. Fewer fasteners are made possible due to joint designs that optimize loading patterns. Each engine type has its own distinct personality, based on construction materials, casting configurations, and design.

Engine Classifications

Today's automotive engines can be classified in several ways depending on the following design features:

- *Operational cycles.* Most technicians will come in contact with only four-stroke cycle engines. A few older cars have used, and some in the future may use, a two-stroke engine.
- *Number of cylinders.* Current engine designs include 3-, 4-, 5-, 6-, 8-, 10-, 12-, and 16-cylinder engines.
- *Cylinder arrangement.* The cylinders of an engine can be arranged inline with each other, in a "V" with an equal number of cylinders on each side, or arranged directly across from each other, these engines are called horizontally opposed **(Figure 9–5)**.
- *Valve train type.* Valve trains can be either the overhead camshaft (OHC) or the camshaft in-block overhead valve (OHV) design. Some engines have separate camshafts for the intake and exhaust valves. These are based on the OHC design and are called **double overhead camshaft (DOHC)** engines. V-type DOHC engines have four camshafts—two on each side.
- *Ignition type.* There are two types of ignition systems: spark and compression. Gasoline engines use a spark ignition system. In a spark ignition system, the air-fuel mixture is ignited by an electrical spark. Diesel engines, or compression ignition engines, have no spark plugs. A diesel engine relies on the heat generated as air is compressed in the cylinder to ignite the fuel.

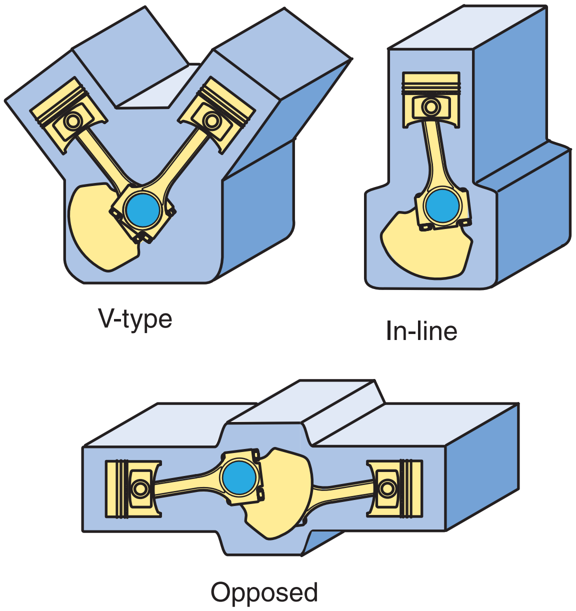


FIGURE 9–5 The basic configurations of V-type.

- *Cooling systems.* There are both air-cooled and liquid-cooled engines in use. All current engines have liquid-cooling systems.
- *Fuel type.* The fuels currently used in automobiles include gasoline, natural gas, methanol, diesel, ethanol, and propane. The most commonly used is gasoline although most gasoline is blended with ethanol.

Four-Stroke Gasoline Engine

The engine provides the rotating power to drive the wheels through the transmission and driving axles. All automotive engines, both gasoline and diesel, are classified as internal combustion engines because the combustion or burning of the fuel takes place inside the engine. They require an engine that is made to withstand the high temperatures and pressures created by the burning of thousands of fuel droplets.

The **combustion chamber** is the space between the top of the piston and the cylinder head. It is an enclosed area in which the fuel and air mixture is burned. If all of the fuel in the chamber is burned, complete combustion has taken place.

In order to have complete combustion, the right amount of fuel must be mixed with the right amount of air. This mixture must be compressed in a sealed container, then shocked by the right amount of heat (spark) at the right time. When these conditions exist, all the fuel that enters a cylinder is burned and converted to power to move the vehicle. Automotive engines have more than one cylinder. Each cylinder

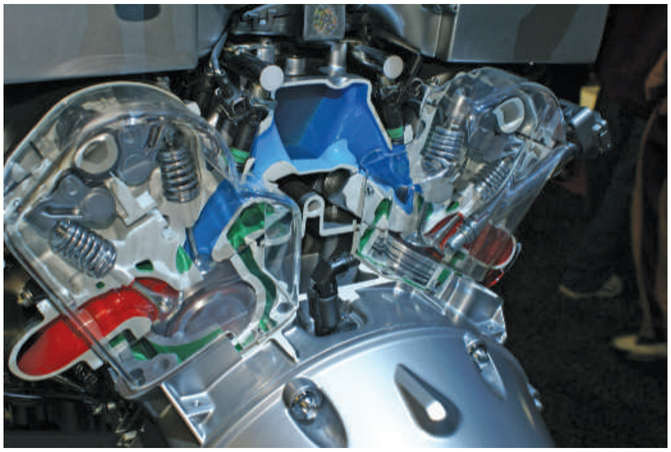


FIGURE 9–6 A cutaway of an engine showing the intake passages (blue) and valve and exhaust passage (red) and valve.

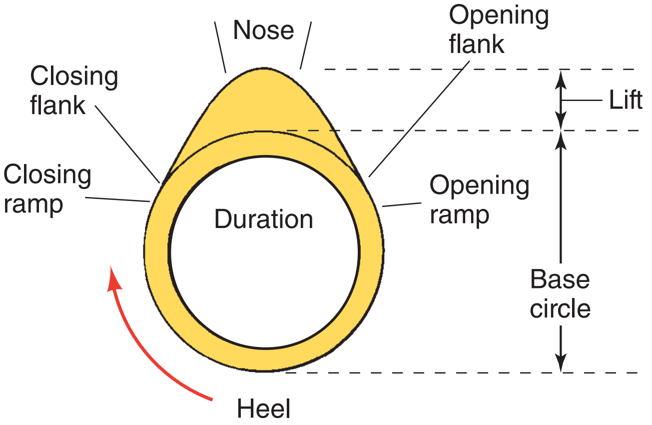


FIGURE 9–7 The height and width of a cam lobe determine when and for how long a valve will be open.

should receive the same amount of air, fuel, and heat, if the engine is to run efficiently.

Although the combustion must occur in a sealed cylinder, the cylinder must also have a way to allow heat, fuel, and air into it. There must also be a way to allow the burnt air-fuel mixture out so a fresh mixture can enter and the engine can continue to run. To meet these requirements, engines are fitted with valves.

There are at least two valves at the top of each cylinder. The air-fuel mixture enters the combustion chamber through an intake valve and leaves (after having been burned) through an exhaust valve **(Figure 9–6)**. A valve is said to be seated or closed when it rests in its opening or seat. When the valve is pushed off its seat, it opens.

A rotating camshaft, driven and timed to the crankshaft, opens and closes the intake and exhaust valves. Cams are raised sections of a shaft that have high spots called **lobes**. Cam lobes are oval shaped. The placement of the lobe on the shaft determines when the valve will open. The height and shape of the lobe determines how far the valve will open and how long it will remain open in relation to piston movement **(Figure 9–7)**.

As the camshaft rotates, the lobes rotate and push the valve open by pushing it away from its seat. Once the cam lobe rotates out of the way, the valve, forced by a spring, closes. The camshaft can be located either in the cylinder block or in the cylinder head. The camshaft is driven by the crankshaft through gears, or sprockets, and a cogged belt, or timing chain.

When the action of the valves and the spark plug is properly timed to the movement of the piston, the combustion cycle takes place in four movements or strokes of the piston: the intake stroke, the compression stroke, the power stroke, and the exhaust stroke. The camshaft turns at half the crankshaft speed and rotates one complete turn during each complete four-stroke cycle.

Four-Stroke Cycle A **stroke** is the full travel of the piston either up or down in a cylinder's bore. It takes two full revolutions of the crankshaft to complete the four-stroke cycle. One complete rotation of the crankshaft is equal to 360 degrees; therefore, it takes 720 degrees to complete the four-stroke cycle. During one piston stroke, the crankshaft rotates 180 degrees.

The piston moves down by the pressure produced during combustion, but this moves the piston only enough to complete one stroke. In order to keep the engine running, the piston must travel through the other three strokes. The inertia of a flywheel attached to the end of the crankshaft keeps the crankshaft rotating and allows the piston to complete the rest of the four-stroke cycle. A heavy flywheel is only found on engines equipped with a manual transmission. Engines fitted to automatic transmissions have a flexplate and a torque converter. The weight and motion of the fluid inside the torque converter serve as a flywheel.

Intake Stroke The first stroke of the cycle is the intake stroke. As the piston moves away from **top dead center (TDC)**, the intake valve opens **(Figure 9–8A)**. The downward movement of the piston increases the volume of the cylinder above it, reducing the pressure in the cylinder. This reduced pressure, commonly referred to as engine vacuum, causes the atmospheric pressure to push air through the open intake valve. (Some engines are equipped with a super- or turbocharger that pushes more air past the valve.) Air continues to enter the cylinder

until the intake valve is closed. In most engines, the intake valve closes after the piston has reached **bottom dead center (BDC)**. This delayed closing of the valve increases the volumetric efficiency of the cylinder by packing as much air into it as possible.

Compression Stroke The compression stroke begins as the piston starts to move from BDC. With the intake valve closed, the air in the cylinder is trapped **(Figure 9–8B)**. The upward movement of the piston compresses the air, thus heating it up. The amount of pressure and heat formed by the compression stroke depends on the amount of air in the cylinder and the compression ratio of the engine. The volume of the cylinder with the piston at BDC compared to the volume of the cylinder with the piston at TDC determines the compression ratio of the engine. In most modern engines, fuel is injected into the cylinder sometime during the compression stroke.

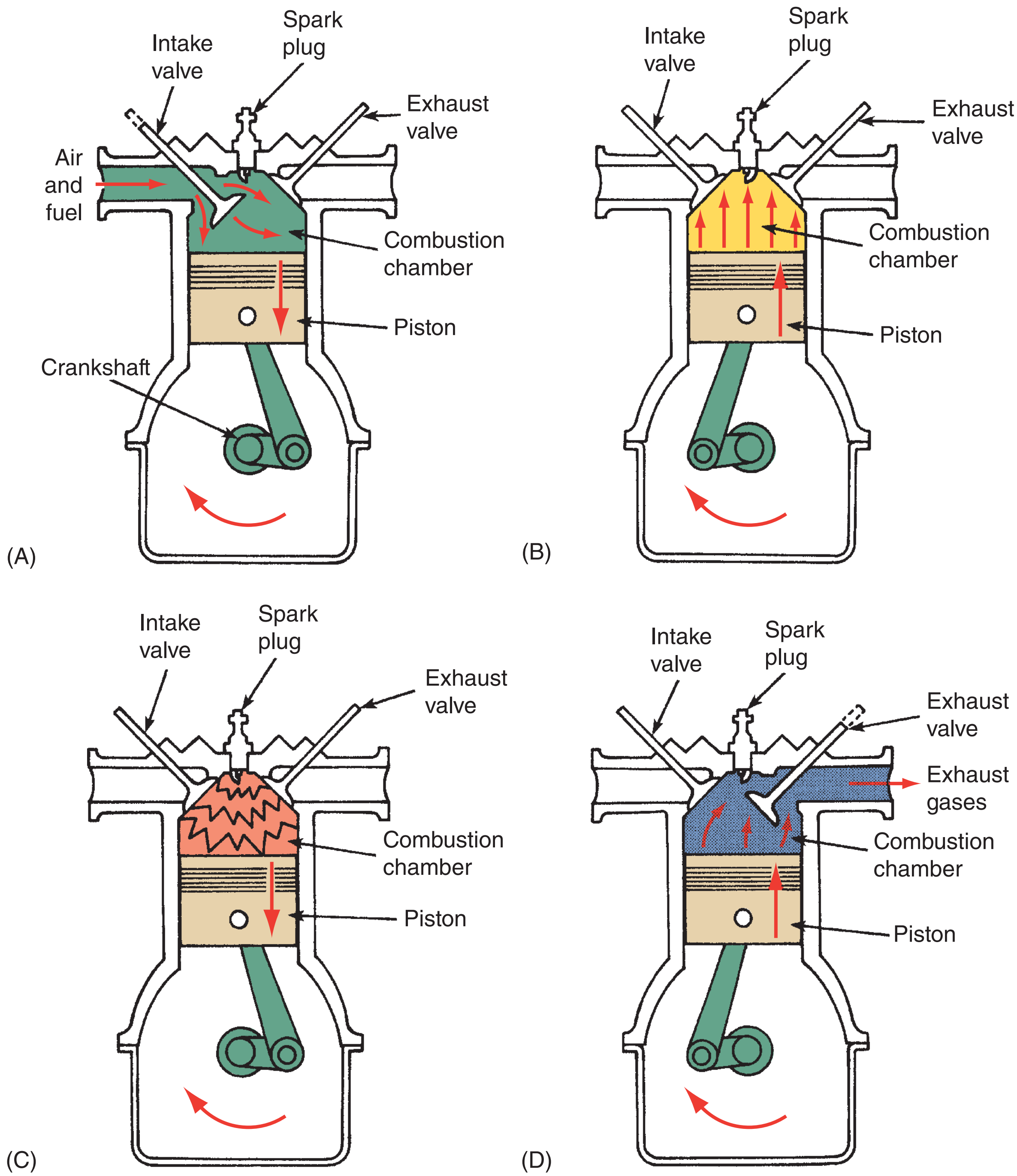


FIGURE 9–8 (A) Intake stroke, (B) compression stroke, (C) power stroke, and (D) exhaust stroke.

Power Stroke The power stroke, also called the expansion stroke, begins as the compressed fuel mixture is ignited **(Figure 9–8C)**. With both valves closed, an electrical spark across the electrodes of a spark plug ignites the air-fuel mixture. The burning mixture rapidly expands, creating a very high pressure against the top of the piston. This drives the piston down toward BDC. The downward movement of the piston is transmitted through the connecting rod to the crankshaft.

Exhaust Stroke The exhaust valve opens just before the piston reaches BDC on the power stroke **(Figure 9–8D)**. Pressure within the cylinder causes the exhaust gas to rush past the open valve and into the exhaust system. Movement of the piston from BDC pushes most of the remaining exhaust gas from the cylinder. As the piston nears TDC, the exhaust valve begins to close as the intake valve starts to open. The exhaust stroke completes the four-stroke cycle. The opening of the intake valve begins the cycle again. This cycle occurs in each cylinder and is repeated over and over, as long as the engine is running.

Firing Order

An engine's **firing order** states the sequence in which an engine's pistons are on their power stroke and therefore the order in which the cylinders' spark plugs fire. The firing order also indicates the position of the other pistons in an engine when a cylinder is firing. For example, consider a four-cylinder engine with a firing order of 1-3-4-2. The sequence begins with piston #1 on the compression stroke. During that time, piston #3 is moving down on its intake stroke, #4 is moving up on its exhaust stroke, and #2 is moving down on its power stroke. These events are identified by what needs to happen in order for #3 to be ready to fire next, and so on.

Not all engines have the same firing order, as it is determined by the design and manufacturer of the engine. The firing order of a particular engine can be found on the engine or on its emissions label and in service information. **Figure 9–9** shows some of the common cylinder arrangements and their associated firing orders.

Common cylinder numbering and firing order

In-line

4-Cylinder		6-Cylinder	
① ② ③ ④		① ② ③ ④ ⑤ ⑥	
Firing Order	1–3–4–2 1–2–4–3	Firing Order	1–5–3–6–2–4

V configuration

V6		V8	
⑤ ③ ①	Right bank	① ② ③ ④	Right bank
⑥ ④ ②	Left bank	⑤ ⑥ ⑦ ⑧	Left bank
Firing Order	1–4–5–2–3–6	Firing Order	1–5–4–8–6–3–7–2
② ④ ⑥	Right bank	① ② ③ ④	Right bank
① ③ ⑤	Left bank	⑤ ⑥ ⑦ ⑧	Left bank
Firing Order	1–6–5–4–3–2	Firing Order	1–5–4–2–6–3–7–8
① ② ③	Right bank	② ④ ⑥ ⑧	Right bank
④ ⑤ ⑥	Left bank	① ③ ⑤ ⑦	Left bank
Firing Order	1–2–3–4–5–6	Firing Order	1–8–4–3–6–5–7–2
① ② ③	Right bank	② ④ ⑥ ⑧	Right bank
④ ⑤ ⑥	Left bank	① ③ ⑤ ⑦	Left bank
Firing Order	1–4–2–3–5–6	Firing Order	1–8–7–2–6–5–4–3

FIGURE 9–9 Examples of cylinder numbering and firing orders.

Two-Stroke Gasoline Engine

In the past, several imported vehicles used two-stroke engines. As the name implies, this engine requires only two strokes of the piston to complete all four operations: intake, compression, power, and exhaust **(Figure 9–10)**. This is accomplished as follows:

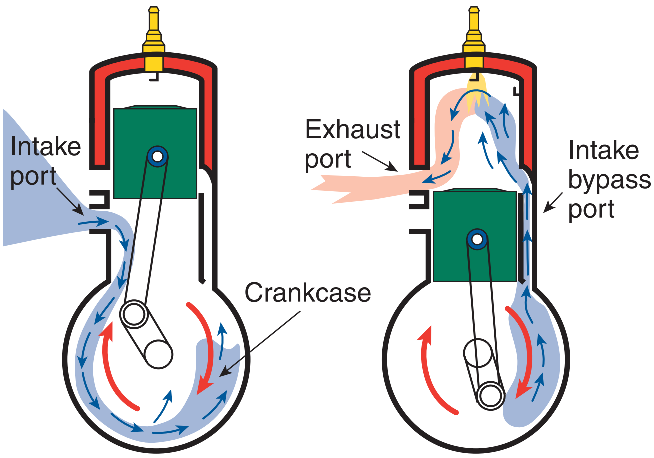
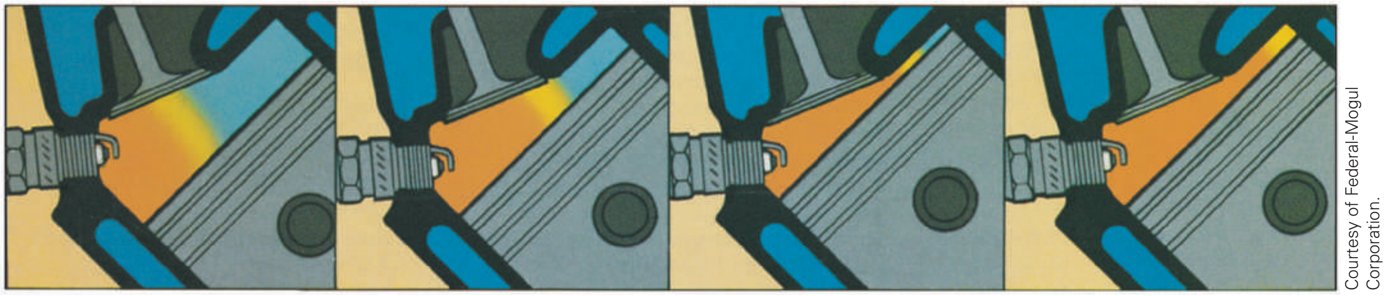


FIGURE 9–10 A two-stroke cycle.



1. Spark occurs 2. Combustion begins 3. Continues rapidly 4. And is completed

FIGURE 9–11 Normal combustion.

1. Movement of the piston from BDC to TDC completes both intake and compression.
2. When the piston nears TDC, the compressed air-fuel mixture is ignited, causing an expansion of the gases. During this time, the intake and exhaust ports are closed.
3. Expanding gases in the cylinder force the piston down, rotating the crankshaft.
4. With the piston at BDC, the intake and exhaust ports are both open, allowing exhaust gases to leave the cylinder and air-fuel mixture to enter.

Although the two-stroke-cycle engine is simple in design and lightweight because it lacks a valve train, it has not been widely used in automobiles. It tends to be less fuel efficient and releases more pollutants than four-stroke engines. Oil is often present in the exhaust because the engines require a constant oil delivery to the cylinders to keep the piston lubricated. Many of these engines require a certain amount of oil to be mixed with the fuel.

Engine Rotation To meet the standards set by the SAE, engines rotate in a counterclockwise direction. This can be confusing because its apparent direction changes with what end of the engine you look at. If one looks at the front of the engine, it rotates in a clockwise direction. The standards are based on the rotation of the flywheel, which is at the rear of the engine, and there the engine rotates counterclockwise.

Combustion

Although many different things can affect the combustion in the engine's cylinders, the ignition system has the responsibility for beginning and maintaining combustion. Obviously when combustion does not occur in any of the cylinders, the engine will not run. If combustion occurs in all but one or two cylinders, the engine may start and run but will run poorly. Poor combustion is not always caused by the ignition system, it can also be caused by problems in the engine, air-fuel system, or exhaust system.

When normal combustion occurs, the burning process moves from the gap of the spark plug across the compressed air-fuel mixture. The movement of this flame front should be rapid and steady and should end when all of the air-fuel mixture has been burned **(Figure 9–11)**. During normal combustion, the rapidly expanding gases push down on the piston with a powerful but constant force.

When all of the air and fuel in the cylinder are involved in the combustion process, complete combustion has occurred. When something prevents this, the engine will misfire or experience incomplete combustion. Misfires cause a variety of driveability problems, such as a lack of power, poor gas mileage, excessive exhaust emissions, and a rough running engine.

Engine Configurations

Depending on the vehicle, either an inline, V-type, slant, or opposed cylinder design can be used. The most popular designs are inline and V-type engines.

Inline Engine In an inline engine design **(Figure 9–12)**, the cylinders are placed in a single row. There is one crankshaft and one cylinder head for all of the cylinders. The block is cast so that all cylinders are located in an upright or slightly slanted position. Currently, inline engines are available in three, four, five, and six-cylinder arrangements.

Inline engine designs have certain advantages and disadvantages. They are easy to manufacture and service. However, because the cylinders are positioned vertically, the front of the vehicle must be higher. This affects the aerodynamic design of the car.

V-Type Engine A V-type engine design has two rows of cylinders located 60 to 90 degrees away from each other. A V-type engine uses one crankshaft,

FIGURE 9-12 The cylinder block for an inline cylinder engine.

which is connected to the pistons on both sides of the V. This type of engine has two cylinder heads, one over each row of cylinders.

One advantage of using a V-configuration is that the engine is not as high or long as one with an inline configuration. If eight cylinders are needed for power, a V-configuration makes the engine much shorter, lighter, and more compact. Many years ago, some vehicles had an inline eight-cylinder engine. The engine was very long and its long crankshaft also caused increased torsional vibrations in the engine.

A variation of the V-type engine is the W-type engine. These engines are basically two V-type engines joined together at the crankshaft. This design makes the engine more compact. They are commonly found in late-model Volkswagens, Bentleys, and the Bugattis.

Slant Cylinder Engine Another way of arranging the cylinders is in a slant configuration. This arrangement is much like an inline engine, except the entire block has been placed at a slant. The slant engine was designed to reduce the distance from the top to the bottom of the engine allowing for more aerodynamic vehicle designs.

Opposed Cylinder Engine In this design, two rows of cylinders are located opposite the crankshaft **(Figure 9–13)**. These engines have a common crankshaft and a cylinder head on each bank of cylinders.

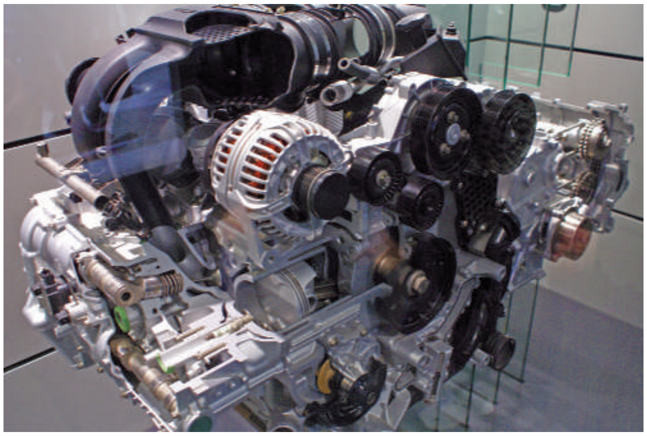


FIGURE 9-13 A horizontally opposed cylinder engine, commonly called a boxer engine.

Porsches and Subarus use this style of engine, commonly called a boxer engine. Boxer engines have a low center of gravity and tend to run smoothly during all operating conditions.

Camshaft and Valve Location

The valves in all modern engines are placed in the cylinder head above the piston. Older engines had valves to the side of the piston. Camshafts are located inside the engine block or above the cylinder head. The placement of the camshaft further describes an engine.

Overhead Valve (OHV) As the name implies, the intake and exhaust valves in an OHV engine are mounted in the cylinder head and are operated by a camshaft located in the cylinder block. This arrangement requires the use of valve lifters, pushrods, and rocker arms to transfer camshaft rotation to valve movement **(Figure 9–14)**.

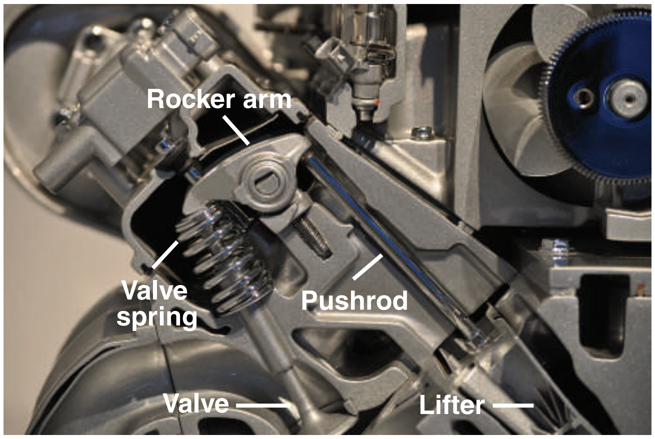


FIGURE 9-14 The basic valve train for an overhead valve engine.

FIGURE 9-15 A look at the setup for a DOHC engine.

Overhead Cam (OHC) An OHC engine also has the intake and exhaust valves located in the cylinder head. But as the name implies, the camshaft is located in the cylinder head. In an OHC engine, the valves are operated directly by the camshaft or through cam followers or tappets. Engines with one camshaft above a cylinder are often referred to as single overhead camshaft (SOHC) engines. Those with two camshafts per cylinder bank are called dual overhead camshaft (DOHC) engines **(Figure 9–15)**.

Engine Location

The engine is placed in one of three locations. In most vehicles, it is in front of the passenger compartment. Front-mounted engines can be positioned either longitudinally or transversely with respect to the vehicle.

The second engine location is a mid-mount position between the passenger compartment and rear suspension. The third, and least common, engine location is the rear of the vehicle. The engines are typically opposed-type engines. Each of these engine locations offers advantages and disadvantages.

Front Engine Longitudinal With this arrangement, the engine, transmission, front suspension, and steering system are located in the front of the vehicle, and the differential and rear suspension are in the rear **(Figure 9–16)**. Most front engine longitudinal vehicles are rear-wheel drive. Some front-wheel-drive cars with a transaxle have this configuration, and many four-wheel-drive vehicles equipped with a transfer case have the engine mounted longitudinally.

Total vehicle weight can be evenly distributed between the front and rear wheels with this configuration. This lightens the steering force and equalizes

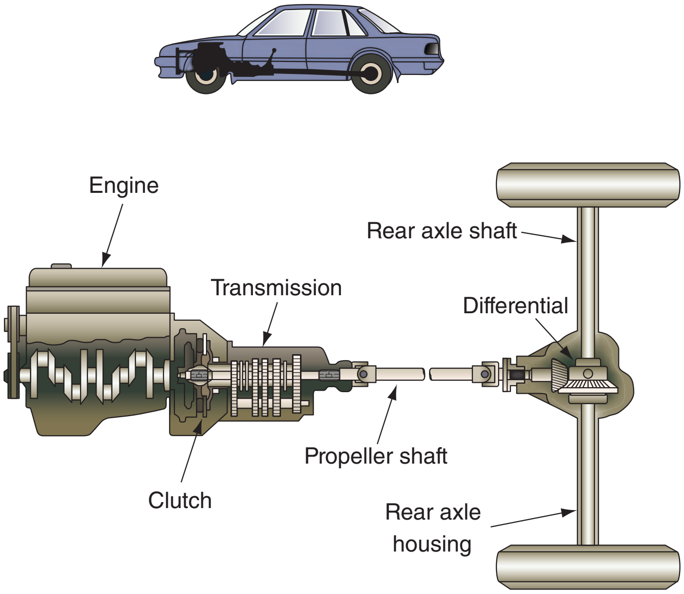


FIGURE 9-16 A longitudinal drivetrain places the engine at the front and drives the rear wheels.

the braking load. Longitudinally mounted engines require large engine compartments. The need for a rear-drive propeller shaft and differential also reduces passenger compartment space.

Front Engine Transverse Engines that are mounted transversely in the front of a vehicle sit sideways in the engine compartment. They are used with transaxles that combine transmission and differential gearing into a single compact housing, fastened directly to the engine **(Figure 9–17)**. Transversely mounted engines reduce the size of the engine compartment and overall vehicle weight.

Transversely mounted front engines allow for down-sized, lighter vehicles with increased interior space. However, most of the vehicle weight is toward the front of the vehicle. While this increases the traction of the drive wheels, the weight also places a greater load on the front suspension and brakes.

Mid-Engine Transverse In this design, the engine and drivetrain are positioned between the passenger compartment and rear axle. The mid-engine location is found in rear-wheel-drive, high-performance sports cars. The central location of heavy components results in a center of gravity very near the center of the vehicle, which vastly improves steering and handling. Since the engine is not under the hood, the hood can be sloped downward, improving aerodynamics and increasing the driver's field of vision. However, engine access and cooling efficiency

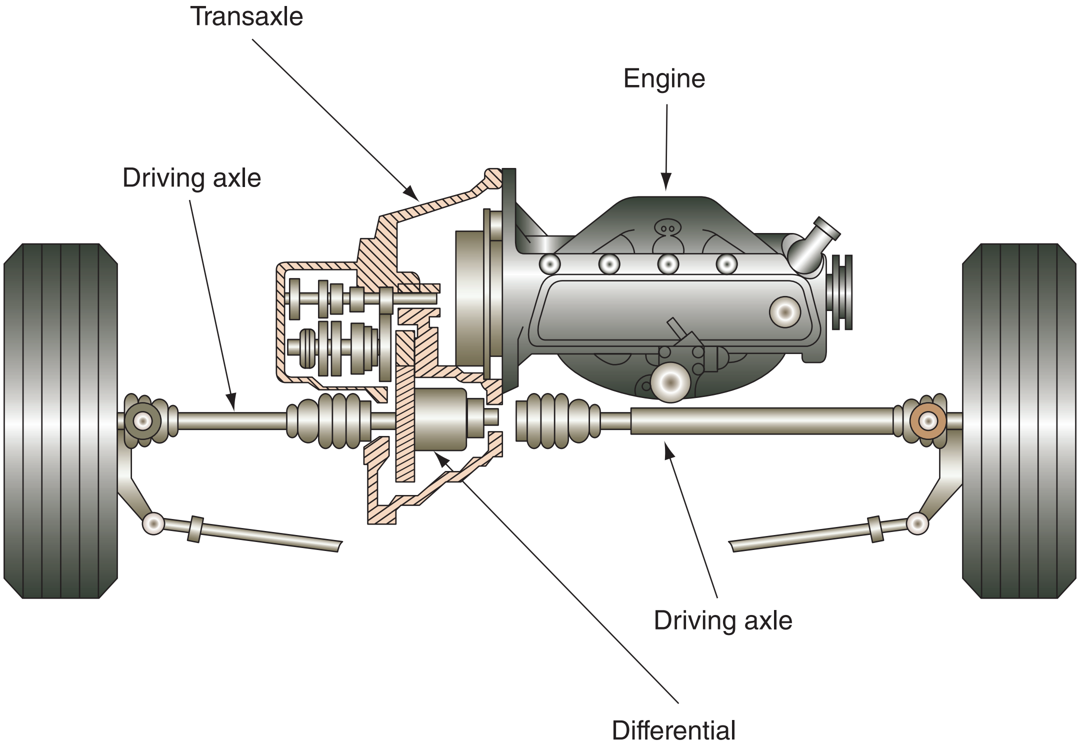


FIGURE 9–17 Front-wheel drive vehicles have a transversely mounted engine and transaxle.

are reduced. A barrier is also required to reduce the transfer of noise, heat, and vibration into the passenger compartment.

Engine Measurement and Performance

Many of the important engine measurements and performance characteristics were discussed in Chapter 3. What follows are some of the important facts of each.

Bore and Stroke

The **bore** of a cylinder is simply its diameter measured in inches (in.) or millimeters (mm). The stroke is the distance the piston travels between TDC and BDC. The bore and stroke determine the displacement of the cylinders. When the bore and stroke are of equal size, the engine is called a *square engine*. Engines that have a larger bore than stroke are called oversquare and engines with a larger stroke than bore are referred to as being undersquare.

Oversquare engines can be fit with larger valves in the combustion chamber and longer connecting rods, which means these engines are capable of running at higher engine speeds. But due to the size of the bore, these engines tend to be physically larger than undersquare engines. **Undersquare** engines have short connecting rods that allow for more power at low engine speeds. A square engine is a compromise between the two designs.

A current trend in engine design is known as rightsizing, which uses 500 cc per cylinder displacements and an undersquare bore and stroke configuration. Undersquare cylinders have improved performance due to having smaller areas for flame travel across the piston while having a long expansion stroke to produce torque.

The **crank throw** is the distance from the crankshaft's main bearing centerline to the connecting rod journal centerline. An engine's stroke is twice the crank throw **(Figure 9–18)**.

Displacement

A cylinder's displacement is the volume of the cylinder when the piston is at BDC. The trend in recent years has been toward smaller displacement engines fitted with turbo- or superchargers. Many manufacturers have moved from 8-cylinder to 6-cylinder or 6-cylinder to 4-cylinder engines to improve fuel economy. Using a turbo- or supercharger maintains high levels of performance while the smaller engine improves economy. As an example, Ford has 1.0

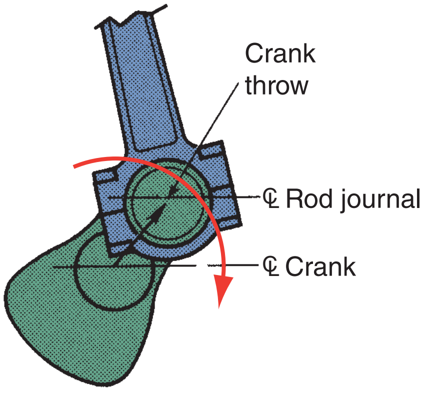


FIGURE 9–18 The stroke of an engine is equal to twice the crank throw.

liter and 1.5 liter turbocharged 3-cylinder EcoBoost engines in production.

An engine's displacement is the sum of the displacements of each of the engine's cylinders **(Figure 9–19)**. Traditionally, an engine with a larger displacement produced more torque than a smaller displacement engine; however, many other factors influence an engine's power output. Many of the newer smaller displacement turbocharged engines produce more power and torque than similarly sized or even larger engines. Engine displacement can be changed by changing the size of the bore and/or stroke of an engine.

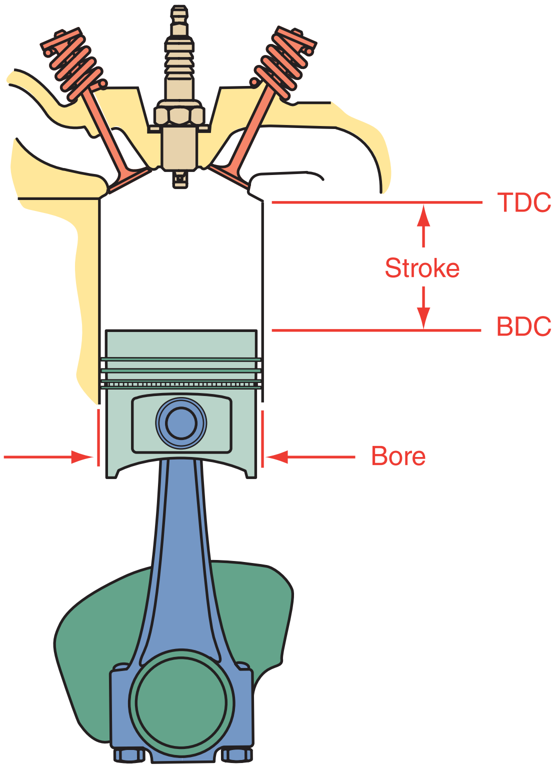


FIGURE 9–19 Displacement is the volume the cylinder holds between TDC and BDC.

Performance TIP

The throw of a crankshaft determines the stroke. The length of the connecting rod only determines where the piston will be as it travels through the stroke. Therefore, if a crankshaft with a longer stroke is installed with standard connecting rods it is possible that the piston may reach out above its bore. That is not desirable! To prevent this, pistons with a higher piston pin hole must be used.

Calculation of an engine's displacement is given in Chapter 3.

Compression Ratio

The compression ratio is a statement of how much the air-fuel mixture will be compressed during the compression stroke. It is important to keep in mind that this ratio can change through wear and carbon and dirt buildup in the cylinders. For example, if a great amount of carbon collects on the top of the piston and around the combustion chamber, the volume of the cylinder changes. This buildup of carbon will cause the compression ratio to increase because the volume at TDC is smaller.

The higher the compression ratio, the more power an engine theoretically can produce. Also, as the compression ratio increases, the heat produced by the compression stroke also increases. Gasoline with a low-octane rating burns fast and may explode rather than burn when introduced to a high-compression ratio, which can cause preignition. The higher a gasoline's octane rating, the less likely it is to explode.

As the compression ratio increases, the octane rating of the gasoline should also be increased to prevent abnormal combustion.

Expansion Ratio

The expansion ratio is based on the length of the compression and power strokes. For most engines, they are the same so the ratio is 1:1. In Atkinson and Miller cycle engines, the expansion ratio is greater than the compression ratio. This is achieved by holding the intake valve open into the compression stroke, well past its normal closing point. Allowing some of the air-fuel charge to exit the cylinder reduces pumping losses and reduces the compression ratio. Once

Performance TIP

Often the bore of an engine is cut larger to fit larger pistons and to increase the engine's displacement. Doing this increases the power output of the engine. However, this also increases the engine's compression ratio. The compression ratio may also be increased by removing metal from the mating surface of the cylinder head and/or the engine block or by installing a thinner head gasket. Care must be taken not to raise the compression too much. High-compression ratios require high-octane fuels and if the required fuel is not available, any performance gains can be lost. Use this formula to determine the exact compression ratio of an engine after modifications have been made:

$$CR = \frac{\text{total cylinder volume with the piston at BDC}}{\text{the total cylinder volume with the piston at TDC}}$$

The volume at BDC is equal to the cylinder's volume when the piston is at BDC plus the volume of the combustion chamber plus the volume of the head gasket. The volume of the head gasket is calculated by multiplying its thickness by the square of the bore and 0.7854. The volume at TDC is equal to the volume in the cylinder when the piston is at TDC plus the volume of the combustion chamber plus the volume of the head gasket.

the compressed air-fuel charge is ignited, the expansion takes place over the entire length of the piston's downward stroke. The result is an expansion cycle that is longer than the compression cycle, increasing the efficiency of the engine.

Engine Efficiency

One of the dominating trends in automotive design is increasing an engine's efficiency. **Efficiency** is simply a measure of the relationship between the amount of energy put into an engine and the amount of energy available from the engine. Other factors, or efficiencies, affect the overall efficiency of an engine.

Volumetric Efficiency Volumetric efficiency describes the engine's ability to fill its cylinders with air and fuel. If the engine's cylinders can be filled during its intake stroke, the engine has a volumetric efficiency of 100 percent. Typically, engines have a volumetric efficiency of 80 percent to 100 percent if they are not equipped with a turbo- or supercharger. Basically, an engine becomes more efficient as its volumetric efficiency is increased.

Turbochargers and superchargers force more air into the cylinders and therefore increase the volumetric efficiency of the engine. In fact, anything that is done to an engine to increase the intake air volume will increase its volumetric efficiency.

Thermal Efficiency Thermal efficiency is a measure of how much of the heat formed during combustion is available as power from the engine. Normally only one-fourth of the heat is used to power the vehicle. The rest is lost to the surrounding air and engine parts and to the engine's coolant **(Figure 9–20)**. Obviously, when less heat is lost, the engine is more efficient.

Mechanical Efficiency Mechanical efficiency is a measure of how much power is available once it leaves the engine compared to the amount of power that was exerted on the pistons during the power stroke. Power losses occur because of the friction generated by the moving parts. Minimizing friction increases mechanical efficiency.

Torque versus Horsepower

Torque is a twisting or turning force. Horsepower is the rate at which torque is produced. When using foot-pounds (ft.-lbs) as units of torque, revolutions per minute (rpm) for engine speed, and horsepower

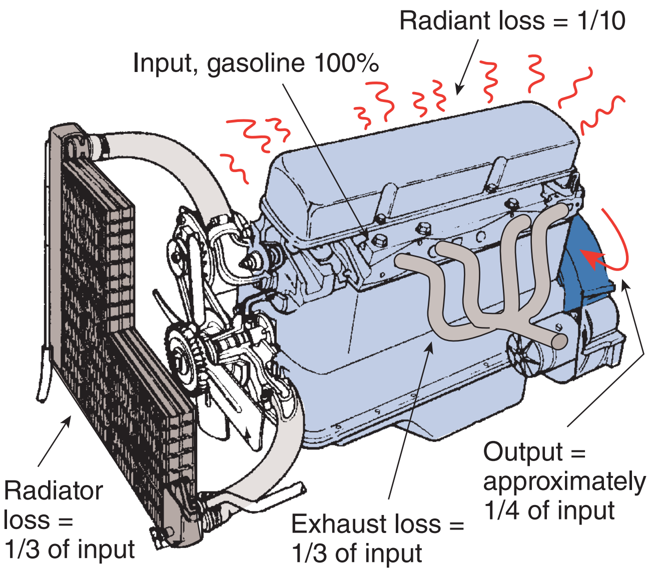


FIGURE 9–20 A gasoline engine is only about 25 percent thermal efficient.

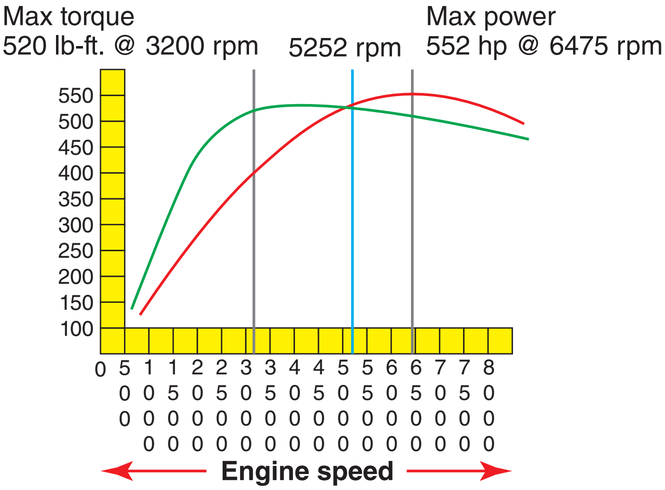


FIGURE 9–21 The relationship between horsepower and torque.

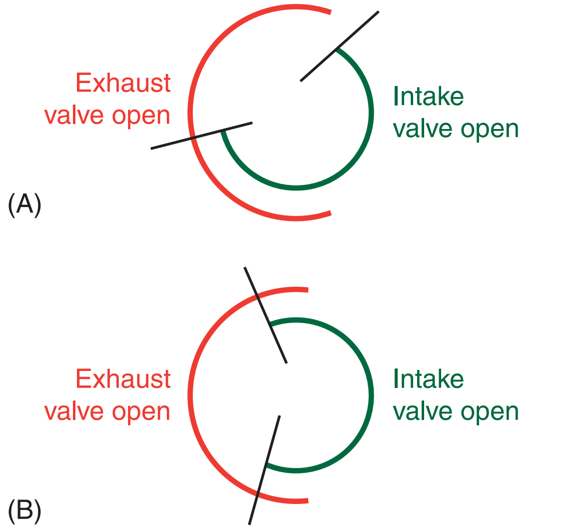


FIGURE 9–22 (A) Typical valve timing for an Atkinson cycle engine. (B) Typical valve timing for a conventional four-stroke cycle engine. Notice that the intake valve in the Atkinson cycle engine opens and closes later.

(hp) for power, power can be calculated with the following formula:

$$\text{hp} = \frac{(\text{ft–lbs} \times \text{rpm})}{5252}$$

A graph of the relationship between the horsepower and torque of an engine is shown in **Figure 9–21**. 5252 is a constant that represents the fact that torque and horsepower will be equal when the engine is running at 5252 rpm. This constant only applies to calculations using the English system of measurement. If the calculated power is expressed in kilowatts (kW) and torque is expressed in Newton-meters (N-m), the constant should be 9549. Therefore the formula for calculating power is:

$$\text{kW} = \frac{(\text{N–m} \times \text{rpm})}{9549}$$

This means that a graph of power and torque based on rpm using metric units would show that torque and power would be equal at 9549 rpm.

Atkinson Cycle Engines

An **Atkinson cycle** engine is a four-stroke cycle engine in which the intake valve is held open longer than normal during the compression stroke **(Figure 9–22)**. As the piston is moving up, the mixture is being compressed and some of it pushed back into the intake manifold. As a result, the amount of mixture in the cylinder and the engine's effective displacement and compression ratio are reduced. Often the Atkinson cycle is referred to as a five-stroke cycle because there are two distinct cycles during the compression stroke. The first is while the intake valve is open and the second is when the intake valve is closed.

In a conventional engine, much engine power is lost due to the energy required to compress the mixture during the compression stroke. The Atkinson cycle reduces this power loss and this leads to greater engine efficiency. The Atkinson cycle also effectively changes the length of time the mixture is being compressed. Most Atkinson cycle engines have a long piston stroke. Keeping the intake valve open during compression effectively shortens the stroke. However, because the valves are closed during the power stroke, that stroke is long. The longer power stroke allows the combustion gases to expand more and reduces the amount of heat that is lost during the exhaust stroke. As a result, the engine runs more efficiently than a conventional engine.

Although these engines provide improved fuel economy and lower emissions, they also produce less power. The lower power results from the lower operating displacement and compression ratio. Power also is lower because these engines take in less air than a conventional engine.

Hybrid Engines Most hybrid vehicles have Atkinson cycle engines. The low power output from the engine is supplemented by the power from the electric motors. This combination offers good fuel economy, low emissions, and normal acceleration.

Most Atkinson cycle engines use variable valve timing to allow the engine to run with low displacement (Atkinson cycle) or normal displacement.

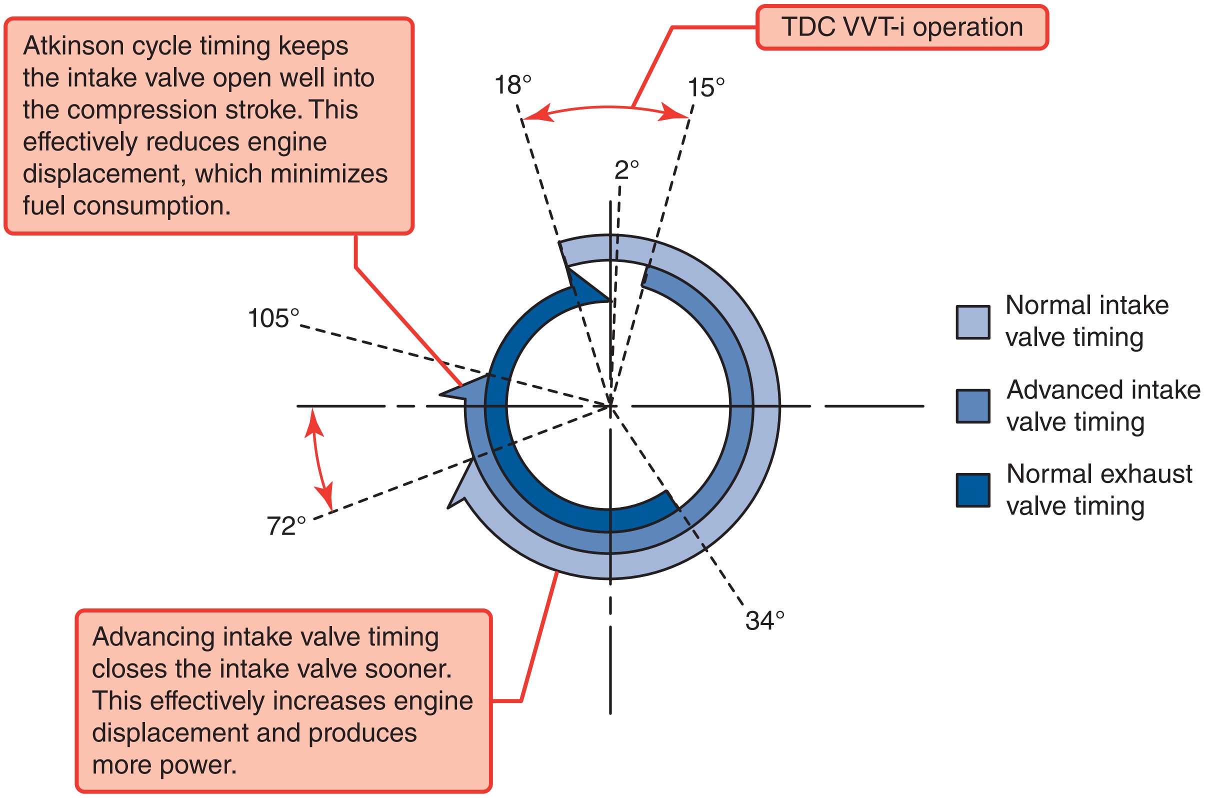


FIGURE 9–23 Toyota's VVT-i (variable valve timing with intelligence) changes the engine from a conventional four-stroke cycle to an Atkinson cycle according to the vehicle's operating conditions.

The opening and closing of the intake valves is controlled by the engine control system **(Figure 9–23)**.

While the valve is open during the compression stroke, the effective displacement of the engine is reduced. When the displacement is low, fuel consumption is minimized, as are exhaust emissions. The engine runs with normal displacement when the intake valves close earlier. This action provides for more power output. The control unit adjusts valve timing according to engine speed, intake air volume, throttle position, and coolant temperature. Because this system responds to operating conditions, the displacement of the engine changes accordingly.

In typical systems, the control unit sends commands to the camshaft timing oil control valve. A controller at the end of the camshaft is driven by the crankshaft. The control unit regulates the oil pressure sent to the controller. A change in oil pressure changes the position of the camshaft and the timing of the valves. An advance in timing results when oil pressure is applied to the timing advance chamber. When the oil control valve is moved and the oil pressure is applied to the timing retard side vane chamber **(Figure 9–24)**, the timing is retarded.

Miller Cycle Engines An Atkinson cycle engine with forced induction (supercharging) is called a Miller cycle engine. The decrease of intake air and resulting low power is compensated for by the supercharger. The supercharger forces air into the cylinder during the compression stroke. Keep in mind that the actual compression stroke in an Atkinson cycle engine does not begin until the intake valve closes. The supercharger in a Miller cycle engine forces more air past the valve and, therefore, there is more air in the cylinder when the intake closes.

Audi's new 2.0 liter turbocharged engine uses the Miller-cycle to improve performance and reduce fuel consumption. The 2.0 liter engine produces up to 220 HP and 258 lb-ft. of torque while achieving an estimated combined 31 mpg. The engine has a shortened intake stroke, 140 degrees of crank angle compared to the 190–200 degrees of a standard engine. The turbocharger boosts intake pressure to offset the short intake stroke. The compression ratio has increased with the new engine from 9.6:1 to 11.7:1.

Diesel Engines

Diesel engines were invented by Dr. Rudolph Diesel, a German engineer, and first marketed in 1897. The diesel engine is now the dominant power plant in heavy-duty trucks, construction equipment, farm

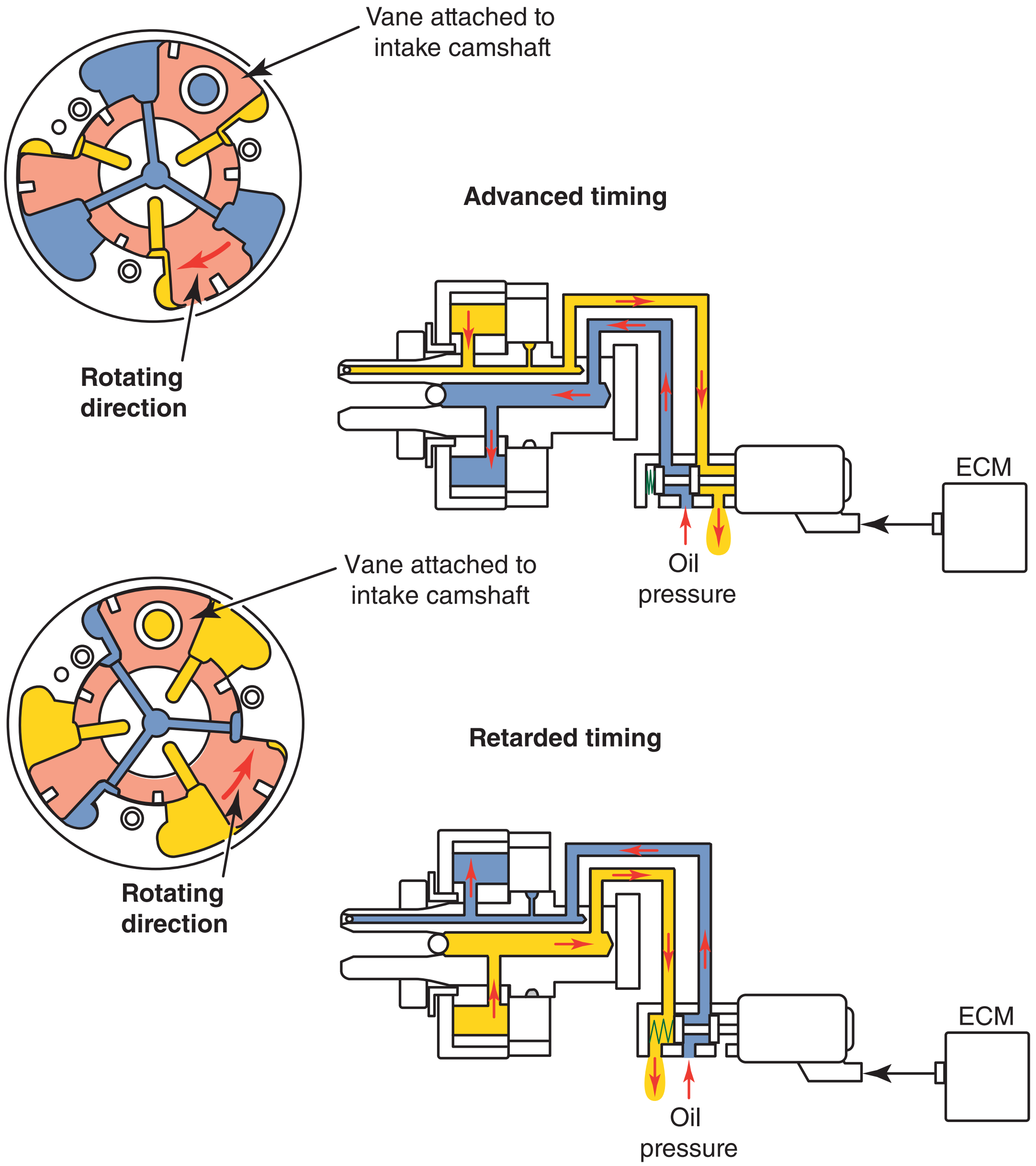


FIGURE 9–24 Oil flow for the VVT-i as it advances and retards the valve timing.

equipment, buses, marine, and some automotive applications. Diesel vehicles are very common in Europe and other places where cleaner fuels are available **(Figure 9–25)**.

The operation of a **diesel engine** is comparable to a gasoline engine. They also have a number of components in common, such as the crankshaft, pistons, valves, camshaft, and water and oil pumps. They both are available as two- or four-stroke combustion cycle engines. However, diesel engines rely on compression ignition **(Figure 9–26)**. A diesel engine uses the heat produced by compressing air in the combustion chamber to ignite the fuel. The compression ratio of diesel engines can be three times (as high as 25:1) that of a gasoline engine though newer engine technologies allow diesel

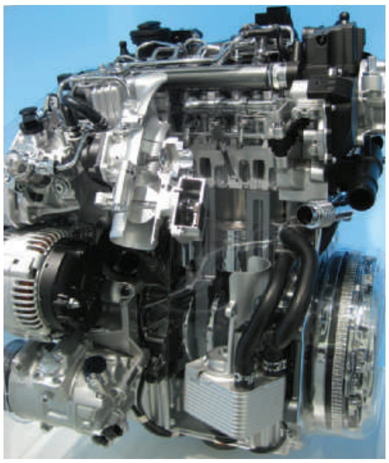


FIGURE 9–25 A European four-cylinder passenger car diesel engine.

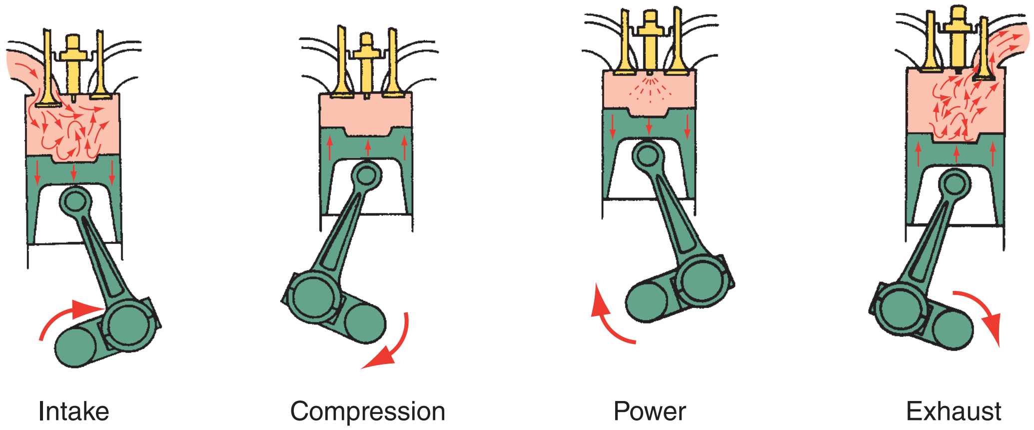


FIGURE 9-26 A four-stroke diesel engine cycle.

engines to use lower compression ratios. As intake air is compressed, its temperature rises to 1,300 °F to 1,650 °F (700 °C to 900 °C). Just before the air is fully compressed, a fuel injector sprays a small amount of diesel fuel into the cylinder. The high temperature of the compressed air instantly ignites the fuel. The combustion causes increased heat and the resulting high pressure moves the piston down on its power stroke.

Construction

A diesel engine must be made stronger to contain the extremely high compression and combustion pressures. A diesel engine produces less horsepower than a same-sized gasoline engine. Therefore, to provide the required power, the displacement of the engine is increased. This results in a physically larger engine. Diesels have high-torque outputs at very low engine speeds but do not run well at high engine speeds **(Figure 9–27)**. On many diesel engines, turbochargers and intercoolers are used to increase their power output.

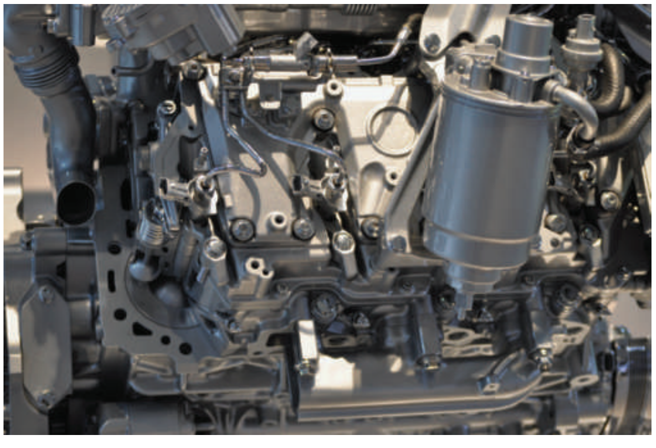


FIGURE 9-27 A high-output turbo diesel engine.

Fuel injection is used on all diesel engines. Older diesel engines had a distributor-type injection pump driven and regulated by the engine. The pump supplied fuel to injectors that sprayed fuel into the engine's combustion chamber. Newer diesel engines are equipped with common rail systems **(Figure 9–28)**. Common rail systems use **direct injection (DI)**. The injectors' nozzles are placed inside the combustion chamber. The top of the pistons have a depression where the initial combustion takes place. The injector must be able to withstand the temperature and pressure inside the cylinder and be able to deliver a fine spray of fuel into those conditions. These systems have a high-pressure (14,500+ psi or 1,000+ bar) fuel rail connected to individual solenoid-type injectors.

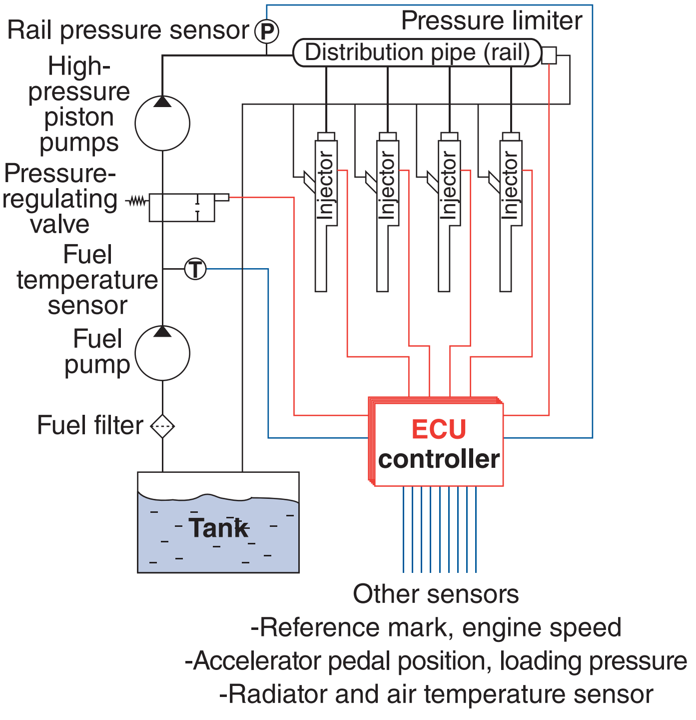


FIGURE 9-28 A common rail fuel injection system.

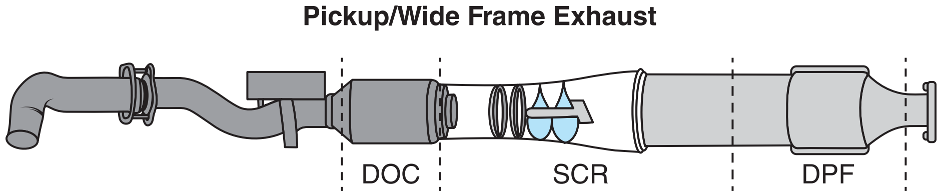


FIGURE 9–29 A catalytic converter and particulate trap for a diesel engine.

These injectors are computer-controlled and attempt to match injector operation to the operating conditions of the engine. Newer diesel fuel injectors rely on stacked piezoelectric crystals rather than solenoids. Piezo crystals expand quickly when electrical current is applied to them. The crystals allow the injectors to respond quickly to the needs of the engine. With this style of injector, diesel engines are quieter, more fuel efficient, cleaner, and have more power.

When compared to gasoline engines, diesel engines offer many advantages. They are more efficient and use less fuel than a gasoline engine of the same size. Diesel engines are very durable. This is due to stronger construction and the fact that diesel fuel is a better lubricant than gasoline. This means that the fuel is less likely to remove the desired film of oil on the cylinder walls and piston rings of the engine. Diesel engines are also better suited for moving heavy loads at low speeds. Many diesel engines are fit with a turbocharger to increase their power. Combining turbochargers with common rail injection systems has resulted in more horsepower.

Starting In cold weather, diesel engines can be difficult to start because the cold air is unable to reach high enough temperatures to cause combustion. This problem is compounded by the fact that the cold metal of the cylinder block and head absorbs the heat generated during the compression stroke. Therefore, many diesel engines use **glow plugs** to help ignite the fuel during cold starting. These small electrical heaters are placed inside the cylinder and are only used when the engine is cold. Other diesels have a resistive grid heater in the intake manifold to warm the air until the engine reaches operating temperature.

Sound A characteristic of a diesel engine is its sound. This noise, knock or clatter, is caused by the sudden ignition of fuel as it is injected into the combustion chamber. Through the use of electronically controlled common rail injector systems, this noise has been reduced.

Emissions This has been an obstacle for diesel cars and new stricter emissions standards go into effect shortly. Cleaner, low-sulfur, diesel fuel has been available in the United States since 2007. With new technologies and the cleaner fuel, a diesel engine is able to run as clean as most gasoline engines. Many diesel vehicles have an assortment of traps and filters to clean the exhaust before it enters the atmosphere. Also diesel engines produce very little CO because they run with an abundance of air.

Diesel vehicles may be equipped with particulate filters and catalytic converters **(Figure 9–29)**. Particulate filters catch the black soot (unburned carbon compounds) that is expelled from a typical diesel's exhaust. Most diesel cars have **selective catalytic reduction (SCR)** systems to reduce NO_x emissions. SCR is a system that has a substance injected into the exhaust stream and then absorbed in a catalyst. This breaks down the exhaust's NO_x to form H_2O and N_2. Others will use NO_x traps.

Homogeneous Charge Compression Ignition (HCCI) Engines

Much research is taking place on the development of Homogeneous Charge Compression Ignition (HCCI) engines. These are four-stroke cycle engines and rely on a combination of spark ignition and compression ignition technologies. In fact, they can run as spark or compression ignited engines. The terms "Homogeneous Charge" mean the fuel is thoroughly mixed with the intake air. In gasoline engines, the air and fuel are mixed (homogenized) before ignition

SHOP TALK

In 2015, the EPA issued notice that VW auto group violated federal emission laws by configuring software in their engine control modules to run a special "emission test" program in order to meet emission standards. VW has since complied with recalls, a buyback program, and paid fines resulting from the violation.

and ignition is caused by a spark. In a diesel engine, the air and fuel are never mixed. The air is compressed and ignition occurs when fuel is sprayed into the high-temperature air.

In the HCCI mode, the temperature of the mixture is greatly increased during the compression stroke. The air and fuel are mixed and heat builds as the mixture is compressed. This heat ignites the mixture without the need for a spark plug. To develop the heat necessary for ignition, these engines have a very high-compression ratio and a very lean air/fuel mixture. To make all of this work, the mixture must get hot enough to "auto-ignite." When the mixture ignites, combustion immediately and simultaneously begins at several points within the mixture **(Figure 9–30)**. The combustion process occurs rapidly and is controlled by the quality and temperature of the compressed mixture. This spontaneous combustion produces a flameless release of energy to drive the piston down. The temperature of the mixture at the beginning of the compression stroke must be increased to auto-ignition temperatures at the end of the compression stroke. This fact makes it hard to control the ignition timing of an HCCI engine.

Auto-ignition of gasoline occurs when the temperature of the mixture reaches 1,430 °F to 1,520 °F (777 °C to 827 °C). To control the timing of ignition, the engine's control unit must supply the correct amount of fuel mixed with the correct amount of air. In addition, the control unit must provide a mixture that is hot enough to be able to auto-ignite at the end of the compression stroke. Therefore, it must be able to vary the compression ratio, the temperature of the intake air, the pressure of the intake air, or the amount of retained or reinducted exhaust gas.

Basic Operation During the intake stroke, fuel is injected directly into each cylinder's combustion chamber. Intake air arrives in the cylinder at the same time as the fuel; however the resulting mixture is very lean (much more air than fuel). Near the end of the intake stroke, the cylinder is filled with the air and fuel mixture. Heat begins to build as the piston begins its compression stroke. When the piston has reached TDC, there is enough heat to spontaneously ignite the mixture. The result of this combustion is a low temperature and flameless release of energy. The resulting release of energy and increase in pressure pushes the piston down on its power stroke.

When the power stroke is completed, the piston moves back up the cylinder to begin the exhaust stroke. In contrast to the conventional exhaust stroke, the goal is not to empty the cylinder of all of its exhaust gases. Rather the exhaust valve closes before the end of the stroke to trap some of the hot gases in the cylinder. Before the next intake stroke begins, a small amount of fuel is injected into the trapped exhaust gases. This pre-charge helps control combustion temperatures and exhaust emissions.

Dual Mode During most driving modes, the engine operates in the HCCI mode. However, the engine does switch to spark ignition at high speeds, heavy acceleration and loads, and cold starting. The latter is necessary because heat is required to cause ignition and when the engine is cold, there is little initial heat. The ability to switch from compression ignition to spark ignition must be done smoothly. This requires precise control of valve timing, air and fuel metering, and ignition timing.

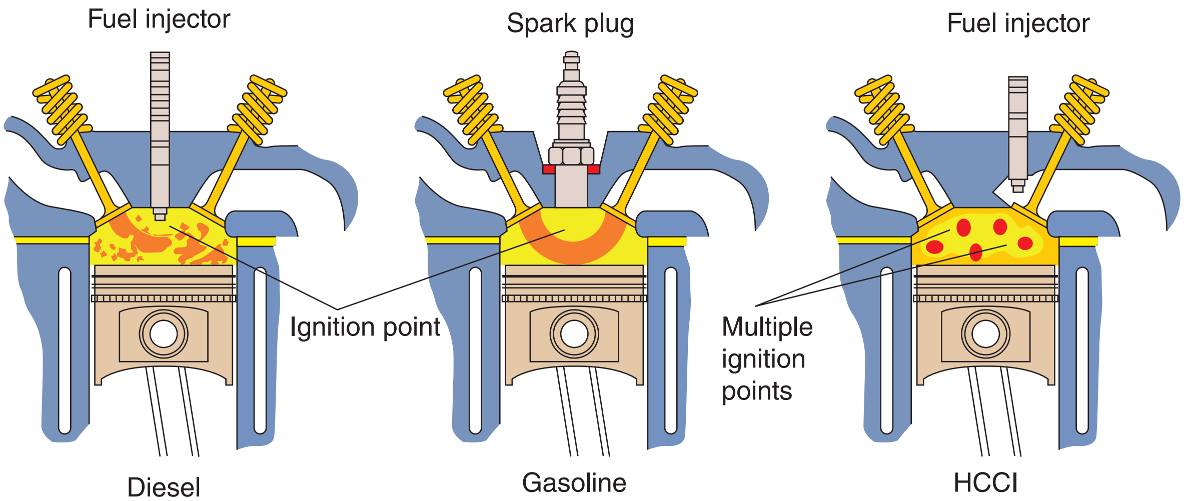


FIGURE 9–30 A comparative look at the ignition of a diesel, gasoline, and HCCI engine.

Benefits A gasoline HCCI engine could deliver almost the same fuel economy as a diesel engine and at a much lower cost. GM estimates that HCCI could improve gasoline engine fuel efficiency by 15 percent, while emitting near-zero amounts of NO_x and particulate matter.

However, a gasoline engine running in the HCCI mode produces more noise and vibrations than a conventional engine. Also, they tend to experience incomplete combustion, which leads to hydrocarbon and carbon monoxide emissions.

To rectify this, HCCI engines are fitted with typical emission control systems, including an oxidizing catalytic converter.

Infiniti VC-T Engine Certain 2019 Infiniti models are available with a variable-compression-ratio engine, called the variable compression-turbocharged (VC-T) engine. The VC-T is a 2.0 inline four-cylinder engine equipped with a unique crankshaft setup and control system that allows the compression ratio to change with a change in engine load.

To meet the needs of the varying compression ratios, the engine is equipped with multipoint injection (MPI) for low compression operation and gasoline direct injection (GDI) for high-compression operation. When the engine is operating under high load and high speeds, both types of injectors are used simultaneously.

The engine is also equipped with VVT: the intake cam is electronically controlled, whereas the exhaust cam is controlled by hydraulics. The VVT not only controls the air in and out of the cylinders but also allows the engine, at times, to run on the Atkinson cycle.

The VC-T is capable of providing compression ratios between 8.0:1 and 14.0:1 and can quickly switch to anywhere between those ratios. To minimize fuel usage during light throttle cruising, the compression ratio increases to 14.0:1. The compression ratio decreases as the need for power increases. At the same time, boost from the turbo adds to the engine's power.

The compression ratio is changed by changing the movement of the piston as it goes up and down the cylinder. When the piston is at its highest point, the compression ratio is 14:1 and when it is at its lowest point, the ratio is 8:1. During engine operation the position of the piston, therefore the compression ratio, will change based on the operating conditions.

The position of the piston within the cylinder is controlled by an elaborate setup of links **(Figure 9–31)** and an electronically controlled harmonic drive (1). Inside this drive is an ECU-controlled electric motor that drives a reduction gear. The gear moves the actuator arm (2) when there is a need to change the compression ratio. The actuator arm rotates the control shaft. In turn, the control shaft changes the angle of the diamond shaped multi-link (3). Ultimately, the angle of the multilink determines how far the piston (4) can move up in the cylinder. However, its angle depends on the rotation of the harmonic drive.

The harmonic drive is controlled by a dedicated ECU that receives data from various engine sensors to calculate the desired compression ratio for the current operating conditions.

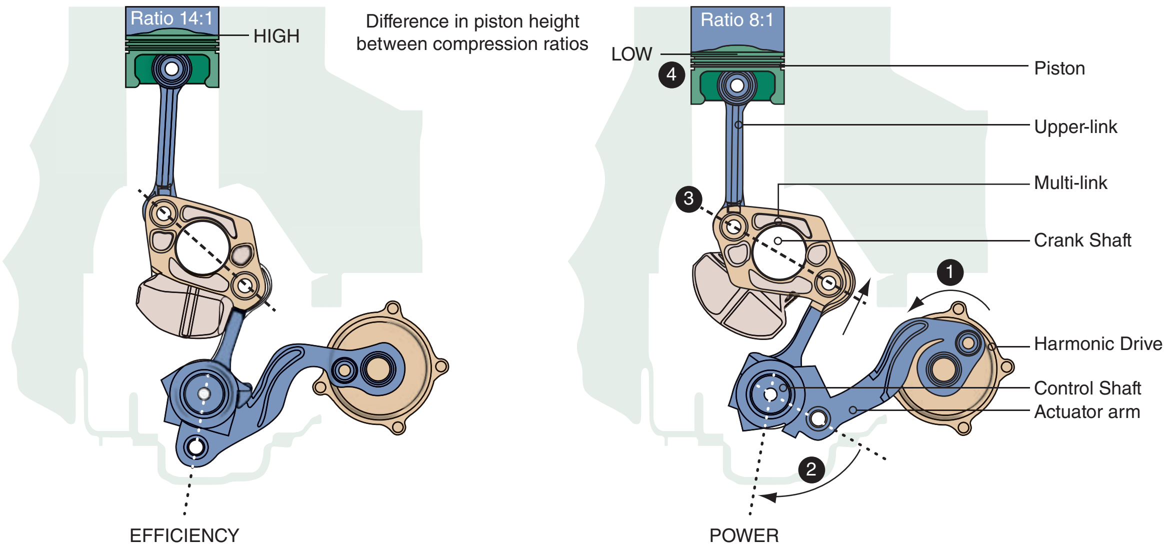


FIGURE 9–31 The variable compression engine uses a complex arrangement of connecting rods to vary compression based on operating conditions.

Mazda SkyActiv-X In 2019, Mazda plans to release HCCI engines (these will be called SkyActiv-X engines). Mazda expects a 20–30 percent increase in efficiency than non-HCCI engines. Basically the efficiency is the result of combustion occurring at a lower than normal temperatures. This means the heat loss from a typical gasoline engine is reduced. As a result of the reduced heat, a much leaner air/fuel mixture can be used.

The engine has spark plugs for cold starting and for use under certain load conditions, when operating conditions are not ideal for compression ignition. Compression ignition works best within a specific temperature range. If the engine is too cold, there will be a loss in performance and if the engine is too hot, knocking or pre-ignition can result.

Through the use of a VVT system, the engine's compression can be reduced to allow it to run as a normal gasoline spark plug fired engine. When the operating conditions are correct, the engine switches to the HCCI mode.

Normally a very lean air/fuel mixture is fed into the engine's cylinders. The air/fuel ratio varies but is always far leaner than the ideal 14.7:1 air/fuel ratio. These lean A/F mixtures cannot be ignited by a spark, the engine moves to allow for compression ignition.

The heat generated in the cylinder determines the amount of pressure in the cylinder, that pressure changes as the system adjusts to its needs. These pressure changes affect the effective compression ratio of the engine. Unlike Infiniti's VC-T engine, which mechanically changes its compression ratio, the SkyActiv-X has a fixed compression ratio but varies effective pressures within the cylinders.

SkyActiv-X engines will also have a small, belt-driven, Roots-type supercharger, to push more air into the cylinders. This supercharger is not there to increase power, rather its purpose is to supply enough air to keep the A/F mixture lean enough for compression ignition at high engine speeds. The boost from the supercharger is controlled by a drive clutch that allows the charger to disengage at low engine speeds and when additional air is not needed.

Other Automotive Power Plants

In an attempt to reduce fuel consumption and harmful exhaust emissions, many manufacturers are supplementing or modifying the basic internal combustion engine. Many of these power plants were developed during the early days of automobiles. Due to the advancements made in electronic controls, they are becoming a viable alternative to the conventional gasoline engine.

Hybrids

A hybrid vehicle has at least two different types of power or propulsion systems. Today's hybrid vehicles have an internal combustion engine and an electric motor (some vehicles have more than one electric motor). A hybrid's electric motor **(Figure 9–32)** is powered by batteries and/or ultracapacitors, which are recharged by a generator that is driven by the engine. They are also recharged through regenerative braking. The engine may use gasoline, diesel, or an alternative fuel. Complex electronic controls monitor the operation of the vehicle. Based on the current operating conditions, electronics control the engine, electric motor, and generator.

Depending on the design of the hybrid vehicle, the engine may power the vehicle, assist the electric motor while it is propelling the vehicle, or drive a generator to charge the vehicle's batteries. The electric motor may propel the vehicle by itself, assist the engine while it is propelling the vehicle, or act as a generator to charge the batteries. Many hybrids rely exclusively on the electric motor(s) during slow-speed operation, on the engine at higher speeds, and on both during certain driving conditions. The engines used in hybrids are specially designed for fuel economy and low emissions. The engines tend to be small displacement engines that use VVT and the Atkinson cycle to provide low fuel consumption.

Often hybrids are categorized as series or parallel designs. In a series hybrid, the engine never

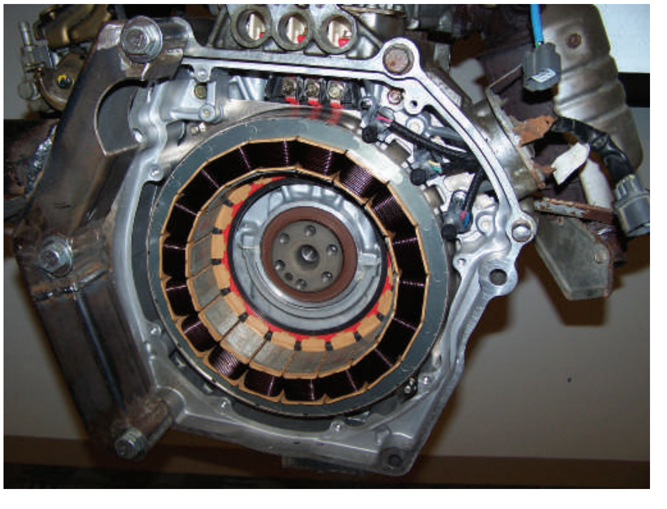


FIGURE 9–32 The Honda Civic Hybrid has a gasoline engine and an electric motor attached to the engine's crankshaft.

directly powers the vehicle. Rather it drives a generator, and the generator either charges the batteries or directly powers the electric motor that drives the wheels **(Figure 9–33)**. A parallel hybrid vehicle uses either the electric motor or the gas engine to propel the vehicle, or both **(Figure 9–34)**. Most current hybrids can be considered as having a series/parallel configuration because they have the features of both designs.

Although most current hybrids are focused on fuel economy, the same construction is used to create high-performance vehicles. The added power of the electric motor boosts the performance levels provided by the engine. Hybrid technology also enhances off-the-road performance. By using individual motors at the front and rear drive axles, additional power can be applied to certain drive wheels when needed.

Battery-Operated Electric Vehicles A battery-operated electric vehicle, sometimes referred to as an EV, uses one or more electric motors to turn its drive wheels. The electricity for the motors is stored in batteries that must be recharged by an external electrical power source. Normally they are recharged by plugging them into an outlet at home or other locations. The recharging time varies with the type of charger, the size and type of battery, and other factors. Normal recharge time is 4 to 8 hours.

An electric motor is quiet and has few moving parts. It starts well in the cold, is simple to maintain, and does not burn petroleum products to run. The disadvantages of an EV are limited speed, power, and range as well as the need for heavy, costly batteries. However, an EV is much more efficient than a conventional gasoline-fueled vehicle when comparing energy used to drive the wheels. EVs are considered zero emissions vehicles because they do not directly pollute the air. The only pollution associated with them is the result of producing the vehicle and creating the electricity to charge their batteries.

In the early days of the automobile, electric cars outnumbered gasoline cars. Today, there are several models of EVs on the road and they are commonly used in manufacturing, shipping, and other industrial plants, where the exhaust of an internal combustion engine could cause illness or discomfort to the workers in the area. Most manufacturers are developing EVs and some pure EVs are available to consumers. Although the idea of having a vehicle that is not dependent on fossil fuels is attractive, to be practical, EVs need to have much longer driving ranges between recharges and must be able to sustain highway speeds for great distances.

Fuel Cell Electric Vehicles Although just experimental at this time, there is much promise for fuel cell EVs. These vehicles are powered solely by electric motors, but the energy for the motors is produced by fuel cells. Fuel cells rely on hydrogen to produce the electricity. A fuel cell generates electrical power through a chemical reaction. A fuel cell EV uses the electricity produced by the fuel cell to power motors that drive the vehicle's wheels **(Figure 9–35)**. The batteries in

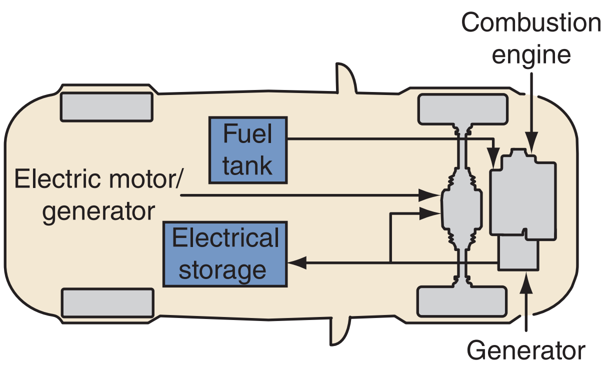


FIGURE 9–33 The configuration of a series hybrid vehicle.

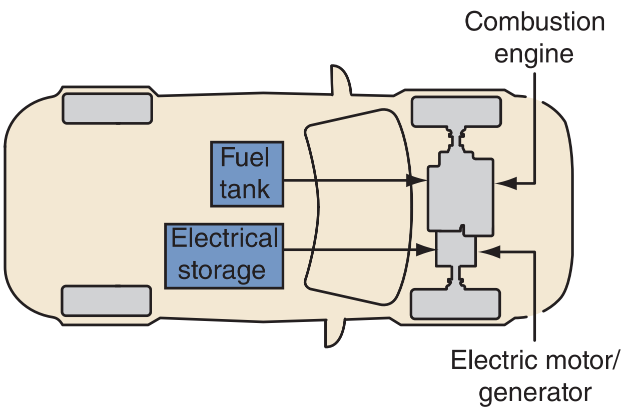
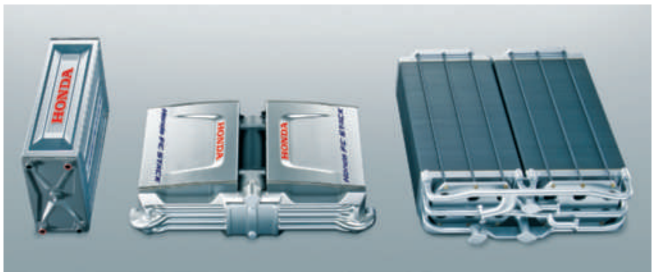


FIGURE 9–34 The configuration of a parallel hybrid vehicle.



Courtesy of American Honda Motor Co., Inc.

FIGURE 9–35 The sources of power for a fuel cell electric vehicle: fuel cell stack (left), power control unit (center), and lithium ion battery pack (right).

these vehicles do not need to be charged by an external source.

Fuel cells convert chemical energy to electrical energy by combining hydrogen with oxygen. The hydrogen can be supplied directly as pure hydrogen gas or through a "fuel reformer" that pulls hydrogen from hydrocarbon fuels such as methanol, natural gas, or gasoline. Simply put, a fuel cell is comprised of two electrodes (the anode and the cathode) located on either side of an electrolyte. As the hydrogen enters the fuel cell, the hydrogen atoms give up electrons at the anode and become hydrogen ions in the electrolyte. The electrons that were released at the anode move through an external circuit to the cathode. As the electrons move toward the cathode, they can be diverted and used to power the vehicle. When the electrons and hydrogen ions combine with oxygen molecules at the cathode, water and heat are formed. There are no smog-producing or greenhouse gases produced. Although vehicles equipped with reformers emit some pollutants, those that run on pure hydrogen are true zero-emission vehicles.

Rotary Engines

The **rotary** engine, or Wankel engine, is somewhat similar to the standard piston engine in that it is a spark ignition, internal combustion engine. Its design, however, is quite different. For one thing, the rotary engine uses a rotating motion rather than a reciprocating motion. In addition, it uses ports rather than valves for controlling the intake of the air-fuel mixture and the exhaust of the combusted charge. This design has been used in a few cars through the years but the public has not accepted them because they are not very fuel efficient and produce high power only at high engine speeds.

The main part of a rotary engine is a roughly triangular rotor that rotates within an oval-shaped housing. The rotor has three convex faces and each face has a recess in it. These recesses increase the overall displacement of the engine. The tips of the rotor are always in contact with the walls of the housing as the rotor moves to seal the sides (chambers) to the walls. As the rotor rotates, it creates three separate chambers of gas. Also, as it rotates, the volume between the sides of the rotor and the housing continuously changes. During rotor rotation, the volume of the gas in each chamber alternately expands and contracts. It is how a rotary engine rotates through the basic four-stroke cycle.

Engine Identification

USING SERVICE INFORMATION

Normally, information used to identify the size of an engine is given in the service information for a vehicle at the beginning of the section covering a particular vehicle.

By referring to the VIN, much information about the vehicle can be determined. Identification numbers are also found on the engine. Engine blocks often have a serial number stamped into them **(Figure 9–36)**. An engine code is generally found beside the serial number. A typical engine code might be DZ or MO. These letters indicate the horsepower rating of the engine, whether it was built for an automatic or manual transmission, and other important details. The engine code

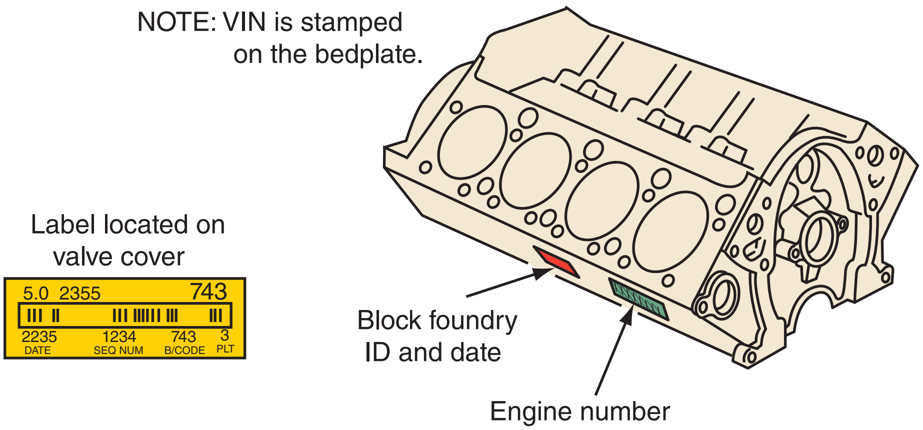


FIGURE 9–36 Examples of the various identification numbers found on an engine.

will help you determine the correct specifications for that particular engine.

GO TO Chapter 7 for instructions on how to decipher a VIN.

Engine ID

Many engines have ID tags or stickers attached to various places on the engine, such as the valve cover or oil pan. The tags include the displacement, assembly plant, model year, change level, engine code, and date of production. The location of these stickers or tags on a particular engine may be given in the service information.

Casting Numbers Whenever an engine part such as an engine block or head is cast, a number is put into the mold to identify the casting and the date when the part was made. This date does not indicate when the engine was assembled or placed into the vehicle. A part made during one year may be installed in the vehicle in the following year; therefore, the casting date may not match the model year of the vehicle. Casting numbers should not be used for identifying the displacement of an engine. They only indicate the basic design of an engine. The same block or head can be used with a variety of different displacement engines.

Underhood Label All vehicles produced since 1972 have an underhood label called the Vehicle Emission Control Information (VECI) label. This **(Figure 9–37)** gives some useful information regarding the emissions' rating of the vehicle and, at times, information necessary to perform maintenance **(Figure 9–38)** and an emissions inspection, or to order engine and engine management parts.

FIGURE 9–37 A current VECI Label.

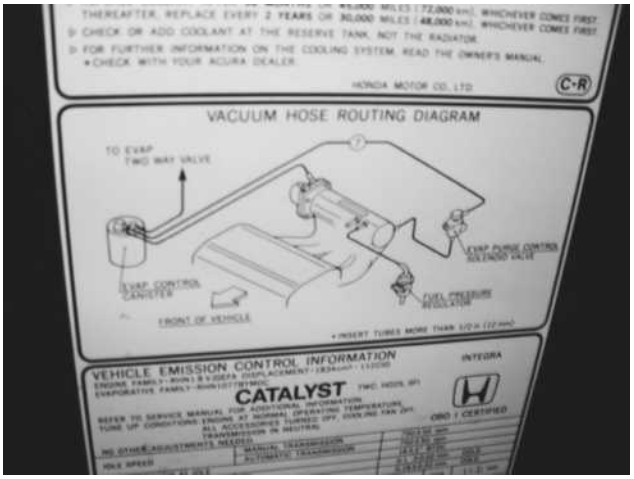


FIGURE 9–38 Some information that may be also included on a VECI.

Engine Diagnostics

As the trend toward the integration of ignition, fuel, and emission systems progresses, new diagnostic tools and techniques are constantly being developed to diagnose electronic engine control systems. However, not all engine performance problems are related to electronic controls; therefore, technicians still need to understand basic engine tests. These tests are an important part of modern engine diagnosis.

Relative Compression Test

A method to quickly and easily determine if each cylinder is drawing in and compressing air is by performing a relative compression test. By measuring the cranking current with a lab scope, each cylinder's draw on the starter motor and battery can be compared to the other cylinders.

Connect a current clamp around the battery positive or negative cable and configure the scope to measure between 200 and 400 amps. Disable the fuel pump and crank the engine for 5 to 7 seconds. A cylinder with low compression will have less current draw **(Figure 9–39)** than one with good compression **(Figure 9–40).**

Cylinder Compression Test

Internal combustion engines depend on the compression of the air-fuel mixture to maximize the power produced by the engine. The upward movement of the piston on the compression stroke compresses the air-fuel mixture within the combustion chamber. The air-fuel mixture gets hotter as it is

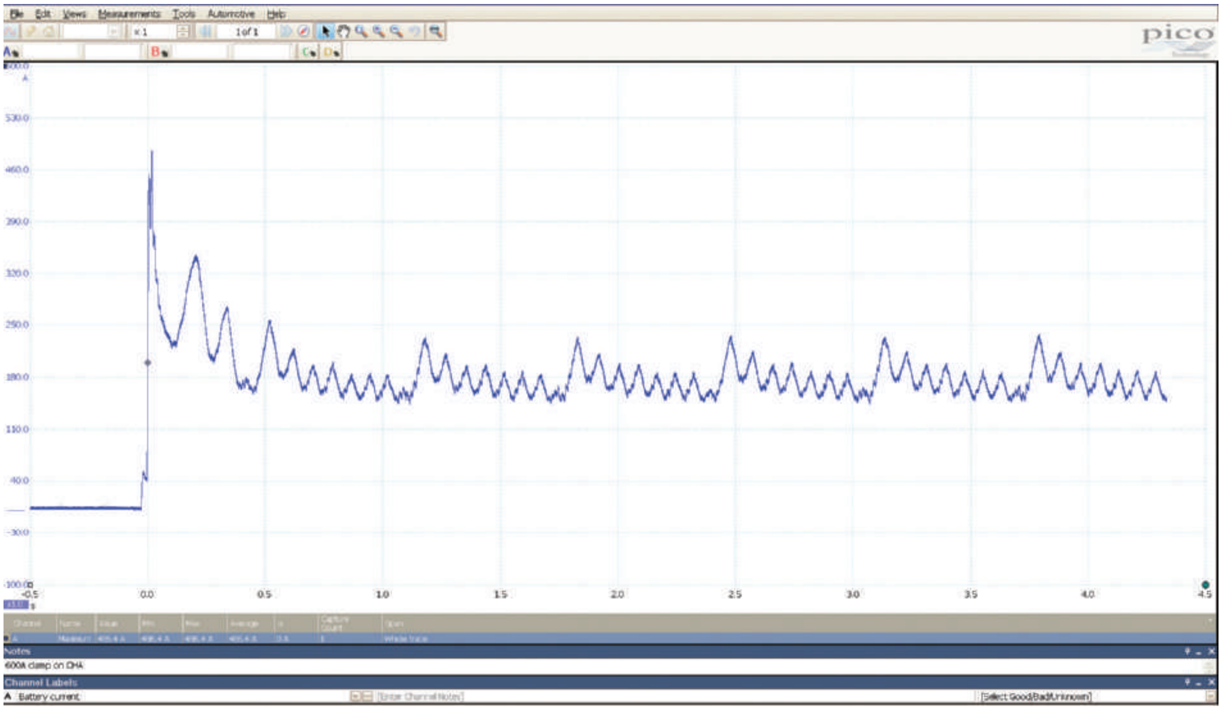


FIGURE 9–39 A relative compression test can quickly show a low compression cylinder.

compressed. The hot mixture is easier to ignite, and when ignited it generates much more power than the same mixture at a lower temperature.

If the combustion chamber or cylinder leaks, some of the air-fuel mixture will escape when it is compressed, resulting in a loss of power and a waste of fuel. The leaks can be caused by burned valves, a blown head gasket, worn rings, slipped timing belt or chain, worn valve seats, a cracked head, and more.

An engine with poor compression (lower compression pressure due to leaks in the cylinder) will not run correctly. If a symptom suggests that the cause of a problem may be poor compression, a compression test is performed.

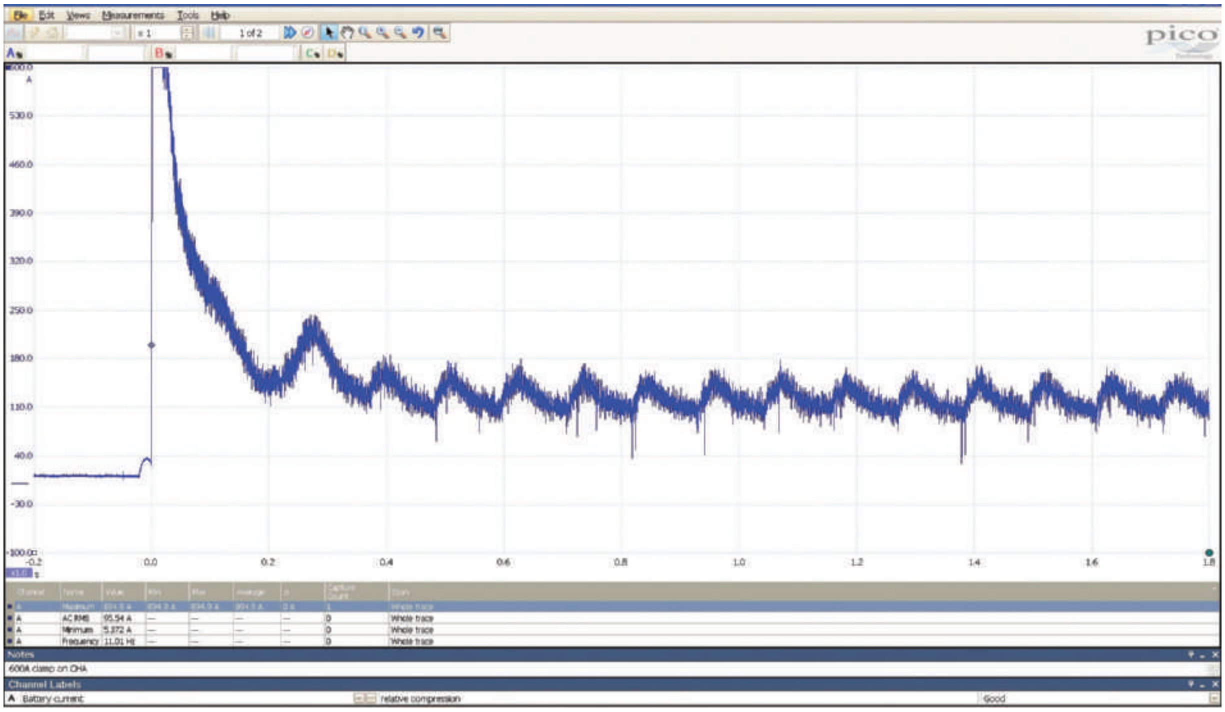


FIGURE 9–40 A good relative compression waveform.

Many technicians use a pressure transducer and a scope to perform a compression test after a problem cylinder had been discovered. Remove the spark plug and install the compression test adaptor hose into the spark plug hole. Connect the scope to the pressure transducer. How to attach and configure the transducer varies with the brand and the scope being used. Refer to the documentation for both to correctly configure the equipment. The scope software may have a preset configuration for compression testing, if so, select Compression Test from the menu. Disable the fuel and ignition system and crank the engine.

A compression gauge is can also be used to check cylinder compression. The dial face on the typical compression gauge indicates pressure in both pounds per square inch (psi) and metric kilopascals (kPa). Most compression gauges have a vent valve that holds the highest pressure reading on its meter. Opening the valve releases the pressure when the test is complete. The steps for conducting a cylinder compression test are shown in Photo Sequence 6.

Many vehicles require using a scan tool to place the engine into a compression test mode **(Figure 9–41)**. This is because turning the ignition key or pressing the Start button does not directly control the starter motor. When commanded, the starter will crank the engine so a compression reading can be obtained.

Ford, Toyota, and other hybrids have Atkinson cycle engines. These engines delay the closing of the intake valve, which means that the overall compression ratio and displacement of the engine are reduced. Therefore, when conducting a compression test on these engines, expect a slightly lower reading than what you would expect from a conventional engine.

To conduct a compression test on a Ford Hybrid, you must use a scan tool and the one from Ford is preferred. The scan tool allows you to enter into the engine cranking diagnostic mode. This mode allows the engine to crank with the fuel injection system disabled. It also makes sure that the starter motor/generator is not activated (except for activating the starter motor to crank the engine), which not only is good for safety purposes, it is also good because the load of the generator cannot affect the test results because it is not energized. Always follow the sequence as stated in the service information. Failure to do so will result in bad readings.

Wet Compression Test Because many things can cause low compression, it is advisable to conduct a wet compression test on the low cylinders. This test allows you to identify if it is caused by worn or damaged piston rings. To conduct this test, add two squirts of oil into the low cylinders. Then measure the compression of that cylinder. If the readings are higher, it is very likely that the piston rings are the cause of the problem. The oil temporarily seals the piston to the cylinder walls, which is why the readings increased. If the readings do not increase, or increase only slightly, the cause of the low readings is probably the valves.

Running Compression Test

Some engine problems, such as worn camshaft lobes, are not easily detected using a cranking compression test. When diagnosing a cylinder that is not producing as much power as other cylinders yet shows normal cranking compression, a running compression test may be needed. Using a standard compression test kit, remove the Schrader valve from the tester's

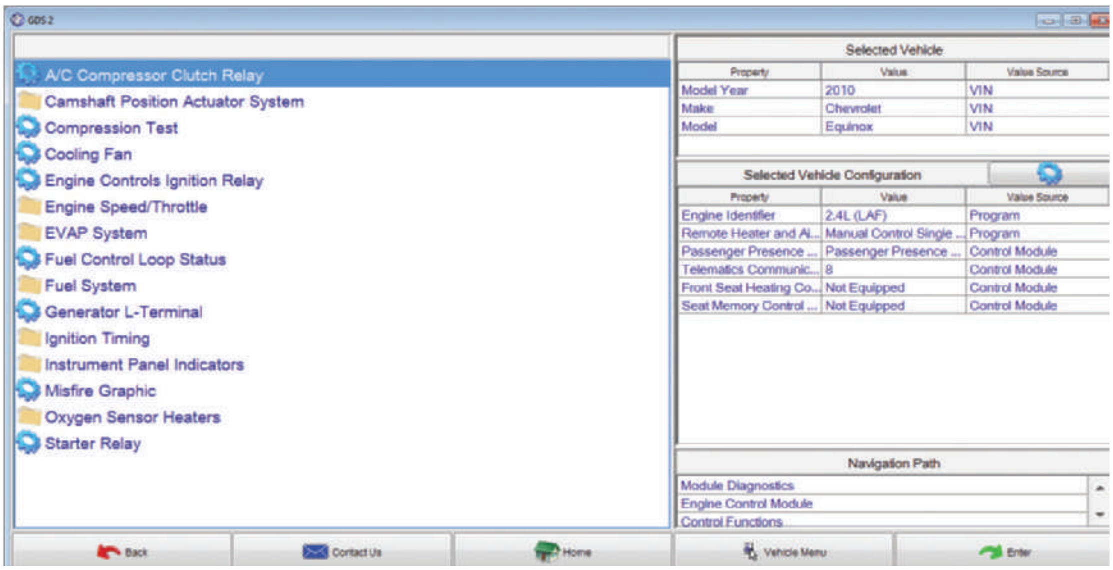


FIGURE 9–41 Using a scan tool to place the system into compression test mode.

adaptor hose and thread it into the spark plug hole for the cylinder being tested. Start the engine and note the gauge. Note, because the gauge will show both pressure and vacuum, the needle will sweep up and down. This can cause the needle to impact the needle stop on some gauges. With the engine running, note the maximum pressure. During running compression tests, cylinder pressures will likely be in the 70 to 80 psi range. To more accurately see what is happening in the cylinder while the engine is running, many technicians perform this test using electronic pressure transducers and a scope.

Cylinder Leakage Test

If a compression test shows some leakage in the cylinders, a cylinder leakage test can be performed to measure the percentage of compression lost and locate the source of leakage. The cylinder leakage tester applies compressed air to a cylinder through its spark plug hole. The tester's pressure regulator controls the pressure supplied into the cylinder. A gauge registers the percentage of air pressure lost when the compressed air is applied to the cylinder. The scale on the gauge typically reads 0 percent to 100 percent. The amount and location of the air that escapes gives a good idea of the engine's condition and can pinpoint where compression is lost.

A zero reading means there is no leakage in the cylinder. Readings of 100 percent indicate that the cylinder will not hold any pressure. Any reading that

PROCEDURE

1. **Make sure the engine is at operating condition.**
2. **Remove the radiator cap, oil filler cap, dipstick tube, air filter cover, and all spark plugs.**
3. **Rotate the crankshaft with a remote starter button so that the piston of the tested cylinder is at TDC on its compression stroke (Figure 9–42). This ensures that the valves of that cylinder are closed.**
4. **Insert the threaded adapter on the end of the tester's air pressure hose into the spark plug hole.**
5. **Allow the compressed air to enter the cylinder.**
6. **Observe the gauge reading (Figure 9–43).**
7. **Listen and feel to identify the source of any escaping air.**

FIGURE 9–42 Rotate the engine so that the piston of the cylinder that will be tested is at TDC before checking leakage.

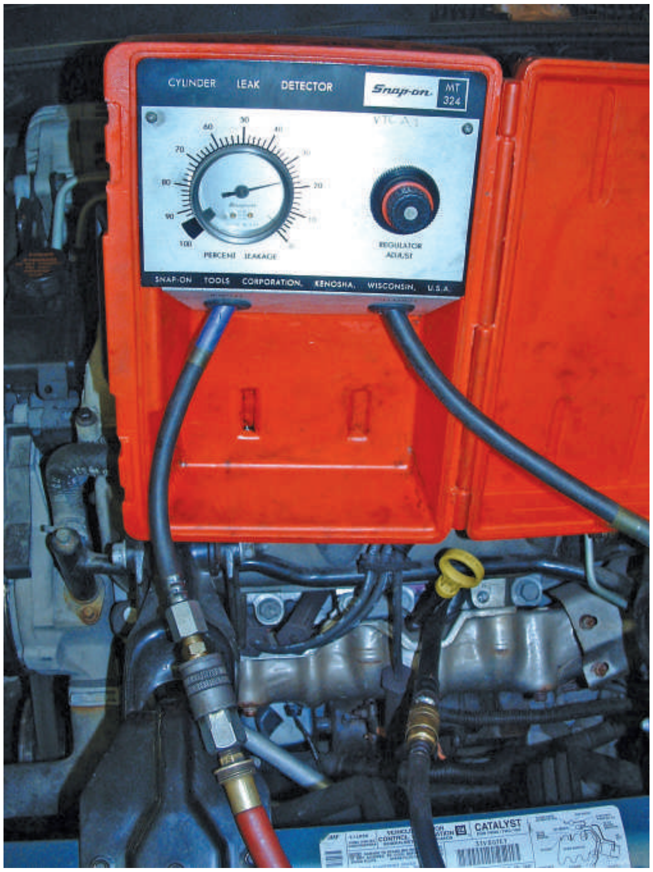


FIGURE 9–43 The reading on the tester is the percentage of air that leaked out during the test.

is more than 0 percent indicates there is some leakage **(Figure 9–44)**. Most engines, even new ones, experience some leakage around the rings. Up to 20 percent is considered acceptable. When the engine is running, the rings will seal much better and the actual leakage will be lower. The location of dominant compression leaks can be found by listening or feeling around various parts of the engine **(Figure 9–45)**.

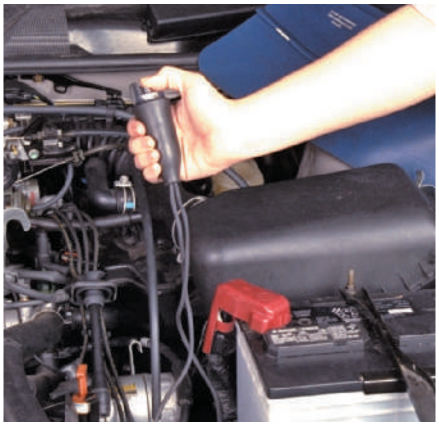
PHOTO SEQUENCE 6

Conducting a Cylinder Compression Test

P6-1 Before conducting a compression test, disable the ignition and the fuel injection system. Most manufacturers recommend that the engine be warm when testing.

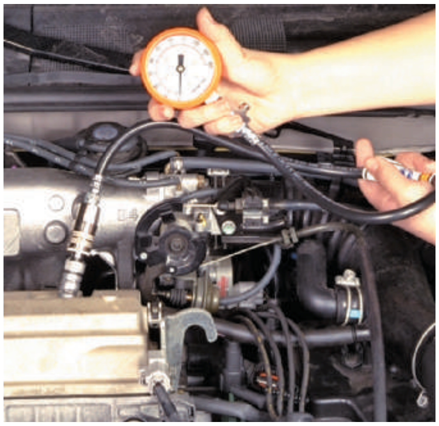
P6-2 Prop the throttle plate into a wide-open position to allow an unrestricted amount of air to enter the cylinders during the test.

P6-3 Remove all of the engine's spark plugs.



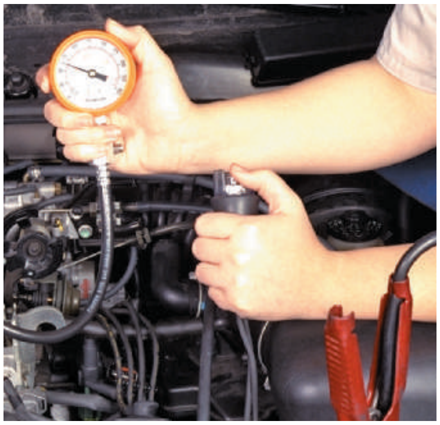
P6-4 Connect a remote starter button to the starter system.

P6-5 Many types of compression gauges are available. The screw-in type tends to be the most accurate and easiest to use.

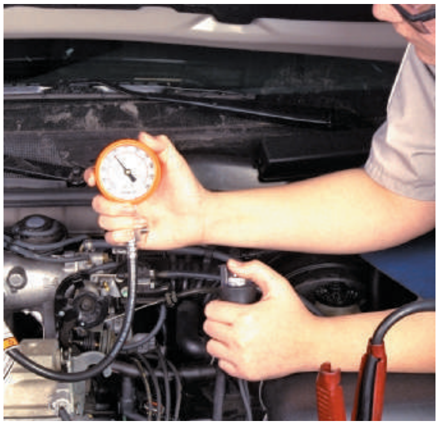


P6-6 Carefully install the gauge into the spark plug hole of the first cylinder.

P6-7 Connect a battery charger to the car to allow the engine to crank at consistent and normal speeds needed for accurate test results.



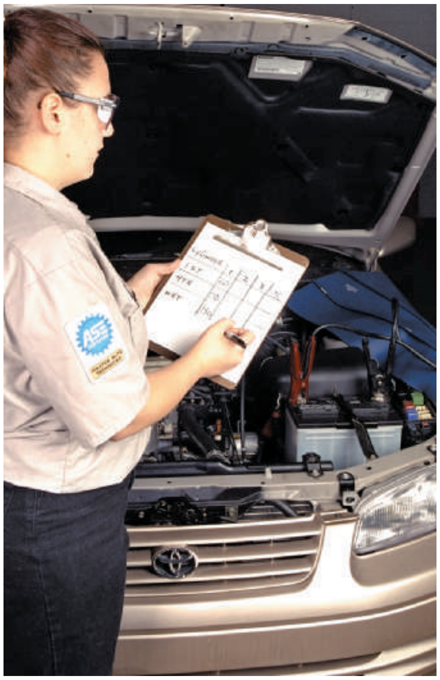
P6-8 Depress the remote starter button and observe the gauge's reading after the first engine revolution.



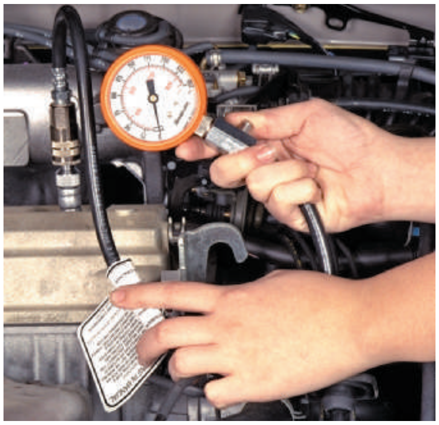
P6-9 Allow the engine to turn through four revolutions, and observe the reading after the fourth. The reading should increase with each revolution.

PHOTO SEQUENCE 6

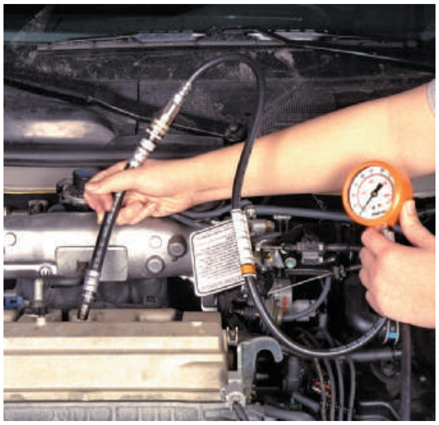
Conducting a Cylinder Compression Test *(continued)*



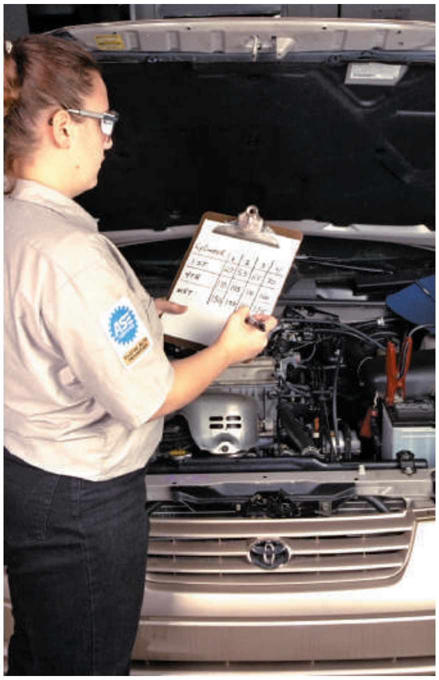
P6-10 Readings observed should be recorded. After all cylinders have been tested, a comparison of cylinders can be made.



P6-11 Before removing the gauge from the cylinder, release the pressure from it using the release valve on the gauge.



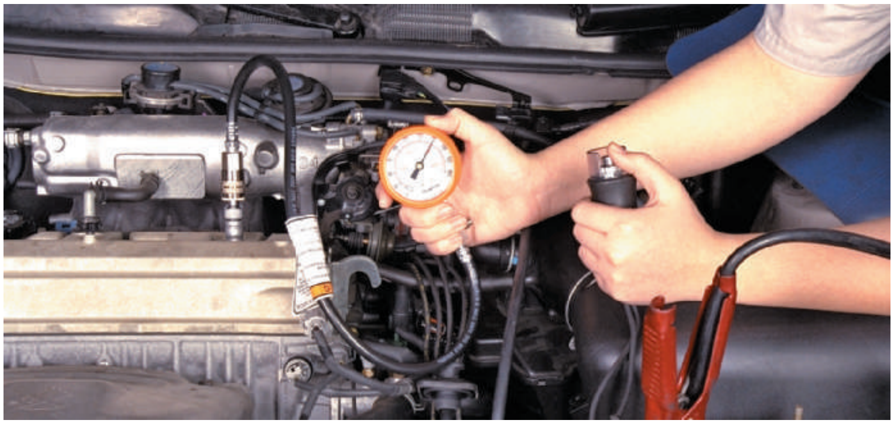
P6-12 Each cylinder should be tested in the same way.



P6-13 After completing the test on all cylinders, compare them. If one or more cylinders is much lower than the others, continue testing those cylinders with the wet test.

P6-14 Squirt a small amount of oil into the weak cylinder(s).

P6-15 Reinstall the compression gauge into that cylinder and conduct the test.



P6-16 If the reading increases with the presence of oil in the cylinder, the most likely cause of the original low readings was poor piston ring sealing. Using oil during a compression test is normally referred to as a wet test.

Measured Leakage	Conclusion
Less than 10%	Good
Between 10 and 20%	Acceptable
Between 20 and 30%	**Worn engine**
Above 30%	Definite problem
100%	Serious problem

FIGURE 9-44 Cylinder leakage test results.

Source of Leakage	Probable Cause
Radiator	Faulty head gasket Cracked cylinder head Cracked engine block
Throttle body	Damaged intake valve
Tailpipe	Damaged exhaust valve
Oil filler or dipstick tube	Worn piston rings
Adjacent spark plug hole	Faulty head gasket Cracked cylinder head

FIGURE 9-45 Sources of cylinder leakage and the probable causes.

Caution! Always follow the precautions given by the manufacturer when conducting a compression test or other engine-related tests, especially when doing this on a hybrid vehicle. In most hybrids, the engine is cranked by a high-voltage motor. Because this motor is required to run the test, the high-voltage system cannot be isolated. Therefore, extreme care must be taken and all appropriate safety precautions must be followed.

SHOP TALK

Some leakage testers read in the opposite way; a reading of 100 percent may indicate a totally sealed cylinder, whereas 0 percent indicates a very serious leak. Always refer to the manufacturer's literature before using test equipment.

Cylinder Power Balance Test

The cylinder power balance test is used to see if all of the engine's cylinders are producing the same amount of power. Ideally, all cylinders will produce the same amount. To check an engine's power balance, each cylinder is disabled, one at a time, and the change in engine speed is recorded. Little or no decrease in speed indicates a weak cylinder. If all of the readings are fairly close to each other, the engine is in good condition. If the readings from one or more cylinders differ from the rest, there is a problem. Further testing may be required to identify the exact cause of the problem. If all of the cylinders are producing the same amount of power, engine speed will drop the same amount as each cylinder is disabled. Unequal cylinder power balance can be caused by the following problems:

- Defective ignition coil
- Defective spark plug wire
- Defective or worn spark plug
- Damaged head gasket
- Worn piston rings
- Damaged piston
- Damaged or burned valves
- Broken valve spring
- Worn camshaft
- Defective lifters, pushrods, and/or rocker arms
- Leaking intake manifold
- Faulty fuel injector

On older vehicles, a power balance test can be performed using an engine analyzer, because the firing of the spark plugs can be automatically controlled or manually controlled by pushing a button. Modern vehicles typically have a power balance test built into the engine control computer. This test is either part of a routine self-diagnostic mode or must be activated by the technician.

Warning! On some computer-controlled engines, certain components must be disconnected before attempting the power balance test. Because of the wide variations from manufacturer to manufacturer, always check the appropriate service information. On all vehicles with an electric cooling fan, override the controls by using jumper wires to make the fan run constantly. If the fan control cannot be bypassed, disconnect the fan. Be careful not to run the engine with a disabled cylinder for more than 15 seconds. The unburned fuel in the exhaust can build up in the catalytic converter and create an unsafe situation. Also, run the engine for at least 10 seconds between testing individual cylinders.

As each cylinder is shorted, a noticeable drop in engine speed should be noted. Little or no decrease in speed indicates a weak cylinder. If all of the readings are fairly close to each other, the engine is in good condition. If the readings from one or more cylinders differ from the rest, there is a problem. Further testing may be required to identify the exact cause of the problem.

Nearly all late-model engines can go through a cylinder balance test as ordered by a scan tool. During this automatic test, the system will attempt to run the engine at a fixed speed. Then once that speed can be maintained, the control system will shut off spark and fuel to one cylinder and the decrease in engine speed will be measured. The system will then activate the fuel and spark to the tested cylinder and wait for several seconds until the idle stabilizes again. Then the system will repeat the process for the next cylinder, repeating this until all cylinders have been tested. After all of the cylinders have been initially checked, the system will perform the test again. The results of both tests will be displayed on the scan tool **(Figure 9–46)**.

Vacuum Tests

Measuring intake manifold vacuum is another way to diagnose the condition of an engine. Vacuum is formed by the downward movement of the pistons during their intake stroke. If the cylinder is sealed, a maximum amount will be formed. This test is most important on engines that are not totally computer-controlled. Keep in mind that the amount of manifold vacuum that is created on the intake stroke is directly related to engine speed and throttle plate position. Also, the faster the engine spins, the higher the vacuum will be if the throttle plates are closed. When the throttle plates open, vacuum will decrease.

Manifold vacuum is measured with a vacuum gauge. The gauge's hose is connected to a vacuum fitting on the intake manifold **(Figure 9–47)**. Normally a "tee" fitting and short piece of vacuum hose are used to connect the gauge.

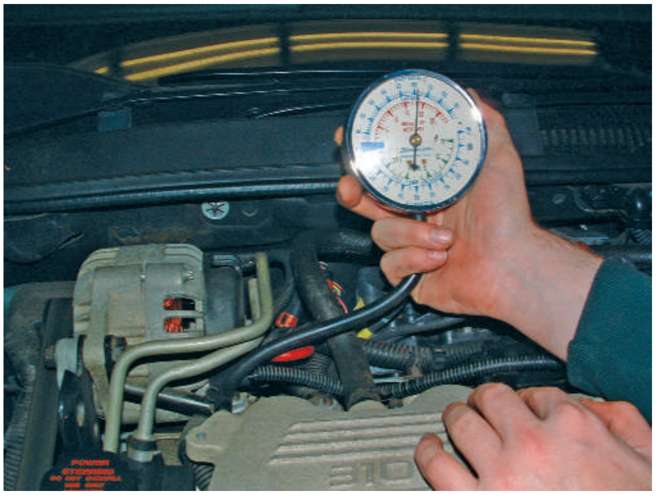


FIGURE 9–47 The vacuum gauge is connected to the intake manifold where it reads engine vacuum.

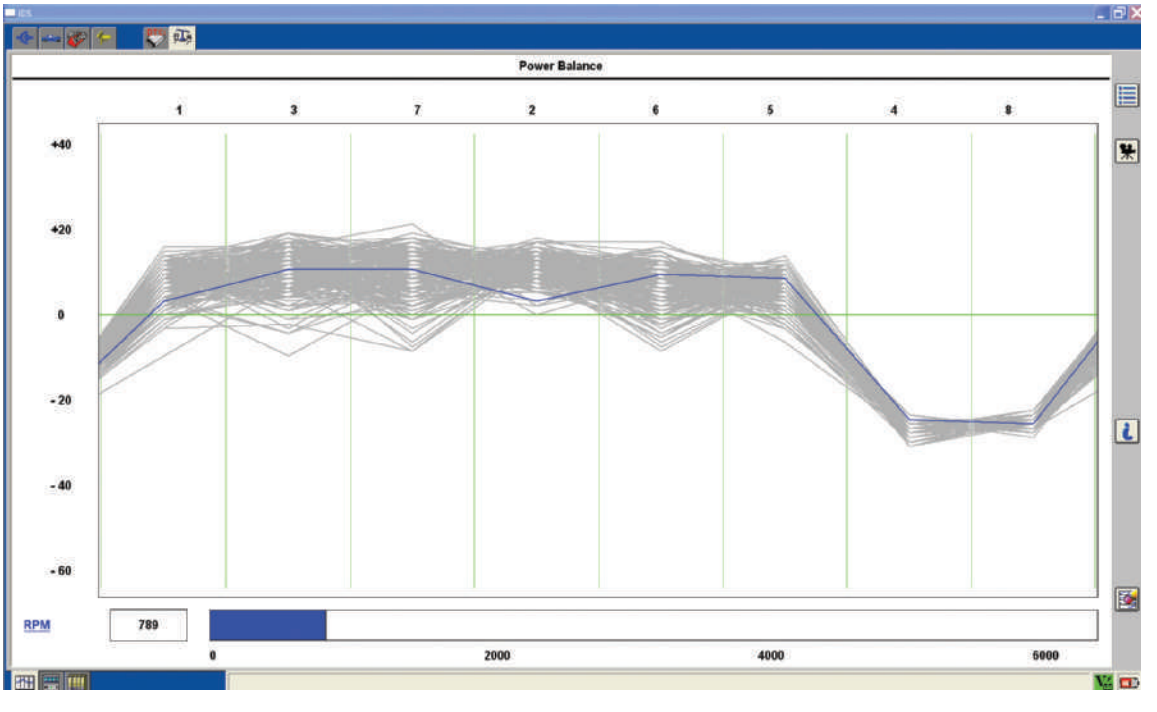


FIGURE 9–46 A cylinder power balance test using Ford's IDS scan tool.

Vacuum gauge readings **(Figure 9–48)** can be interpreted to identify many engine conditions, including the ability of the cylinder to seal, the timing of the opening and closing of the engine's valves, and ignition timing.

Ideally each cylinder of an engine will produce the same amount of vacuum; therefore, the vacuum gauge reading should be steady and give a reading of at least 17 inches of mercury (in. Hg). If one or more cylinders produce more or less vacuum than the others, the needle of the gauge will fluctuate. The intensity of the fluctuation indicates the severity of the problem. For example, if the reading on the vacuum gauge fluctuates between 10 and 17 in. Hg we should look at the rhythm of the needle. If the needle seems to stay at 17 most of the time but drops to 10 and quickly rises, we know that the reading is probably caused by a problem in one cylinder. Fluctuating or low readings can indicate many different problems. For example, a low, steady reading might be caused by retarded ignition timing or incorrect valve timing. A sharp vacuum drop at regular intervals might be caused by a burned intake valve. Other conditions that can be revealed by vacuum readings follow:

- Stuck or burned valves
- Improper valve or ignition timing
- Weak valve springs
- Faulty PCV, EGR, or other emission-related system
- Uneven compression
- Worn rings or cylinder walls
- Leaking head gaskets
- Vacuum leaks
- Restricted exhaust system
- Ignition defects

Vacuum Transducers A vacuum or pressure transducer is an excellent way to check an engine's vacuum. A transducer can transform a condition and convert it into an electronic signal. This has many advantages—the signal, as viewed on a scope, can allow you to observe other engine activities and that may help you discern what is going on in the engine.

The transducer is connected to a scope and to a source of manifold vacuum. View the displayed pattern on the scope; keep in mind the vacuum waveform will be inverted. An increase in pressure, or decrease in vacuum, moves the waveform lower.

Verifying Valve Timing

An engine that does not run properly, or possibly at all, may have incorrect valve timing. As timing belts, chains, tensioners, and guides wear, the belt or chain may develop enough slack to jump time, meaning the crank and cam are no longer synchronized correctly. There are two ways to verify the timing, using a lab scope and by physically checking the timing marks.

To check cam timing with a scope, connect one channel to the crankshaft position (CKP) sensor signal and a second channel to the camshaft position (CMP)

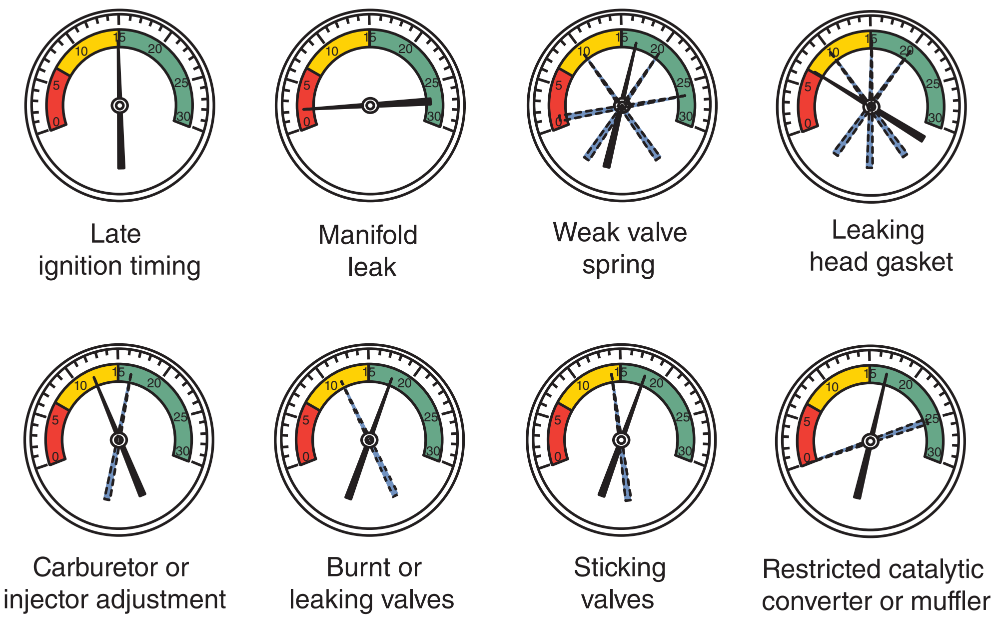


FIGURE 9–48 Vacuum gauge readings and the engine condition indicated by each.

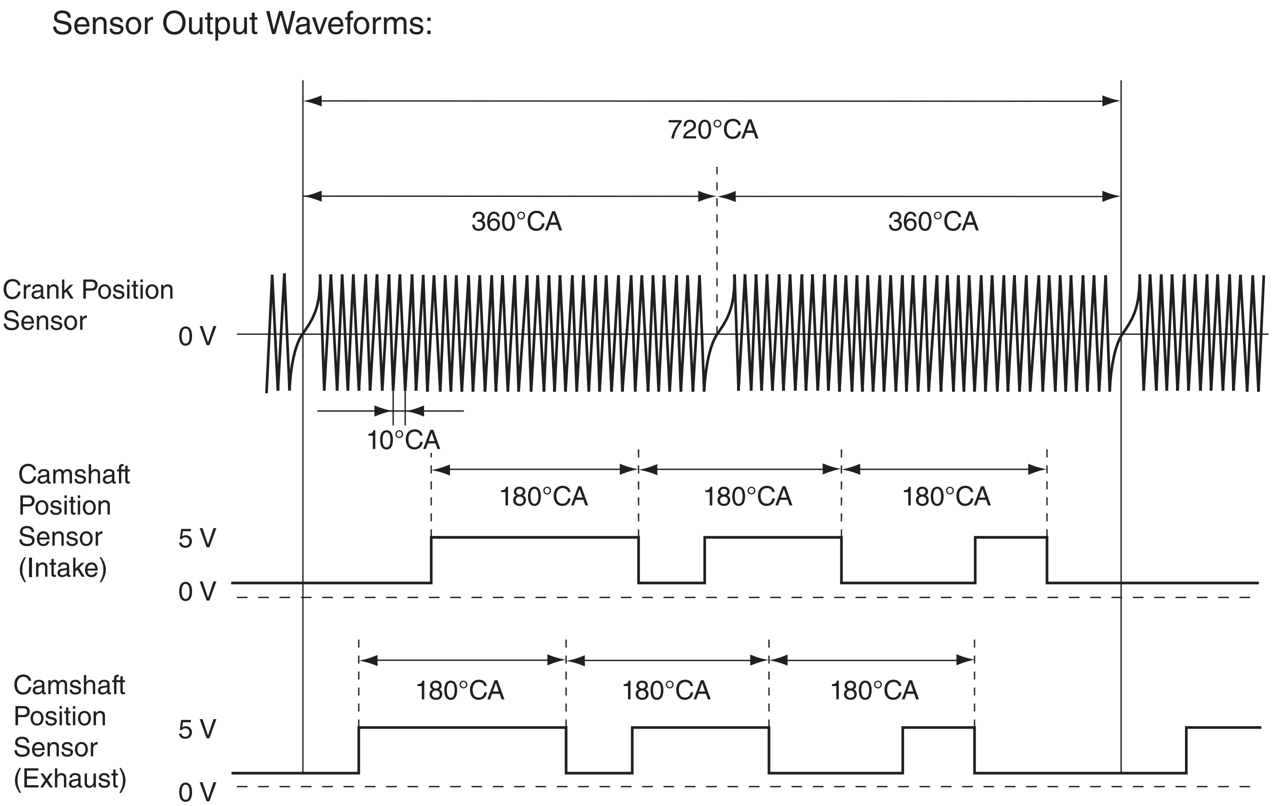


FIGURE 9–49 An example of how to use a scope to check cam and crank timing.

sensor. Crank or start the engine and pause the signal patterns on the screen **(Figure 9–49).** To determine if the correlation is correct, you may need to compare your pattern to a known good pattern. These may be available from the vehicle manufacturer or you may find an example online. Many examples of known good patterns are posted on iATN.net, which are available to paid subscribers.

To physically check the timing, rotate the crankshaft to number 1 TDC and align the crank timing marks **(Figure 9–50)**. Remove the upper timing cover or valve cover as necessary to expose the timing marks on the camshaft(s) **(Figure 9–51)**. Refer to the manufacturer's service information to see how the marks should appear. If the marks all align properly, the valve timing is correct. Incorrect valve timing can cause drivability concerns such as a rough idle, misfires, a lack of power, excessive emissions, and the MIL to stay on. If the valve timing gets too far out, several teeth or more, the valves may contact the pistons, causing severe engine damage.

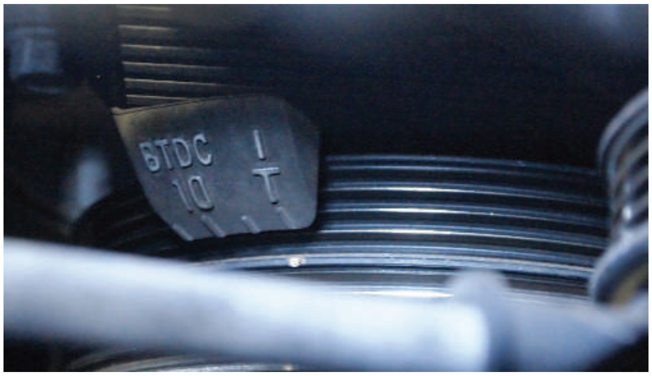


FIGURE 9–50 Setting the crankshaft to number 1 TDC on the compression stroke.

FIGURE 9–51 Aligning the cam sprocket and verifying the timing mark through the hole.

Oil Pressure Testing

An oil pressure test is used to determine the wear of an engine's parts. The test is performed with an oil pressure gauge, which measures the pressure of the oil as it circulates through the engine. Basically, the pressure of the oil depends on the efficiency of the oil pump and the clearances through which the oil flows. Excessive clearances, most often caused by wear between a shaft and its bearings, will cause a decrease in oil pressure. Excessive bearing clearances are not the only possible causes for low oil pressure readings; others are oil pump-related problems, a plugged oil pickup screen, weak or broken oil pressure relief valve, low oil level, contaminated oil, or low oil viscosity. Higher than normal pressures can be caused by too much oil, cold oil, high oil viscosity, restricted oil passages, or a faulty pressure regulator.

A loss of performance, excessive engine noise, and poor starting can be caused by abnormal oil pressure. When the engine's oil pressure is too low, premature wear of its parts will result.

An oil pressure tester is a gauge with a high-pressure hose attached to it. The scale of the gauge typically reads from 0 to 100 psi (0 to 690 kPa). Using the correct fittings and adapters, the hose is connected to an oil passage in the engine block. The test normally includes the following steps:

1. Remove the oil pressure sensor **(Figure 9–52)** and tighten the threaded end of the gauge's hose into that bore.
2. Run the engine until it reaches normal operating temperature.
3. Observe the gauge reading while the engine is running at about 1,000 rpm and at 2,500 rpm (or the specified engine speed).
4. Compare the readings to the manufacturer's specifications.

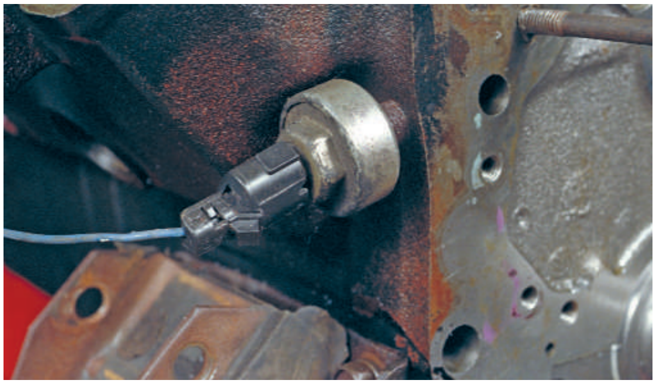


FIGURE 9–52 The oil pressure gauge is installed into the oil pressure sending unit's bore in the engine block.

Oil Pressure Warning Lamp The instrument panel in most vehicles has an oil pressure warning lamp that lights when the oil pressure drops below a particular amount. This lamp should turn on when the ignition key is initially turned to the *on* position and the engine is not running. Once the engine starts, the lamp should go out. If the lamp fails to turn off, there may be an oil pressure problem or a fault in the warning lamp electrical circuit. To determine if the problem is the engine, conduct an oil pressure test. If there is normal oil pressure, the cause of the lamp staying on is an electrical problem.

Evaluating the Engine's Condition

Once the compression, cylinder leakage, vacuum, and power balance tests are performed, further testing can be done to evaluate the engine's condition. For example, an engine with good relative compression but high cylinder leakage past the rings is typical of a high-mileage worn engine. This engine would have these symptoms: excessive blowby, lack of power, poor performance, and reduced fuel economy.

If comparable compression and leakage test results are found on an engine with comparatively low mileage, the problem is probably stuck piston rings that are not expanding properly. If this is the case, try treating the engine with a combustion chamber cleaner, oil treatment, or engine flush. If this fails to correct the problem, an engine overhaul is required.

A cylinder that has poor compression but minimal leakage indicates a valve train problem. Under these circumstances, a valve might not be opening at the right time, might not be opening enough, or might not be opening at all. This condition can be confirmed on engines with a pushrod-type valve train by pulling the rocker covers and watching the valves operate while the engine is cycled. If one or more valves fail to move, either the lifters are collapsed or the cam lobes are worn. If all of the cylinders have low compression with minimal leakage, the most likely cause is incorrect valve timing.

If compression and leakage are both good, but the power balance test reveals weak cylinders, the cause of the problem is outside the combustion chamber. Assuming there are no ignition or fuel problems, check for broken, bent, or worn valve train components, collapsed lifters, leaking intake manifold, or excessively leaking valve guides. If the latter is suspected, squirt some oil on the guides. If they are leaking, blue smoke will be seen in the exhaust.

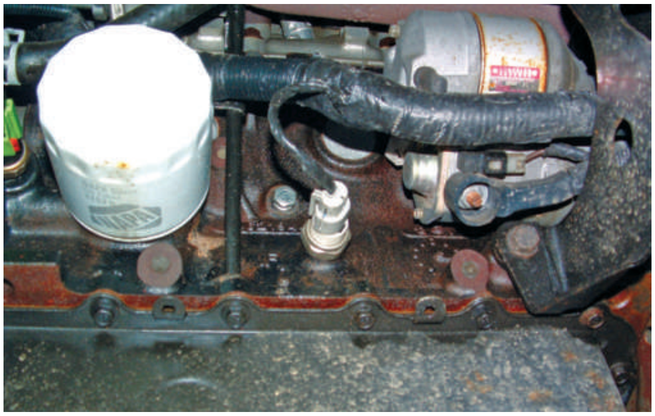


FIGURE 9–53 Oil leaking from around the oil pan gasket.

Description	Probable Source
Honey or dark greasy fluid	Engine oil
Honey or dark thick fluid with a chestnut smell	Gear oil
Green, sticky fluid	Engine coolant
Slippery clear or yellowish fluid	Brake fluid
Slippery red fluid	Transmission or power-steering fluid
Bluish watery fluid	Washer fluid

FIGURE 9–54 Identification of fluid leaks.

Fluid Leaks

When inspecting the engine, check it for leaks **(Figure 9–53)**. There are many different fluids under the hood of an automobile so care must be taken to identify the type of fluid that is leaking **(Figure 9–54)**. Carefully look at the top and sides of the engine, and note any wet residue that may be present. Sometimes road dirt will mix with the leaking fluid and create a heavy coating. Also look under the vehicle for signs of leaks or drips; make sure you have good lighting. Note the areas around the leaks and identify the possible causes. Methods for positively identifying the source of leaks from various components are covered later in this section. All leaks should be corrected because they can result in more serious problems.

Sometimes smell will identify the fluid. Gasoline evaporates when it leaks out and may not leave any residue, but it is easy to identify by its smell.

Exhaust Smoke Diagnosis

Examining and interpreting the vehicle's exhaust can give clues of potential engine problems. Basically there should be no visible smoke coming out of the tailpipe. There is an exception to this rule, on a cold day after the vehicle has been idling for awhile, it is normal for white smoke to come out of the tailpipe. This is caused by the water that has condensed in the exhaust system as it becomes steam due to the heat of the exhaust system. However, the steam should stop once the engine reaches normal operating temperature. If it does not, a problem is indicated. The color of the exhaust is used to diagnose engine concerns **(Figure 9–55)**.

Engine Type	Visible Sign	Diagnosis	Probable Causes
Gasoline	Gray or black smoke	Incomplete combustion or excessively rich A/F mixture	■ Clogged air filter ■ Faulty fuel injection system ■ Faulty emission control system ■ Ignition problem ■ Restricted intake manifold
Diesel	Gray or black smoke	Incomplete combustion	■ Clogged air filter ■ Faulty fuel injection system ■ Faulty emission control system ■ Wrong grade of fuel ■ Engine overheating
Gasoline and diesel	Blue smoke	Burning engine oil	■ Oil leaking into combustion chamber ■ Worn piston rings, cylinder walls, valve guides, or valve stem seals ■ Oil level too high
Gasoline	White smoke	Coolant/water is burning in the combustion chamber	■ Leaking head gasket ■ Cracked cylinder head or block
Diesel	White smoke	Fuel is not burning	■ Faulty injection system ■ Engine overheating

FIGURE 9–55 Exhaust analysis.

Noise Diagnosis

More often than not, an engine malfunction will reveal itself first as an unusual noise. This can happen well before the problem affects the driveability of the vehicle. Problems such as loose pistons, badly worn rings or ring lands, loose piston pins, worn main bearings and connecting rod bearings, loose vibration damper or flywheel, and worn or loose valve train components all produce telltale sounds. Unless the technician has experience in listening to and interpreting engine noises, it can be very hard to distinguish one from the other.

When correctly interpreted, engine noise can be a very valuable diagnostic aid. Always do a noise analysis before moving on to any repair work. This way, there is a much greater likelihood that only the necessary repair procedures will be done.

Using a Stethoscope

Some engine sounds can be easily heard without using a listening device, but others are impossible to hear unless amplified. A stethoscope **(Figure 9–56)** is very helpful in locating engine noise by amplifying the sound waves. It can also distinguish between normal and abnormal noise. The procedure for using a stethoscope is simple. Use the metal prod to trace the sound until it reaches its maximum intensity. Once the precise location has been discovered, the sound can be better evaluated. A sounding stick, which is nothing more than a long, hollow tube, works on the same principle, though a stethoscope gives much clearer results.

The best results, however, are obtained with an electronic listening device. With this tool you can tune into the noise. Doing this allows you to eliminate all other noises that might distract or mislead you.

FIGURE 9-56 Using a stethoscope helps to identify the source of an abnormal noise.

CUSTOMER CARE

When attempting to diagnose the cause of abnormal engine noise, it may be necessary to temper the enthusiasm of a customer who thinks they have pinpointed the exact cause of the noise using nothing more than their own two ears. While the owner's description may be helpful (and should always be asked for), it must be stressed that one person's "rattle" can be another person's "thump." You are the professional. The final diagnosis is up to you. If customers have been proven correct in their diagnosis, make it a point to tell them so. Everyone feels better about dealing with an automotive technician who listens to them.

Warning! Be very careful when listening for noises around moving belts and pulleys at the front of the engine. Keep the end of the hose or stethoscope probe away from the moving parts. Physical injury can result if the hose or stethoscope is pulled inward or flung outward by moving parts.

Common Noises

Figure 9–57 gives examples of abnormal engine noises, including a description of the sound, and their likely causes. An important point to keep in mind is that insufficient lubrication is the most common cause of engine noise. For this reason, always check the fluid levels first before moving on to other areas of the vehicle. Some noises are more pronounced on a cold engine because clearances are greater when parts are not expanded by heat. Remember that aluminum and iron expand at different rates as temperatures rise. For example, a knock that disappears as the engine warms up probably is piston slap or knock. An aluminum piston expands more than the iron block, allowing the piston to fit more closely as engine temperature rises.

Type	Sound	Mostly Heard During	Possible Causes
Ring noise	High-pitched rattle or clicking	Acceleration	■ Worn piston rings ■ Worn cylinder walls ■ Broken piston ring lands ■ Insufficient ring tension
Piston slap	Hollow, bell-like	Cold engine operation and is louder during acceleration	■ Worn piston rings ■ Worn cylinder walls ■ Collapsed piston skirts ■ Misaligned connecting rods ■ Worn bearings ■ Excessive piston to wall clearance ■ Poor lubrication
Piston pin knock	Sharp, metallic rap	Hot engine operation at idle	■ Worn piston pin ■ Worn piston pin boss ■ Worn piston pin bushing ■ Lack of lubrication
Main bearing noise	Dull, steady knock	Louder during acceleration	■ Worn bearings ■ Worn crankshaft
Rod bearing noise	Light tap to heavy knocking or pounding	Idle speeds and low-load higher speeds	■ Worn bearings ■ Worn crankshaft ■ Misaligned connecting rod ■ Lack of lubrication
Thrust bearing noise	Heavy thumping	Irregular sound, may be heard only during acceleration	■ Worn thrust bearing ■ Worn crankshaft ■ Worn engine saddles
Tappet noise	Light regular clicking	Mostly heard during idle	■ Improper valve adjustment ■ Worn or damaged valve train ■ Dirty hydraulic lifters ■ Lack of lubrication
Timing chain noise	Severe knocking	Increases with increase in engine speed	■ Loose timing chain

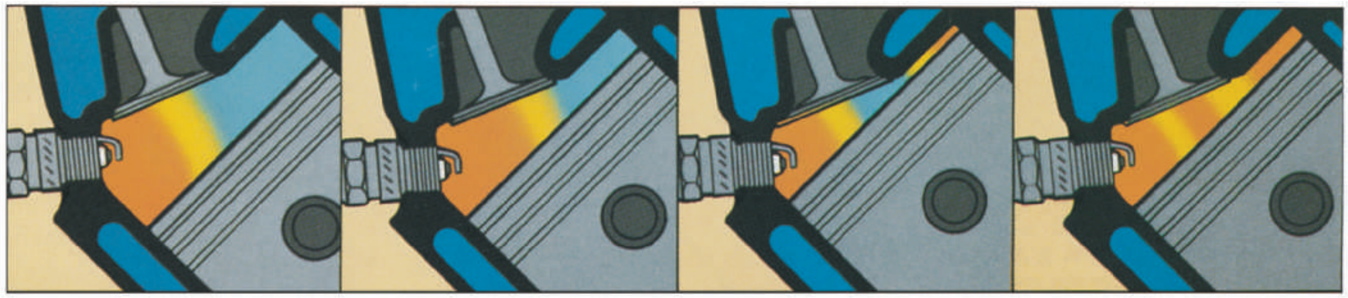
FIGURE 9–57 Common engine noises.

Also keep in mind that loose accessories, cracked flexplates, damaged harmonic balancers, loose bolts, bad belts, broken mechanical fuel pump springs, and other noninternal engine problems can be mistaken for more serious internal engine problems. Always attempt to identify the exact source before completing your diagnosis. In most cases, the source of internal engine noises is best identified by tearing down the engine and inspecting all parts.

Abnormal Combustion Noises

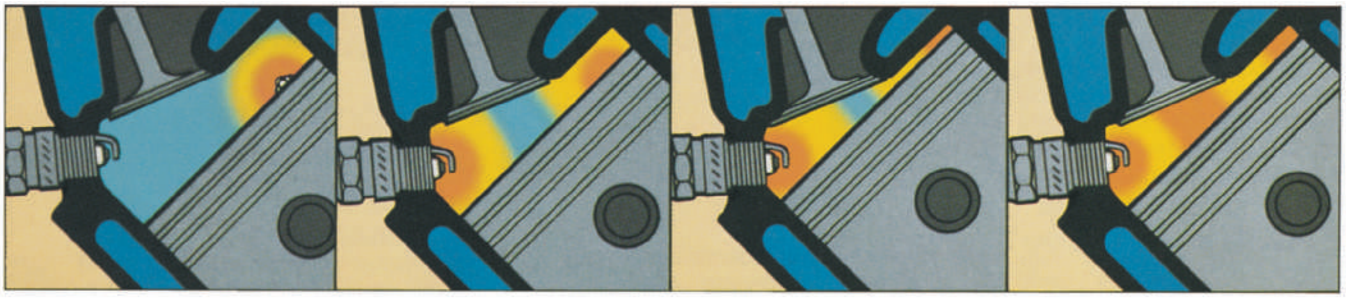
Noises caused by detonation and preignition are caused by abnormal engine combustion. **Detonation** knock or ping is a noise most noticeable during acceleration with the engine under load and running at normal temperature. Detonation occurs when part of the air-fuel mixture begins to ignite on its own. This results in the collision of two flame fronts **(Figure 9–58)**. One flame front moves from the spark plug tip. The other begins at another point in the combustion chamber. The air-fuel mixture at that point is ignited by heat, not by the spark. The colliding flame fronts cause high-frequency shock waves (heard as a knocking or pinging sound) that could cause physical damage to the pistons, valves, bearings, and spark plugs. Excessive detonation can be very harmful to the engine.

Detonation is caused by excessively advanced ignition timing, engine overheating, excessively lean mixtures, or the use of gasoline with too low of an octane rating. A malfunctioning EGR valve can also cause detonation and even rod knock. Another condition that causes pinging or spark knocking is called **preignition**. This occurs when combustion begins before the spark plug fires **(Figure 9–59)**. Any hot spot within the combustion chamber can cause



Courtesy of Federal-Mogul Corporation.

FIGURE 9–58 Detonation.



Courtesy of Federal-Mogul Corporation.

FIGURE 9–59 Preignition.

preignition. Common causes of preignition are carbon deposits in the combustion chamber, a faulty cooling system, too hot of a spark plug, poor engine lubrication, and cross firing. Preignition can lead to detonation; however, preignition and detonation are two separate events. Preignition normally does not cause engine damage; detonation does.

Sometimes abnormal combustion will result in another type of noise. As an example, *rumble* is a term used to describe the vibration of the crankshaft and connecting rods caused by multisurface ignition. This is a form of preignition in which several flame fronts occur simultaneously from overheated deposit particles.

Cleaning Carbon Deposits A buildup of carbon on the top of the piston, intake valve **(Figure 9–60)**, or in the combustion chamber can cause a number of driveability concerns, including preignition. There are a number of techniques used to remove or reduce the amount of carbon inside the engine. One way, of course, is to disassemble the engine and remove the carbon with a scraper or wire wheel.

Two other methods are more commonly used. One is simply adding chemicals to the fuel. These chemicals work slowly so do not expect quick results. The other method requires more labor but is more immediately effective. This uses a carbon blaster, which is a machine that uses compressed air to force crushed walnut shells into the cylinders. The shells beat on the piston top and combustion chamber walls to loosen and remove the carbon. Basically to use a carbon blaster, the intake manifold and spark plugs are removed. The output hose of the blaster is attached to a cylinder's intake port or inserted into the bore for the fuel injector. A hose is inserted into the spark plug bore; this is where the shells and carbon exit the cylinder. Once connected to the cylinder, the blaster forces a small amount of shells in and out of the cylinder. Hopefully, the carbon deposits leave with the shells. To help remove any remaining bits of shells, compressed air is applied to the cylinder. This operation is done at each cylinder. It is important to note that any remaining shell bits will be burned once the engine is run again.

FIGURE 9–60 Carbon build-up on the intake and exhaust valves.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2000	**Make:** Honda	**Model:** Civic	**Mileage:** 164,285	**RO:** 5512
Concern:	Customer complains the engine has a rough idle and does not have as much power as it used to but seems to smooth out at highway speeds.			
After confirming the complaint, the technician performs a relative compression test. One cylinder draws slightly less current than the other three, so he installs a scan tool and performs a cylinder power balance test. The test shows cylinder 3 only drops 10 rpm. After verifying spark at the plug and that the fuel injector is flowing fuel, he performs a cranking compression test. The compression reading was slightly low but not, it seemed, enough to account for the dead cylinder. He next performs a running compression test and has only 20 psi. The technician then removed the valve cover to inspect the cam, believing there is a problem with getting air into the cylinder.				
Cause:	Found a severely worn camshaft lobe, number three cylinder intake lobe.			
Correction:	Replaced cam and lifters. Engine operation normal.			

KEY TERMS

- Atkinson cycle
- Bore
- Bottom dead center (BDC)
- Combustion chamber
- Crank throw
- Detonation
- Diesel engine
- Direct injection (DI)
- Double overhead camshaft (DOHC)
- Efficiency
- Firing order
- Glow plug
- Lobe
- Oversquare
- Preignition
- Rotary
- Selective catalytic reduction (SCR)
- Stroke
- Top dead center (TDC)
- Undersquare

SUMMARY

- Automotive engines are classified by several different design features such as operational cycles, number of cylinders, cylinder arrangement, valve train type, valve arrangement, ignition type, cooling system, and fuel system.
- The basis of automotive gasoline engine operation is the four-stroke cycle. This includes the intake stroke, compression stroke, power stroke, and exhaust stroke. The four strokes require two full crankshaft revolutions.
- The most popular engine designs are the inline (in which all the cylinders are placed in a single row) and V-type (which features two rows of cylinders). The slant design is much like the inline, but the entire block is placed at a slant. Opposed cylinder engines use two rows of cylinders located opposite the crankshaft.
- The two basic valve and camshaft placement configurations currently in use on four-stroke engines are the overhead valve and overhead cam.
- Bore is the diameter of a cylinder, and stroke is the length of piston travel between top dead center (TDC) and bottom dead center (BDC). Together these two measurements determine the displacement of the cylinder.
- Compression ratio is a measure of how much the air and fuel are compressed during the compression stroke.
- In an Atkinson cycle engine the intake valve is held open longer than normal during the compression stroke. As a result, the amount of mixture in the cylinder and the engine's effective displacement and compression ratio are reduced.
- Diesel engines have compression ignition systems. Rather than relying on a spark for ignition, a diesel engine uses the heat produced by compressing the intake air to ignite the fuel.
- A hybrid electric vehicle has two different types of power or propulsion systems: an internal combustion engine and an electric motor.
- A compression test is conducted to check a cylinder's ability to seal and therefore its ability to compress the air-fuel mixture inside the cylinder.

- A cylinder leakage test is performed to measure the percentage of compression lost and to help locate the source of leakage.
- A cylinder power balance test reveals whether all of an engine's cylinders are producing the same amount of power.
- Vacuum gauge readings can be interpreted to identify many engine conditions, including the ability of the engine's cylinders to seal, the timing of the opening and closing of the engine's valves, and ignition timing.
- An oil pressure test measures the pressure of the engine's oil as it circulates throughout the engine. This test is very important because abnormal oil pressures can cause a host of problems, including poor performance and premature wear.
- Carefully observing the exhaust can aid engine diagnosis.
- An engine malfunction often reveals itself as an unusual noise. When correctly interpreted, engine noise can be a very helpful diagnostic aid.

REVIEW QUESTIONS

Short Answer

1. What defines the combustion chamber of a four-stroke engine?
2. Describe what takes place during the four strokes of a four-stroke cycle engine.
3. As an engine's compression ratio increases, what should happen to the octane rating of the gasoline?
4. What test can be performed to check the efficiency of individual cylinders?
5. Describe five ways in which an engine can be classified.
6. In a four-cylinder engine with a firing order of 1–3–4–2, what stroke is piston #4 on when #1 is on its compression stroke?

True or False

1. *True or False?* In an HCCI engine, combustion immediately and simultaneously produces a steady flame across the mixture.
2. *True or False?* SAE mandates that engine, when viewed from the front, will be rotating in a counterclockwise direction.
3. *True or False?* The camshaft is always located in the engine block.

Multiple choice

1. Which of the following statements about engines is *not* true?
   a. The engine provides the rotating power to drive the wheels through the transmission and driving axle.
   b. Only gasoline engines are classified as internal combustion.
   c. The combustion chamber is the space between the top of the piston and the cylinder head.
   d. For the combustion in the cylinder to take place completely and efficiently, air and fuel must be combined in the right proportions.
2. Which stroke in the four-stroke cycle begins as the piston reaches BDC after combustion takes place?
   a. Power stroke
   b. Exhaust stroke
   c. Intake stroke
   d. Compression stroke
3. Which of the following is not a true statement about diesel engines?
   a. The operation and main components of a diesel engine are comparable to those of a gasoline engine.
   b. Diesel and gasoline engines are available as four-stroke combustion cycle engines.
   c. Diesel engines rely on glow plugs instead of spark plugs to initiate ignition.
   d. The compression ratio of diesel engines is typically three times that of a gasoline engine.
4. Technician A says head gasket thickness has an effect on compression ratio. Technician B says connecting rod length has an effect on compression ratio. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. The stroke of an engine is the ___ crank throw.
   a. half
   b. twice
   c. four times
   d. equal to
6. Which of the following is an expression of how much of the heat formed during the combustion process is available as power from the engine?
   a. Mechanical efficiency
   b. Engine efficiency
   c. Volumetric efficiency
   d. Thermal efficiency

ASE-STYLE REVIEW QUESTIONS

1. While diagnosing the cause for blue smoke from the tailpipe of a gasoline engine: Technician A says that a faulty fuel injection system is a likely cause. Technician B says that it is most likely caused by coolant leaking into the combustion chamber. Who is correct?
   a. Technician A c. Both A and B
   b. Technician B d. Neither A nor B
2. While discussing piston slap: Technician A says that it is a high-pitched clicking that becomes louder during deceleration caused by detonation. Technician B says that it is the noise made by the piston when it contacts the cylinder wall due to excessive clearances. Who is correct?
   a. Technician A c. Both A and B
   b. Technician B d. Neither A nor B
3. While determining the cause for air leaking out of the oil throttle body during a cylinder leakage test: Technician A says that a burnt intake valve is indicated. Technician B says that a warped cylinder head or bad head gasket is indicated. Who is correct?
   a. Technician A c. Both A and B
   b. Technician B d. Neither A nor B
4. While diagnosing the cause for an engine having good results from a compression test and cylinder leakage test but poor results from a cylinder power balance test: Technician A says that incorrect valve timing is the most likely cause. Technician B says that a severely worn cam lobe is a likely cause. Who is correct?
   a. Technician A c. Both A and B
   b. Technician B d. Neither A nor B
5. While looking at the results of an oil pressure test: Technician A says that higher than normal readings can be caused by using an incorrect viscosity oil. Technician B says that higher than normal readings can be expected on a cold engine. Who is correct?
   a. Technician A c. Both A and B
   b. Technician d. Neither A nor B
6. A vehicle is producing a sharp, metallic rapping sound originating in the upper portion of the engine. It is most noticeable during idle. Technician A diagnoses the problem as piston pin knock. Technician B says that the problem is most likely a loose crankshaft thrust bearing. Who is correct?
   a. Technician A c. Both A and B
   b. Technician B d. Neither A nor B
7. While conducting an engine vacuum test: Technician A says that a steady low vacuum reading can be caused by a burned intake valve. Technician B says that an overall low vacuum reading is caused by something that affects all of the engine's cylinders. Who is correct?
   a. Technician A c. Both A and B
   b. Technician B d. Neither A nor B
8. While determining the most likely problem of an engine with poor compression test results but acceptable cylinder leakage readings: Technician A says that the problem may be incorrect valve timing. Technician B says that the problem is worn valve seats. Who is correct?
   a. Technician A c. Both A and B
   b. Technician B d. Neither A nor B
9. When a customer states that black exhaust smoke is coming from the exhaust: Technician A says faulty oil rings may be the cause. Technician B says a faulty head gasket may be the cause. Who is correct?
   a. Technician A c. Both A and B
   b. Technician B d. Neither A nor B
10. Technician A says that if an engine had good results from a compression test, it will have good results from a cylinder leakage test. Technician B says that if an engine had good results from a cylinder leakage test, it will have good results from a running compression test. Who is correct?
    a. Technician A c. Both A and B
    b. Technician B d. Neither A nor B

CHAPTER 10

ENGINE DISASSEMBLY AND CLEANING

OBJECTIVES

- Prepare an engine for removal.
- Remove an engine from a FWD and a RWD vehicle.
- Separate the engine into its basic components.
- Clean engine parts using the appropriate method for the construction of the part.
- Perform common services to an engine while it is in a vehicle.

Most of this chapter covers the removal and installation of an engine. However, it ends with some of common repairs that can be made to an engine while it is still in a vehicle. It also covers basic disassembly and general cleaning of the components. The material is presented so that it applies not only to engine rebuilding, but also to the replacement of individual parts when a total rebuild is not necessary. Complete disassembly and assembly of the engine block and cylinder head are covered in Chapters 11 and 12.

Removing an Engine

Before removing the engine, clean it and the area around it. Also, check the service information for the correct procedure for removing the engine from a particular vehicle. Make sure you adhere to all precautions. Make sure you have the tools and equipment required for the job. In addition to hand tools and some special tools, you will need an engine hoist or crane **(Figure 10–1)** and a jack.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2010	**Make:** Chevrolet	**Model:** Equinox	**Mileage:** 89,110	**RO:** 14484
Concern:	Customer states engine is leaking oil.			
History:	Oil was changed a week ago.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

FIGURE 10–1 To pull an engine out of a vehicle, the chain on the lifting crane is attached to another chain secured to the engine.

The procedures for engine removal vary, depending on whether the engine is removed from the bottom of the vehicle or through the hood opening. Many FWD vehicles require that the engine be removed from under the vehicle, whereas the engine in most RWD vehicles is removed from the hood opening. The engine exit point is something to keep in mind while you are disconnecting and removing items in preparation for engine removal.

General Procedures

When removing an engine, setting the vehicle on a frame contact hoist is recommended. When the vehicle is sitting on the floor, block the wheels so that it does not move while you are working. Open the hood and put fender covers on both front fenders **(Figure 10–2)**. Once the vehicle is in position, relieve the pressure in the fuel system using the procedures given by the manufacturer.

FIGURE 10–2 Before doing anything, put covers on the fenders.

CUSTOMER CARE

Make sure your hands, shoes, and clothing are clean before getting into a customer's car. Disposable seat and floor coverings should be used to help protect the interior.

Battery Install a memory saver before you disconnect the battery to prevent the vehicle's computers and other devices from losing what they have stored in their memory. Disconnect all negative battery cables **(Figure 10–3)**, tape their connectors, and place them away from the battery. If the battery will be in the way of engine removal, remove the positive cables and the battery.

Hood The vehicle's hood may get in the way during engine removal. If the hinges allow the hood to be set straight up above the engine compartment, prop it in that position with wood or a broom. In many cases, the hood should be removed and set aside in a safe place on fender covers or cardboard. Make sure not to damage the vehicle's paint while doing this. Before removing the hood, mark the location of the hinges on the hood. Then unbolt and remove the hood with the help of someone else.

Fluids Drain the engine's oil and remove the oil filter. Then drain the coolant from the radiator **(Figure 10–4)** and engine block, if possible. To increase the flow of the coolant out of the cooling system, remove the

FIGURE 10–3 After the negative battery cable is disconnected, tape the terminal end to prevent it from accidentally touching the battery.

SHOP TALK

Often the safest place to store the hood is on the vehicle's roof.

FIGURE 10-4 Drain the engine's coolant and recycle it.

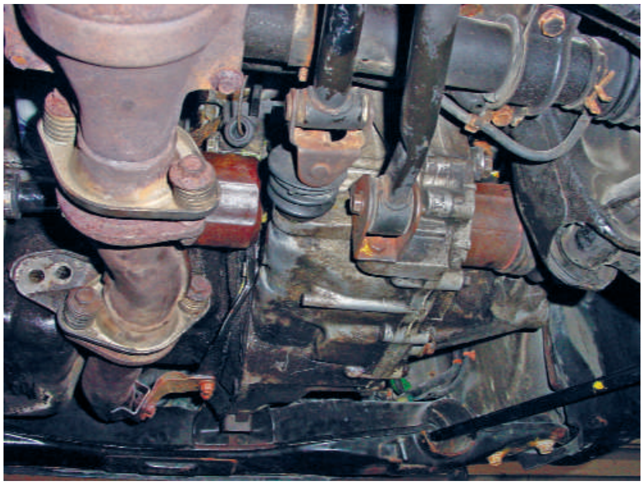


FIGURE 10-5 If the transmission will be removed with the engine, disconnect all linkages, lines, and electrical connectors.

radiator cap. After collecting the old coolant, recycle it. If the transmission needs to be removed with the engine, drain its fluid.

Underbody Connections While you are under the vehicle to drain the fluids, disconnect the shift linkage, transmission cooling lines, all electrical connections, vacuum hoses, and clutch linkages from the transmission **(Figure 10–5)**. If the clutch is hydraulically operated, unbolt the slave cylinder and set it aside, if possible. If this is not possible, disconnect and plug the line to the cylinder.

Air-Fuel System Remove the air intake ducts and air cleaner assembly. Disconnect and plug the fuel line at the fuel rail. If the engine is equipped with a return fuel line from a fuel pressure regulator, disconnect that as well **(Figure 10–6)**. Make sure all fuel lines are closed off with pinch pliers or an appropriate plug or cap. Most late-model fuel lines have quick-connect fittings that are separated by squeezing the retainer tabs together and pulling the fitting off the fuel line nipple.

Disconnect all vacuum lines at the engine. Make sure these are labeled before disconnecting them. Late model vehicles have a VECI decal under the hood. The diagram and labels will make it easier to reconnect the hoses when the engine is reinstalled.

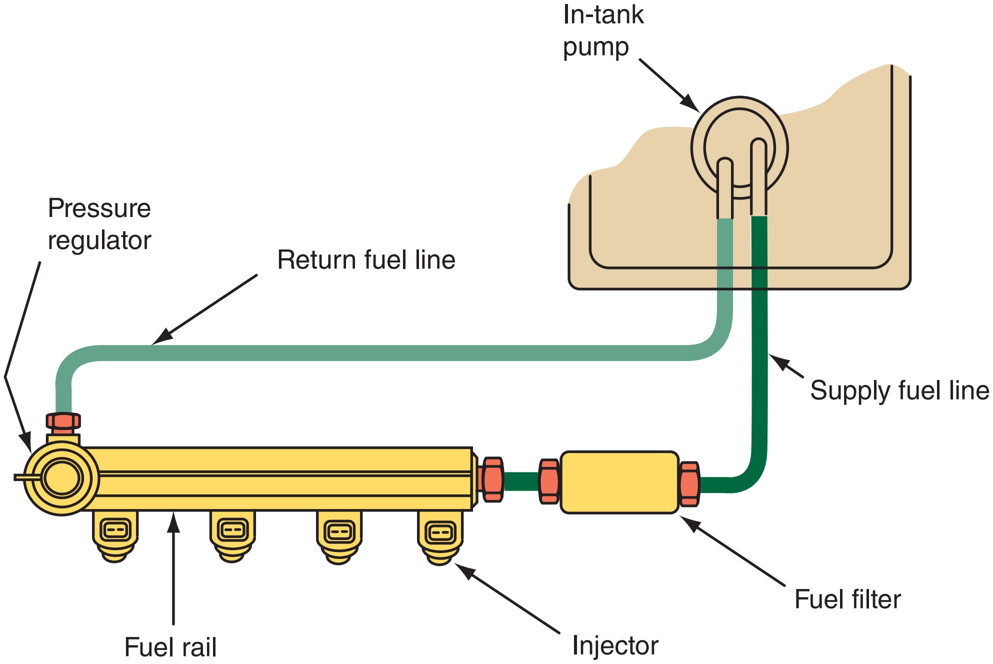


FIGURE 10-6 Disconnect and plug the fuel lines at the fuel rail and the pressure regulator.

SHOP TALK

Some technicians use cell phones or cameras to help recall the locations of underhood items before work is started. This can be quite valuable considering how complex the underhood systems of current cars have become.

Now disconnect the throttle linkage and the electrical connector to the throttle position (TP) sensor.

Accessories Remove all drive belts **(Figure 10–7)**. Unbolt and move the power-steering pump and air-conditioning (A/C) compressor out of the way. Do not disconnect the lines unless it is necessary. If the pressure hoses at the A/C compressor must be disconnected, do not loosen the fittings until the refrigerant has been captured by a refrigerant reclaimer/recycling machine. Once disconnected, plug the lines and connections at the compressor to prevent dirt and moisture from entering.

Remove or move the A/C compressor bracket, power-steering pump, air pump, and any other components attached to the engine. Disconnect and plug all transmission and oil cooler lines.

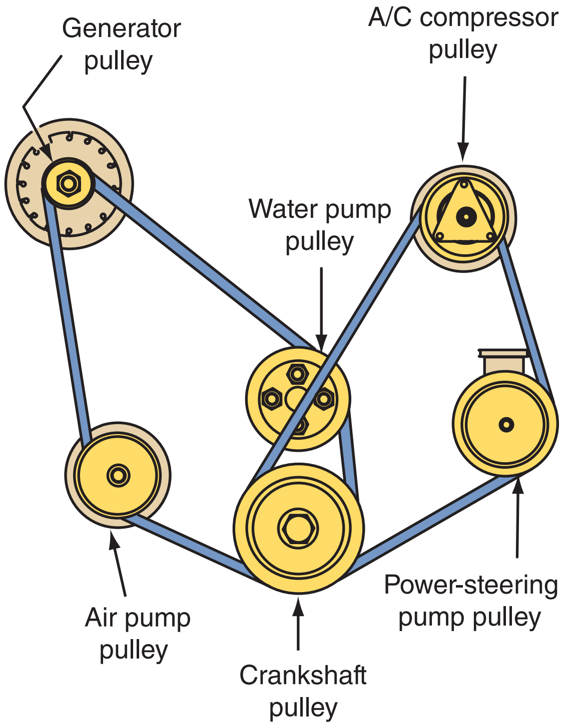


FIGURE 10–7 Before removing the drive belts, pay attention to the routing of each belt.

SHOP TALK

When removing the fasteners, pay close attention to their size and type. The brackets used to secure accessories use different size fasteners. Mark and organize the fasteners so that their proper location can be easily identified later. It is a good idea to store the fasteners in different containers, one for each system or section of the engine.

Electrical Connections Unplug all electrical connectors between the engine and the vehicle. Use masking tape to label all wires that are disconnected **(Figure 10–8)**. Most engines have a crankshaft position sensor attached above the flywheel or flexplate. This sensor must be removed before separating the engine from the bell housing. Make sure the engine ground strap is disconnected, preferably at the engine.

Cooling System Disconnect the heater inlet and outlet hoses. Then disconnect the upper and lower radiator hoses. If the radiator is fitted with a fan shroud, carefully remove it along with the cooling fan. If the vehicle is equipped with an electric cooling fan, disconnect the wiring to it. Then unbolt and remove the radiator mounting brackets and remove the radiator. Normally the electric cooling fan assembly and radiator can be removed as a unit **(Figure 10–9)**.

Miscellaneous Stuff Disconnect the exhaust system; try to do this at the exhaust manifold **(Figure 10–10)**.

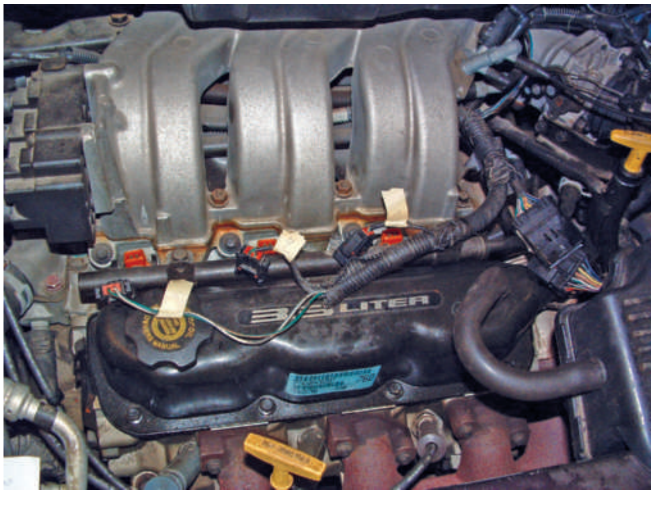


FIGURE 10–8 Before unplugging the electrical wires between the engine and the vehicle, use masking tape as a label to identify all disconnected wires.

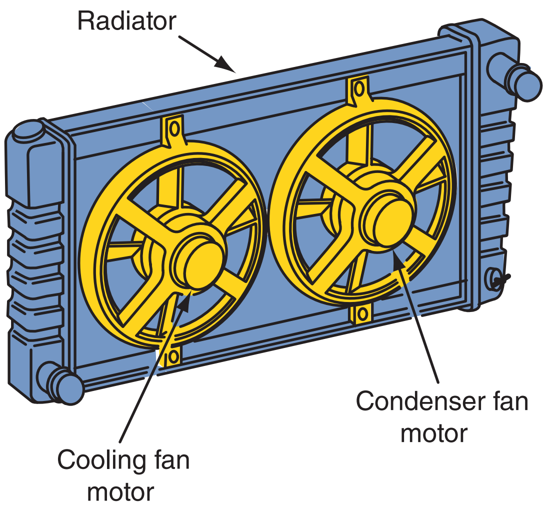


FIGURE 10–9 Typically the electric cooling fans can be removed as a unit with the radiator.

FIGURE 10–10 The exhaust system must be disconnected to remove the engine. Often this is the condition of the exhaust, so take care not to damage anything.

When disconnecting the exhaust system, make sure the wires connected to the exhaust sensors are disconnected before the system is moved. Remove any heat shields that may be in the way of moving or removing the exhaust system. Then carefully check under the hood to identify and remove anything that may interfere with engine removal.

Because there is typically easy access to the cables, wiring, and bell housing bolts, removing the engine from a RWD vehicle is more straightforward than removing one from a FWD model, Engines in FWD cars can be more difficult to remove because large assemblies such as engine cradles, suspension components, brake components, splash shields, or other pieces may need to be disassembled or removed.

FIGURE 10–11 A transverse engine support bar provides the necessary support when removing an engine from a FWD vehicle.

FWD Vehicles

Most often the engine and powertrain in a FWD vehicle is removed through the bottom of the vehicle. Special tools may be required to hold the transaxle and/or engine in place as it is being disconnected from the vehicle **(Figure 10–11)**. Always refer to the service information before proceeding to remove the transaxle. You will waste much time and energy if you do not check the information first.

Use an engine cradle and dolly to support the engine. However, if the manufacturer recommends engine removal through the hood opening, use an engine hoist. Regardless of the method of removal, the engine and transaxle are typically removed as a unit. The transaxle can be separated from the engine once it is lifted out of the vehicle.

Drive Axles Using a large breaker bar, loosen and remove the axle shaft hub nuts **(Figure 10–12)**. It is recommended that these nuts be loosened with the vehicle on the floor and the brakes applied.

Raise the vehicle so that you can comfortably work under it. Then remove the front wheel and tire assemblies. Tap the splined CV joint shaft with a soft-faced hammer to loosen it. Most will come loose with a few taps.

Disconnect all suspension and steering parts that need to be removed according to the service information. Index the parts so the wheel alignment will be close after reassembly. Normally the lower ball joint must be separated from the steering knuckle. The ball joint will either be bolted to the lower control arm or the ball joint will be held into the knuckle with

FIGURE 10-12 Use a large breaker bar to loosen the axle shaft hub nuts.

a pinch bolt. Once the ball joint is loose, the control arm can be pulled down and the knuckle can be pushed outward to allow the CV joint shaft to slide out of the hub **(Figure 10–13)**.

The inboard joint can then either be pried out or will slide out. Some transaxles have retaining clips that must be removed before the inner joint can be removed. Others have a flange-type mounting. These should be unbolted to remove the shafts. In some cases, flange-mounted drive shafts may be left attached to the wheel and hub assembly and only unbolted at the transmission flange. The free end of the shafts should be supported and placed out of the way.

Pull the drive axles from the transaxle. While removing the axles, make sure the brake lines and hoses are not stressed. Suspend them with wire to relieve the weight on the hoses and to keep them out of the way.

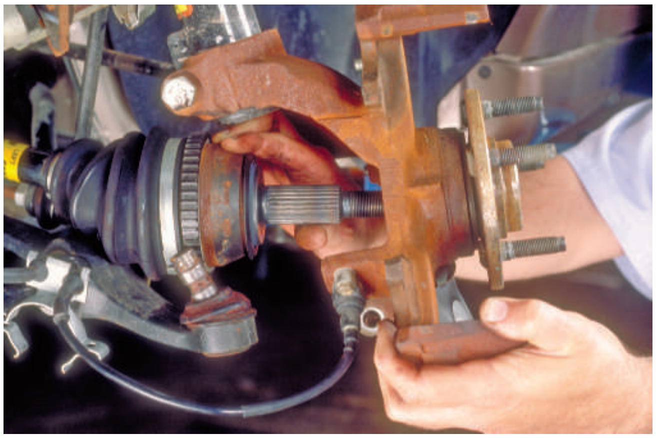


FIGURE 10-13 Pull the steering knuckle outward to allow the CV joint shaft to slide out of the hub.

Transaxle Connections Disconnect all electrical connectors and the speedometer cable, if so equipped, at the transaxle. Then disconnect the shift linkage or cables and the clutch cable or hydraulic lines.

Starter Now, remove the starter. The starter wiring may be left connected, or you can also completely remove the starter from the vehicle to get it totally out of the way. The starter should never be left to hang by the wires attached to it. The weight of the starter can damage the wires or, worse, break the wires and allow the starter to fall, possibly on you or someone else. Always securely support the starter and position it out of the way after you have unbolted it from the engine.

Removing the Engine through the Hood Opening Connect the engine sling or lifting chains to the engine. Use the lifting hooks on the engine **(Figure 10–14)** or fasten the sling to the points given in the service information. Connect the sling or chains to the crane and raise it just enough to support the engine.

From under the vehicle, remove the cross member. Then remove the mounting bolts at the engine and transaxle mounts. With a transmission jack supporting the transmission, remove the transaxle mounts.

From under the hood, remove all remaining mounts. Then slowly raise the engine from the engine compartment. Guide the engine around all wires and hoses to make sure nothing gets damaged. Once the engine is cleared from the vehicle, prepare to separate it from the transaxle.

Removing the Engine from under the Vehicle Position the engine cradle and dolly under the engine. Adjust the pegs of the cradle so that they fit

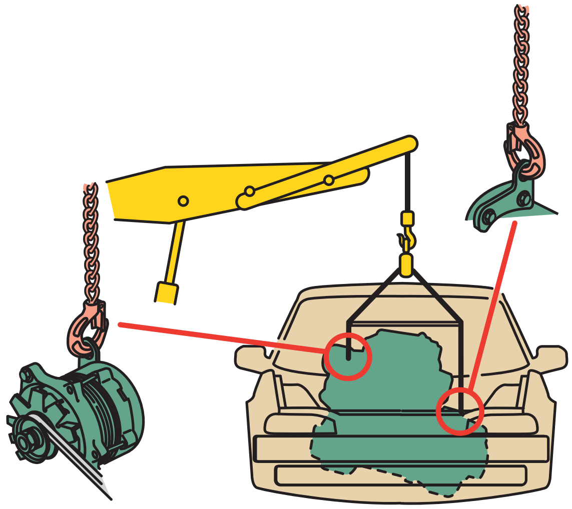


FIGURE 10-14 Some engines are equipped with eye plates to which the hoist can be safely attached.

into the recesses on the bottom of the engine, and secure the engine.

Remove all engine and transaxle mount bolts. If required, remove the frame member from the vehicle. It may also be necessary to disconnect the steering gear from the frame. Double-check to ensure that all wires and hoses are disconnected from the engine. With the transmission jack supporting the transmission, remove the transaxle mounts.

Slowly raise the vehicle, lifting it slightly away from the engine. As the vehicle is lifted, the engine remains on the cradle. During this process, continually check for interference with the engine and the vehicle. Also watch for any wires and hoses that may still be attached to the engine. Once the vehicle is clear of the engine, prepare to separate the engine from the transaxle.

FIGURE 10–15 Mark the alignment of the rear U-joint and the pinion flange before removing the drive shaft.

RWD Vehicles

The engine is removed through the hood opening with an engine hoist on most RWD vehicles. Refer to the service information to determine the proper engine lift points. Attach a pulling sling or chain to the engine. Some engines have eye plates for lifting. If they are not available, the sling must be bolted to the engine. The attaching bolts for the sling must be strong enough to support the engine and must thread into the block a minimum of 1½ times the bolt diameter.

If the transmission is being removed with the engine, position the hook of the engine hoist to the lifting chain so that the engine tips a little toward the transmission. Lift the engine slightly and check for any additional things behind and under the engine that should be disconnected.

Transmission If the engine and transmission must be separated before engine removal, remove all clutch (bell) housing bolts. If the vehicle has an automatic transmission, remove the torque converter mounting bolts.

If the transmission is being removed with the engine, place a drain pan under the transmission and drain the fluid from the transmission. Once the fluid is out, move the drain pan under the rear of the transmission. Use chalk to index the alignment of the rear U-joint and the pinion flange **(Figure 10–15)**. Then remove the drive shaft.

Disconnect all electrical connections and the speedometer cable, if so equipped, at the transmission. Make sure you place these away from the transmission so that they are not damaged during transmission removal or installation.

Disconnect and remove the transmission and clutch hydraulic lines or linkage. Disconnect the parts of the exhaust system that may get in the way.

Use a transmission jack to securely support the transmission **(Figure 10–16)** and unbolt the engine

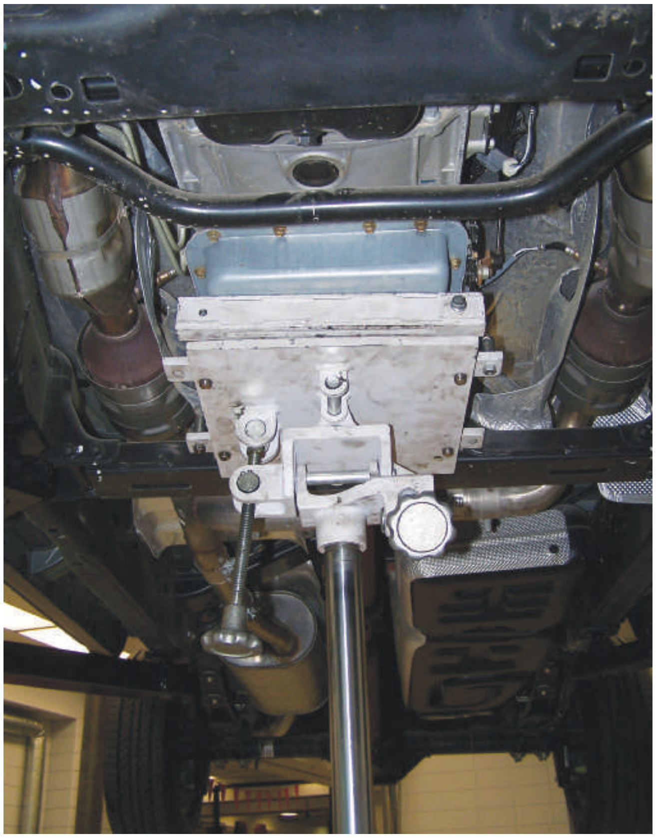


FIGURE 10–16 Use a transmission jack to securely support the transmission before removing the motor mounts.

FIGURE 10–17 If the engine is removed with its transmission, remove the transmission mount and cross member.

mounts. If the engine is removed with its transmission, the front of the engine must come straight up as the transmission moves away from the bottom of the vehicle. Remove the transmission mount and cross member **(Figure 10–17)**.

Removing the Engine Center the boom of the crane (hoist) directly over the engine and raise the engine slightly. Make sure nothing else is still attached to the engine. Continue raising the engine while pulling it forward. Make sure that the engine does not bind or damage anything in the engine compartment. When the engine is high enough to clear the front of the vehicle, roll the crane and engine away.

Lower the engine close to the floor so that it can be safely moved to the desired location. If the transmission was removed with the engine, remove the bell housing bolts and inspection plate bolts. On vehicles with an automatic transmission, also remove the torque converter-to-flexplate bolts. Use a C-clamp or other brace to prevent the torque converter from falling. Also mark the location of the torque converter in relation to the flexplate.

Engine Disassembly and Inspection

Raise the engine and position it next to an engine stand **(Figure 10–18)**. In most cases, the flywheel or flexplate must be removed to mount the engine on its stand. Mark the position of the flywheel on the crankshaft. This aids the reassembly of the engine. To do this, loosen—but do not remove—the attaching bolts in a "star" pattern to reduce the chance of distorting the flywheel. At times, the flywheel will turn with the wrench as the bolts are being loosened. When this happens, a flywheel lock should be used to stop the flywheel from turning. Once all of the bolts are loosened, take hold of the flywheel while removing the bolts. The flywheel can be quite heavy and if it falls, you can be injured or the flywheel can be damaged. The flywheel for manual transmissions should be inspected for possible damage and for signs of clutch problems. Place the flywheel on a flat surface.

Mount the engine to the stand. Most stands use a plate with several holes or adjustable arms. The engine must be supported by at least four bolts that fit solidly into it. The engine should be positioned so that its center is in the middle of the engine stand's adapter plate.

Once the engine is securely mounted to the engine stand, remove the sling or lifting chain. The engine can now be disassembled and cleaned. Always refer to the service information before you start to disassemble an engine.

Slowly disassemble the engine and visually inspect each part for any signs of damage. Look for excessive wear on the moving parts. Check all parts for signs of overheating, unusual wear, and chips. Look for signs of gasket and seal leakage.

Cylinder Head Removal

The first step in disassembly of an engine is normally the removal of the intake and exhaust manifolds. On some inline engines, the intake and exhaust manifolds

Courtesy of SPX Service Solutions.

FIGURE 10–18 A typical engine stand.

USING SERVICE INFORMATION

Look up the specific model car and engine prior to disassembling the engine.

are often removed as an assembly. Note that intake manifold bolts often need to be removed in reverse torque sequence to prevent warping of the manifold.

To start cylinder head removal, remove the valve cover or covers and disassemble the rocker arm components **(Figure 10–19)** according to the guidelines given by the manufacturer. Check the rocker area for sludge. Excessive buildup can indicate a poor maintenance schedule and is a signal to look for wear on other components.

On OHC engines, the timing cover must be removed. Under the cover is the timing belt or chain and sprockets. In the service information, there will be a description of the type and location of the timing marks on the crankshaft and camshaft sprockets. If possible, rotate the crankshaft to check the alignment of the sprockets. If the shafts are not aligned, make note of this for later reference. The valves will hit the pistons on some engines when the timing belt or chain slips, skips, or breaks. These engines are commonly called interference engines. When the valves hit the piston, they will bend. The valves in **freewheeling engines** will not hit the piston when valve timing is off. However, the keys and keyways in the camshaft sprocket may be damaged.

Interference engines typically have a decal on the cam cover that states the belt must be changed at a particular mileage interval. Potential valve and/or piston damage is the reason why timing belt replacement is recommended.

The belt or chain must be removed before removing the cylinder head. Locate and move the belt's tensioner pulley to remove its tension on the belt. Slip the belt off the camshaft and crankshaft sprockets, if possible.

When removing the cylinder head, keep the pushrods and rocker arms or rocker arm assemblies in exact order. Use an organizing tray or label the parts with a felt-tipped marker to keep them together and labeled accurately. This type of organization greatly aids in diagnosing valve-related problems. Remove the lifters from the block and place them in the order they were installed.

SHOP TALK

It is important to let an aluminum cylinder head cool before removing it.

FIGURE 10–19 Remove the valve cover and disassemble the rocker arm components. Check the rocker area for sludge. Keep the rocker arms or rocker arm assemblies in the order they were installed.

The cylinder head bolts are loosened one or two turns each, following the pattern specified by the manufacturer **(Figure 10–20)**. The sequence is typically the opposite of the tightening sequence. If there is no specified procedure, the bolts ought to be loosened one or two turns, beginning at the ends and working toward the center. This prevents the distortion that can occur if bolts are all loosened at once. The bolts are then removed and the cylinder head can be lifted off.

Once the head is removed, inspect the head gasket. The head gasket should be saved to compare with the new head gasket during reassembly. Set the cylinder head(s) on cardboard or another soft surface to prevent damage to the sealing surfaces.

GO TO

Chapter 12 for the procedures for disassembling and servicing cylinder heads.

The water pump is normally mounted to the front of the engine. Unbolt and remove it. Rotate the engine block, on its stand, so the oil pan is up. Remove the pan's attaching bolts. Then lift the oil

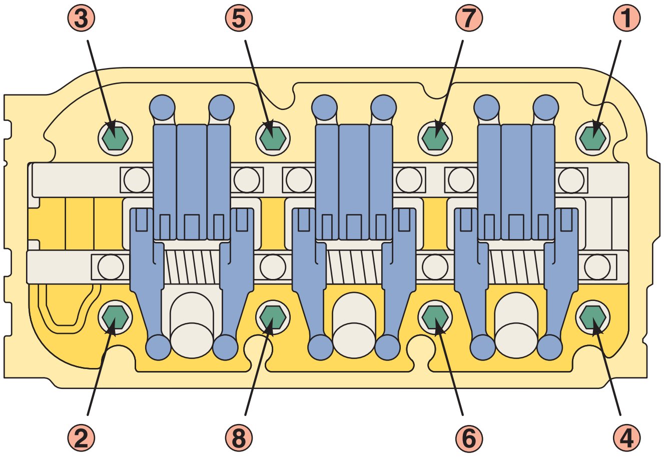


FIGURE 10-20 When loosening cylinder head bolts, follow the sequence given by the manufacturer.

FIGURE 10-21 A major buildup of sludge on the bottom of this oil pan.

pan off. Once the pan is removed, look inside for metal shavings and sludge **(Figure 10–21)**. Both of these are indications of problems.

GO TO Chapter 11 for the procedures for disassembling and servicing engine short blocks.

Cleaning Engine Parts

After the engine has been disassembled, its parts should be thoroughly cleaned. The cleaning method depends on the component and the type of equipment available. An incorrect cleaning method or agent can often be more harmful than no cleaning at all. For example, using caustic soda to clean aluminum parts will dissolve the part.

Warning! Always wear the appropriate eye protection and gloves when working with cleaning solvents.

Types of Contaminants

Being able to recognize the type of dirt you are to clean will save you time and effort. Basically there are four types of dirt.

Water-Soluble Soils The easiest dirt to clean is **water-soluble** soils, meaning those that will dissolve in water, which includes dirt, dust, and mud.

Organic Soils **Organic soils** Contain carbon and cannot be effectively removed with plain water. There are three distinct groupings of organic soils:

- Petroleum by-products derived from crude oil, including tar, road oil, engine oil, gasoline, diesel fuel, grease, and engine oil additives
- By-products of combustion, including carbon, varnish, gum, and sludge
- Coatings, including such items as rust-proofing materials, gasket sealers and cements, paints, waxes, and sound-deadener coatings

Rust **Rust** is the result of a chemical reaction that takes place when iron and steel are exposed to oxygen and moisture. Corrosion, like rust, results from a similar chemical reaction between oxygen and metal containing aluminum. If left unchecked, both rust and corrosion can physically destroy metal parts. In addition to metal destruction, rust also acts to insulate and prevent proper heat transfer inside the cooling system.

Scale When water containing mineral deposits is heated, suspended minerals and impurities tend to dissolve, settle out, and attach to the surrounding hot metal surfaces. This buildup inside the cooling system is known as **scale**. Over a period of time, scale can accumulate to the extent that passages become blocked, cooling efficiency is compromised, and metal parts start to deteriorate.

Cleaning with Chemicals

There are three basic processes for cleaning automotive engine parts. Chemical cleaning uses chemical action to remove dirt, grease, scale, paint, and/or rust.

> Caution! When working with any type of cleaning solvent or chemical, be sure to wear protective gloves and goggles and work in a well-ventilated area. Prolonged immersion of your hands in a solvent can cause a burning sensation. In some cases a skin rash might develop. Read the labels on the solvent container(s) carefully before mixing or using them.

Chlorinated hydrocarbons and mineral spirits may have some health risks associated with their use through skin exposure and inhalation of vapors. Hydrocarbon cleaning solvents are also flammable. The use of water-based nontoxic chemicals can eliminate such risks.

> Warning! Prior to using any chemical, read through all of the information given on the safety data sheet (SDS) or the Canadian workplace hazardous materials information systems sheets (WHMIS) for that chemical. Become aware of the health hazards presented by the various chemicals.

Hydrocarbon solvents are labeled hazardous or toxic and require special handling and disposal procedures. Many water-based cleaning solutions are biodegradable. Once the cleaning solution has become contaminated with grease and grime, it too becomes a hazardous or toxic waste that can be subject to the same disposal rules as a hydrocarbon solvent.

Chemical Cleaning Machines

Parts Washers Parts washers (often called solvent tanks) are one of the most widely used and inexpensive methods of removing grease, oil, and dirt from metal surfaces. A typical parts washer **(Figure 10–22)** has a tank that holds the solvent and some method of applying the solvent. These methods include soaking, soaking and agitation, solvent streams, and spray gun applicators.

> Caution! Care needs to be taken with alloy blocks with sleeves or liners. The different metals react differently to chemicals. Check the service information before using a cleaning solution on these parts. The wrong chemical can cause damage to the block and/or sleeves.

FIGURE 10–22 A typical parts washer.

Soak Tanks There are two types of soak tanks: cold and hot. Cold soak tanks are commonly used to clean carburetors, throttle bodies, and aluminum parts. A typical cold soak unit has a basket to hold the parts to be cleaned. After soaking with or without gentle agitation is complete, the parts are removed, flushed with water, and blown dry with compressed air.

Cleaning time is short, about 20 to 30 minutes, when the chemical cleaner is new. The time becomes progressively longer as the chemical ages. Agitation by raising and lowering the basket will reduce the soak period to about 10 minutes. Some more elaborate tanks are agitated automatically.

Hot soak tanks are actually heated cold tanks. The source of heat is electricity, natural gas, or propane. The solution inside the hot tanks usually ranges from 160 °F to 200 °F (71 °C to 93 °C). Most tanks are generally large enough to hold an entire engine block and its related parts.

Hot tanks use a simple immersion process that relies on a heated chemical to lift the grease and grime off the surface. Agitation may also be used to speed up the job. Agitation helps shake the grime loose and also helps the liquid penetrate blind passageways and crevices in the part. Generally speaking, it takes one to several hours to soak most parts clean.

Hot Spray Tanks The hot spray tank works like a large automatic dishwasher and removes organic and rust soils from a variety of automotive parts. As

SHOP TALK Caustic soda, also known as sodium hydroxide, can be a very dangerous irritant to the eyes, skin, and mucous membranes. These chemicals should be used and handled with care. It is also considered a hazardous waste material and must be disposed of in accordance with EPA guidelines.

with the hot soak method, spray washers soak the parts, but they also have the benefit of moderate pressure cleaning.

Using a hot jet spray washer can cut cleaning time to less than 10 minutes. Normally, a strong soap solution is used as the cleaning agent. The speed of this system, along with lower operating costs, makes it popular with many shop owners.

Spray washers are often used to preclean engine parts prior to disassembly. A pass-through spray washer is fully automatic. Once the parts are loaded, the cabinet prevents runoff from going down the drain or onto the ground (which is not permitted in many areas because of local waste disposal regulations). Spray washers are also useful for post-machining cleanup to remove machine oils and metal chips.

Thermal Cleaning

Thermal cleaning relies on heat to bake off or oxidize dirt and other contaminants. Thermal cleaning ovens especially the pyrolytic type, have become increasingly popular. The main advantage of thermal cleaning is a total reduction of all oils and grease on and in blocks, heads, and other parts. The high temperature inside the oven (generally 650 °F to 800 °F (343 °C to 426 °C)) oxidizes the grease and oil, leaving behind a dry, powdery ash on the parts. The ash must then be removed by shot blasting or washing. The parts come out dry, which makes subsequent cleanup with shot blast or glass beads easier because the shot will not stick.

One of the major attractions of cleaning ovens is that they offer a more environmentally acceptable process than chemical cleaning. But although there is no solvent or sludge to worry about with an oven, the ash residue that comes off the cleaned parts must still be handled according to local disposal regulations.

SHOP TALK A slow cooling rate is recommended to prevent distortion that could be caused by unequal cooling rates within complex castings.

Abrasive Cleaners

Another way to clean parts involves the use of abrasives. Most abrasive cleaning machines are used in conjunction with other cleaning processes rather than as a primary cleaning process itself.

Cleaning by Hand Some manual cleaning is inevitable. Heavy buildups of grease and/or carbon should initially be removed by scraping or wire brushing. Cleaning aluminum and other soft metals with either technique should be done with extreme care, especially while using a steel scraper or brush. Scrapers are used to remove old gasket material and heavy sludge. Power tools with a small sanding disc (normally emery cloth) are available **(Figure 10–23)**. These are designed to remove all soft materials without damaging the hard metal surface. After the item has been scraped, an additional cleaning method is used to finalize cleaning.

Carbon can be removed with a handheld wire brush or a wire wheel driven by an electric or air drill motor **(Figure 10–24)**. Moving the wire wheel in a light circular motion against the carbon helps to crack and dislodge the carbon.

Wire brushes are used to clean the inside of oil and coolant galleries. The brushes are soaked in a cleaning solvent and then passed through the passages in the block. To do this, the gallery plugs must be removed **(Figure 10–25)**.

Abrasive Blaster Compressed air shot and grit blasters are best used on parts that will be machined after they have been cleaned. Two basic types of media are available: shot and grit. Shot is round; grit

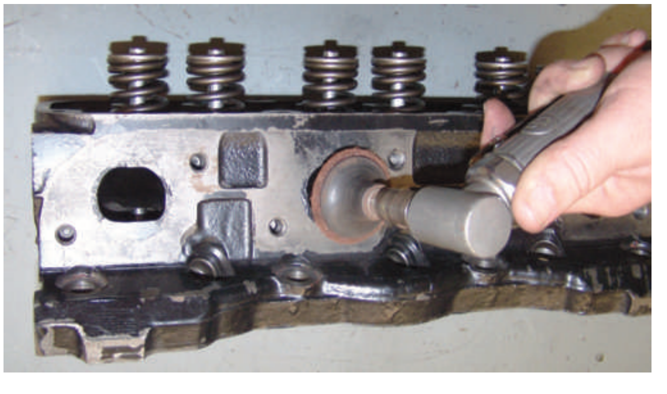


FIGURE 10–23 Using a power scraper pad will prevent any metal from being removed.

FIGURE 10–24 Carbon can be removed with a wire wheel driven by an electric or air drill motor.

FIGURE 10–25 It is often necessary to remove the gallery plugs and hand clean the oil galleries.

is angular in shape. Parts must be dry and grease-free when they go into an abrasive blast machine. Otherwise, the shot or beads will stick. **Peening** is a process of hammering on the surface. This packs the molecules tighter to increase the part's resistance to fatigue and stress. Steel shot is normally used with airless wheel blast equipment, which hurls the shot at the part by the centrifugal force of the spinning wheel. Glass beads are blown through a nozzle by compressed air in an enclosure **(Figure 10–26)**.

Grit is primarily used for aggressive cleaning or on surfaces that need to be etched to improve paint

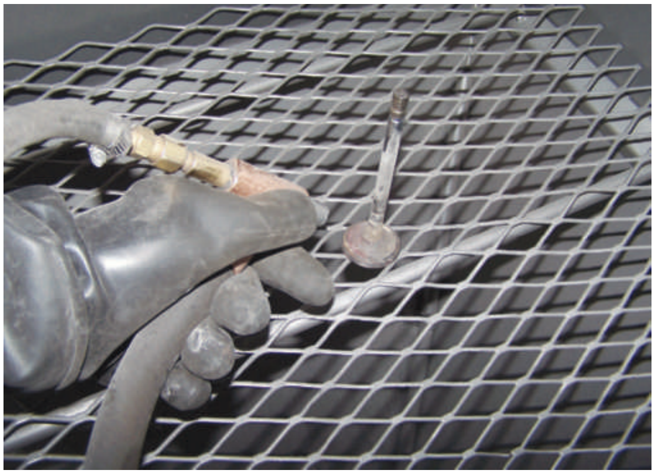


FIGURE 10–26 Using a blast nozzle to clean the backside of a valve.

adhesion. However, it removes metal, which can lead to some changes in tolerances. Grit blasting also leaves behind pits in the surface into which pollutants and blast residue can settle. This leads to stress corrosion unless the surface is painted or treated. These tiny crevices can also form surface stresses in the metal, which can lead to cracking in highly loaded parts. Steel and aluminum oxide are the two most common types of grit.

Parts Tumbler A cleaning alternative that can save considerable labor when cleaning small parts such as engine valves is a tumbler. Various cleaning media can be used in a tumbler to scrub the parts. This saves considerable hand labor and eliminates dust.

Vibratory Cleaning Shakers, as they are frequently called, use a vibrating tub filled with ceramic, steel, porcelain, or aluminum abrasive to scrub parts. Most shakers have a tub filled with solvent to help loosen and flush away the dirt and grime. The solvent drains out the bottom and is filtered to remove the sludge.

Alternative Cleaning Methods

Three of the most popular alternatives to traditional chemical cleaning systems are ultrasonic cleaning, citrus chemicals, and salt baths.

Ultrasonic Cleaning This cleaning process has been used for a number of years to clean small parts like jewelry, dentures, and medical instruments. Recently, however, the use of larger ultrasonic units has expanded into small engine parts cleaning. **Ultrasonic cleaning (Figure 10–27)** utilizes high-frequency sound waves to create microscopic bubbles that burst into

FIGURE 10–27 An ultrasonic parts cleaner.

energy to loosen soil from parts. Because the tiny bubbles do all the work, the chemical content of the cleaning solution is minimized, making waste disposal less of a problem. At the present time, however, the initial cost and handling capacity of ultrasonic equipment is its major disadvantage.

Citrus Chemicals Some chemical producers have citrus-based cleaning chemicals available to serve as a replacement for hazardous solvents and alkaline-based chemicals. Because of their citrus origin, these chemicals are safer to handle, easier to dispose of, and even smell good.

Salt Bath The salt bath is a unique process that uses high-temperature molten salt to dissolve organic materials, including carbon, grease, oil, dirt, paint, and some gaskets. For cast iron and steel, the salt bath operates at about 700 °F to 850 °F (371 °C to 454 °C). For aluminum or combinations of aluminum and iron, a different salt solution is used at a lower temperature (about 600 °F (315 °C)). The contaminants precipitate out of the solution and sink to the bottom of the tank, where they must be removed periodically. Cycling times with a salt bath are fairly quick, averaging 20 to 30 minutes. Like a hot tank, the temperature of the salt bath is maintained continuously.

Crack Detection

Once engine parts have been cleaned, everything should be carefully inspected. This inspection should include a check for cracks, especially in the engine block and cylinder head. If cracks in the metal casting are discovered during the inspection, they should be repaired or the part replaced.

Cracks in metal castings are the result of stress or strain on a section of the casting. This stress finds a weak point in the casting and causes it to distort or separate at that point. These stresses can be caused by the following:

- Pressure or temperature changes during the casting process can cause internal material structure defects, inclusion, or voids.
- Fatigue may result from fluctuating or repeated stress cycles. It might begin as small cracks and progress to larger ones due to the stress.
- Flexing of the metal may result because of its lack of rigidity.
- Impact damage may occur by a solid, hard object hitting a component.
- Constant impacting of a valve against a hardened seat may produce vibrations that could possibly lead to fracturing a thin-walled casting.
- Chilling of a hot engine by a sudden rush of cold water or air over it.
- Excessive overheating is due to improper operation of an engine system.

Methods

Cracks can be found by visual inspection; however, many are not easily seen. Therefore, engine rebuilders use special equipment to detect cracks, especially if there is reason to suspect a crack.

Pressure Checks Pressure checking a cylinder block or head is done in the same way as a tire is checked for leaks. All of the coolant passages are plugged with rubber stoppers or gaskets. Compressed air is injected into a water jacket and the point of air entry is sealed. The block or head is then submerged into water. Bubbles will form in the water if there is a leak. The spot where the bubbles are forming identifies the location of the leak.

Magnetic Checks Magnetic particle inspection (MPI) uses a permanent or electromagnet to create a magnetic field in a cast iron part **(Figure 10–28)**. When the legs of the tool are placed on the metal, the magnetic field travels through the metal. Iron filings are sprinkled in the surface to detect a secondary magnetic field resulting from a crack **(Figure 10–29)**. Because the secondary magnetic field will not form if the crack is in the same direction as the magnet, the magnet must be rotated and the metal checked in both directions.

Dye Penetrant Another common way to detect cracks relies on the use of three separate chemicals:

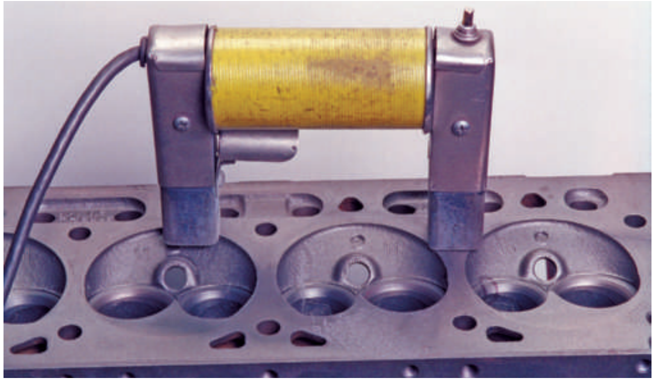


FIGURE 10-28 MPI testing passes a magnetic field through the iron item being checked.

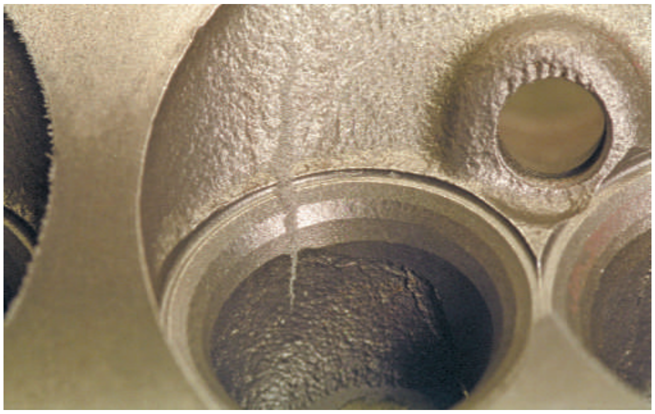


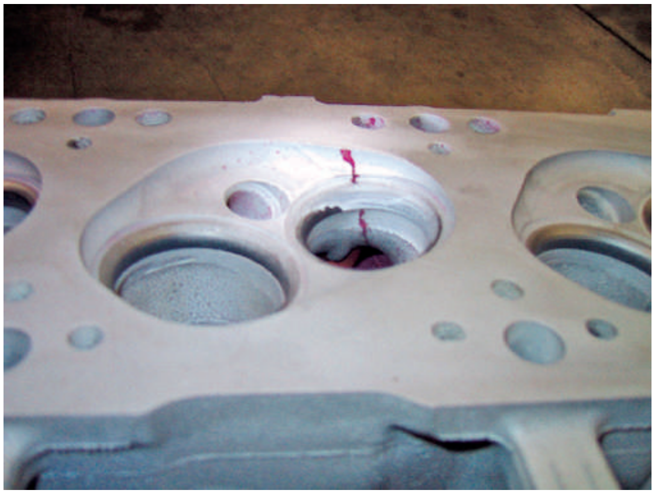
FIGURE 10-29 A crack will cause two opposing magnetic poles to form on each side; the iron filings used with the magnet will show these fields.

penetrant, cleaner, and developer. Before checking a part, it must be clean and dry. This check must be done following this sequence:

1. Spray or brush the penetrant onto the surface.
2. Wait 5 minutes.
3. Spray the cleaner onto a clean cloth.
4. Wipe off all visible penetrant.
5. Spray the developer on the tested area.
6. Wait until the developer is totally dry.
7. Inspect the area. Cracks will appear as a red line **(Figure 10–30)**.

Crack Repair

If a crack is found, a decision must be made as to whether the part should be replaced or repaired. This decision should be based on the cost of repair as well as any other repair that the part may need. Further inspection of the cylinder block and head and the service and repair procedures for each are covered in the Chapters 11 and 12.



Courtesy of LOCK-N-STITCH Inc.

FIGURE 10-30 Cracks appear as red lines when a dye penetrant is used.

In-Vehicle Engine Service

Some services on an engine can be performed with the engine still in a vehicle. Some of these are simpler with the engine removed. However if that is not necessary, you can save time by not removing the engine.

Many of the procedures for performing under-the-hood services involve the same steps as when the engine is removed. Also, many other in-vehicle services are covered in the appropriate section of this book.

Oil Pan Gasket

Often a damaged oil pan gasket is the source of oil leaks. Replacing the gasket can be done with the engine in the vehicle. The procedure for doing this varies with the vehicle model, so always refer to the service information before attempting to correct this type of leak. The basic procedure is different for RWD and FWD vehicles.

RWD Vehicles The typical procedure for removing the oil pan on a RWD vehicle begins with raising the vehicle. With the vehicle raised and jack stands in place, disconnect the battery and remove the starter. Drain the engine's oil, then remove the cross member or any other parts that get in the way of removing the oil pan. Loosen and remove the attaching bolts for the pan and carefully lower it.

Once the pan is removed, clean the sealing surfaces on the pan and the engine block. In most cases the manufacturer will recommend a way to

SHOP TALK

You should wait at least 30 minutes after you have installed the oil pan before you add oil to the engine; this allows ample time for the sealant to set and seal.

remove the sealant used to seal the pan. However, never use metal scrapers, wire brushes, or other abrasives to clean the sealing surfaces.

After the pan and block have been cleaned, place the new gasket **(Figure 10–31)** on the pan or apply silicone sealant to the oil pan sealing areas. On some engines, the rear seal for the pan is a separate piece and it should be installed before fitting the pan against the engine block.

Once the pan is in position, insert the attaching bolts and hand tighten them. Once all of the bolts are installed, tighten them to specifications. Now install the oil pan drain plug, lower the vehicle, and fill the engine with clean engine oil.

FWD Vehicles The procedure for replacing an oil pan gasket on a FWD vehicle is similar to the above, but some additional steps should be followed. The initial steps are completed from under the hood. These include disconnecting the battery and A/C compressor electrical connector, and removing the drive belt, radiator, and A/C compressor.

FIGURE 10–31 A typical oil pan gasket.

After the vehicle has been raised, the engine's oil should be drained and all splash shields under the engine should be removed. Remove or disconnect anything that may get in the way of dropping the oil pan. Once the area is clear, remove the oil pan bolts and the oil pan.

When the oil pan is away from the engine, clean the sealing surfaces on the pan and the engine block. Then apply the appropriate sealer to the pan and install it. Tighten the retaining bolts to specifications. Then continue to install the pan in the reverse order of its removal procedure. Make sure you refill the engine with the proper oil.

Vibration Damper

Replacing an engine's vibration (harmonic) damper can be a bit complex, depending on the engine and its placement.

Longitudinal Engines The following is a typical procedure for replacing a damper on an engine that is positioned longitudinally. Remove the drive belt and then hold the crankshaft pulley and remove the bolt in the center of the pulley. When the bolt is removed, the pulley may easily pull off with its washer. If the pulley does not easily pull off, you will need to use a crankshaft pulley puller. Depending on the engine, a steering wheel puller may be used or a special puller may be required. To use a steering wheel-type puller, remove the bolts holding the drive belt pulley to the crankshaft pulley. Install the puller to the crankshaft pulley and tighten the puller's center bolt against the crankshaft to remove the pulley.

Clean the pulley's mating surface on the crankshaft, bolt, and washer. It is normally recommended that the bolt be replaced. The new bolt should be coated with engine oil before it is installed.

Install the new pulley onto the crankshaft. Make sure it is properly aligned. The alignment procedure can be found in the service information. Insert the washer and center bolt and hand tighten the bolt. Hold the pulley and tighten the bolt to specifications. This is typically a torque-to-yield bolt. So, make sure it is tightened to specifications and further tightened to the specified angle.

Now a new drive belt can be installed along with the right front wheel.

Transverse Engines Begin by disconnecting the battery. Then remove the accessory drive belt. Depending on the vehicle, you may need to remove

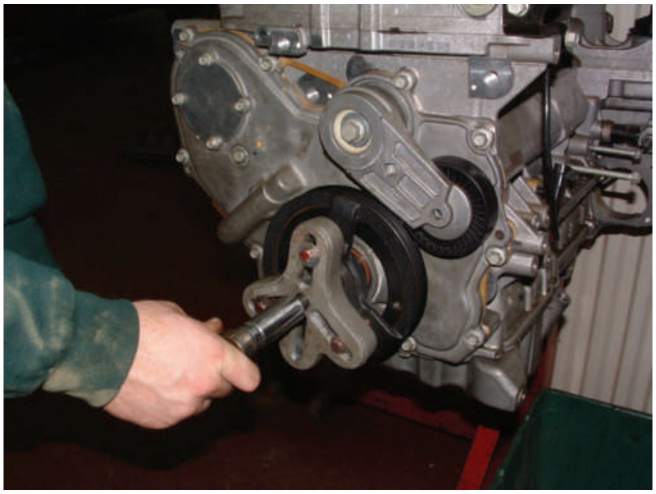


FIGURE 10–32 Using a puller to remove a crankshaft pulley.

the lower engine cover at the wheel well to gain access to the crank pulley. While holding the balancer, loosen and remove its center bolt. (It may be necessary to use a flywheel locking tool or special crank pulley tool to stop the engine from rotating while attempting to remove the center bolt.) Now pull the balancer assembly off the end of the crankshaft with a suitable puller **(Figure 10–32)**. Make sure you do not damage the crankshaft while doing this. Also check the woodruff key in the crankshaft for damage. If it is damaged, replace it.

Discard the old bolt and lubricate the new one, the front oil seal, and the seal contact area on the balancer. Apply sealant to the woodruff key slot on the pulley. Then install the new pulley within 4 minutes and push it in as far as it can go. Using the appropriate tool, fully seat the pulley onto the crankshaft. Install and tighten the bolt to specifications. This is typically a torque-to-yield bolt. Therefore, make sure it is tightened to specifications and further tightened to the specified angle.

If a flywheel locking tool was needed, remove it and install the flywheel cover plate. Then reinstall the drive belt and the cooling fan and shroud. Now, reconnect the battery.

Cylinder Head

Removing a cylinder head on an engine that is still in the vehicle follows many of the same steps as removing it when the engine is on an engine stand. The exact procedure varies with the vehicle and the type of engine. Below is an example of performing this service on a late-model V engine and an in-line engine. These procedures include the removal and installation of many parts that may require service without the need for removing the head. Before beginning, connect a scan tool to the data link connecter (DLC), and check the engine's coolant temperature. Wait until the temperature is below 100 °F (38 °C) before proceeding. This is done to prevent damage to the intake manifold and cylinder head(s). Once the temperature is acceptable, remove the intake manifold.

Removal on All Engines

The procedures begin with the same steps. Drain the engine's oil. Then remove the cylinder block drain plugs and drain the coolant. Reinstall the cylinder block drain plugs. Disconnect the battery ground cable; wait at least 3 minutes before beginning work.

Mark all electrical connectors and wire harness clamps, so you know their original location and disconnect them from the intake manifold and cylinder head.

Remove the intake air duct, air cleaner outlet pipe, and the air cleaner assembly. Then remove the accessory drive belt.

Remove the upper radiator hose bracket, valve covers, front engine cover, and all spark plugs. Disconnect the evaporative emission canister hose, the brake booster vacuum hose, and the positive crankcase ventilation hose. Now, disconnect the vacuum lines to the EGR valve or EGR module. Remove the ignition coil assemblies.

Disconnect the upper radiator hose and heater hoses from the cylinder head. Disconnect the water bypass hoses, and then plug them. Remove the thermostat housing.

Relieve the fuel pressure at the fuel rail and disconnect the fuel supply hose. Disconnect the fuel feed hose and remove the fuel rail.

V-Type Engines

Some V-type engines have an upper and lower intake manifold, these are serviced individually. Remove the bolts that retain the upper manifold and then pull it away from the engine. Inspect the manifold for damage and clean the sealing surface. Then, unbolt the lower intake manifold **(Figure 10–33)** and remove its gasket and front and rear seals. Now, remove the exhaust manifold from the cylinder head you are servicing.

For some OHC engines, the camshaft roller followers should be removed next. To do this, use the appropriate tool to compress the valve springs so that the followers can be removed. Also, make sure

FIGURE 10-33 A lower intake manifold.

the lobe on the camshaft is away from the follower while you are attempting to remove it. Make sure to label the location of each follower so that they can be installed in their original location. On OHV engines, loosen the rocker arms and remove the push rods. Keep the push rods in order so that they are reinstalled correctly.

Rotate the crankshaft until the timing marks on the camshaft sprockets are at the specified position. Now remove the timing chain or belt tensioning system from the timing chains or belts. Remove the timing chains or belts.

Remove the cylinder head bolts according to the specified order. Then, pull off the cylinder head. The head bolts are tightened-to-yield and cannot be reused, so obtain new bolts. You may need to gently pry on the cylinder head to remove it from the block. Remove the head and place it on cardboard or another soft surface to prevent damage to the mating surfaces.

In-Line Engines The following steps should be taken after the steps for all engines has been completed. Remove the intake manifold. Turn the crankshaft so that the crank and cam are set to number 1 cylinder TDC compression stroke and make sure the timing marks are properly aligned. Then, remove the camshaft timing chain or belt. Now, remove the cylinder head bolts and the cylinder head.

> Caution! Inspect the sealing bead for hydraulic tensioners. If there are cracks, tears, or a separation of the tensioner's seal, the tensioner must be replaced. Oil leaking from the tensioner can decrease the pressure applied by the tensioner, resulting in timing chain noise.

Installation for All Engines

Clean the cylinder head-to-block mating surfaces. Use a plastic scraper to remove silicone or gasket material. It may be necessary to use silicone gasket remover to totally clean the sealing surfaces. Use a straightedge and feeler gauge set to check the flatness of the sealing surfaces of the cylinder head and block.

Place the new head gasket(s) over the locating dowels in the block or cylinder head **(Figure 10–34)**. Then carefully lower the cylinder head in place. After installing the cylinder head bolts, tighten them in the specified sequence and to the specified torque.

V-Type Engines Properly position and install the crankshaft sprocket. Then position the right and left timing chain guides. Then install and tighten their retaining bolts. Now align the right and left camshaft sprockets according to specifications. Rotate the crankshaft so that piston number 1 is at TDC. Install the inner timing chain or belt on the crankshaft sprocket, making sure it is properly aligned with the timing marks on the sprocket. Install the chain tensioner for that timing chain. Tighten the tensioner to specifications. Repeat the same procedure for installing the outer timing chain. For engines with a timing belt, make sure the crank and cams are properly set and install the belt. Apply tension to the belt and rotate the crankshaft two complete revolutions and recheck all timing mark alignments.

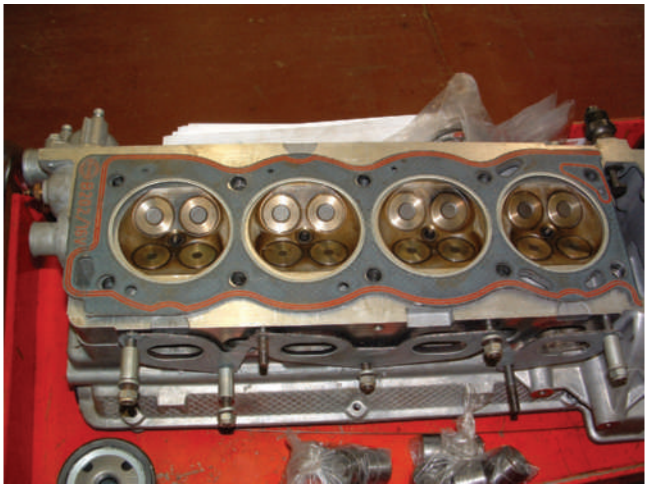


FIGURE 10-34 To make sure a new head gasket is the correct one for the engine, place it over the cylinder block or head.

SHOP TALK

On some engines, the plunger of the chain tensioner must be compressed before it can be installed. To do this, the unit is placed in a vise to squeeze the plunger into the tensioner. After the plunger is compressed, a retaining clip is installed to hold the plunger in place. Once the tensioner is installed, the retaining clip is removed.

For engines with timing chains, position a new engine front cover gasket onto the cover, then install the cover. With clean engine oil, lubricate and install new seals for the front cover and crankshaft. Now install the camshaft position sensors. Put some silicone gasket and sealant material into the woodruff key slot in the crankshaft pulley. Then, using the appropriate tool, install the pulley and tighten it according to specifications.

Install the accessory drive belt idler pulleys and the accessory drive belt tensioner. Compress the valve springs and install the camshaft roller followers. Make sure the followers are reinstalled in their original locations.

Install the intake manifold. If a V-type engine has an upper and lower intake manifold, position a new gasket and front and rear seals for the lower manifold. Then, install the manifold's retaining bolts and tighten them to specifications. Now, do the same for the upper manifold.

Install the wiring harness brackets and connect the electrical connectors to the intake manifold. Now connect the PCV, brake booster, and EGR hoses to the manifold. Install the ignition coil assemblies. Inspect and clean the sealing surfaces for the valve covers and install them tightening the bolts to specifications. Now install the exhaust manifold gaskets and exhaust manifolds.

In-Line Engines Position the crankshaft so that piston number 1 is at TDC. Then align the camshaft sprocket(s) according to specifications. Now install the timing chain or belt and tensioner. If necessary, adjust the valve clearance. Install the intake manifold with new gaskets, making sure its bolts are tightened to specifications. Install the wiring harness clamps and hose brackets to the manifold.

Install the cylinder head cover, thermostat housing, and the ignition coils. Connect the engine's wiring harness, and install the harness clamps to the cylinder head. Connect all disconnected coolant and heater hoses.

All Cylinder Heads Connect all disconnected sensor connections. Install the fuel rail(s) and connect the fuel feed hose to the rail. Now connect all remaining disconnected vacuum lines and install the air cleaner assembly. Install the drive belt(s) and reconnect the negative battery cable. Turn the ignition switch to the ON position to allow the fuel pump to run for about 2 seconds. Then check the fuel connections for signs of leakage. Repeat this two or more times. Correct all fuel leaks before proceeding.

Now, refill the engine's cooling system with coolant, and bleed the air from the system. Carefully check all connections for leaks. The last step is performing the necessary re-learn procedures, these vary with the manufacturer and engine.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2010	**Make:** Chevrolet	**Model:** Equinox	**Mileage:** 89,110	**RO:** 14484
Concern:	Customer states engine is leaking oil.			
History:	Oil was changed a week ago.			
After reviewing the vehicle history, the technician inspected the vehicle and confirmed the oil leak. Noting that the leak was coming from the oil drain plug, the technician tried to tighten the plug. The plug was noticeably loose and would not tighten.				
Cause:	Confirmed oil leak, found stripped drain plug threads.			
Correction:	Replaced oil pan to correct stripped drain plug threads. Refilled with oil.			

KEY TERMS

Freewheeling engines
Organic soils
Peening
Rust
Scale
Ultrasonic cleaning
Water soluble

SUMMARY

- When preparing an engine for removal and disassembly, it is important to always follow the specific service information procedures for the particular vehicle being worked on.
- A hoist and chain are needed to lift an engine out of its compartment. Mount the engine to an engine stand with a minimum of four bolts, or set it securely on blocks.
- While an engine teardown of both the cylinder head and block is a relatively standard procedure, exact details vary among engine types and styles. The vehicle's service information should be considered as the final word.
- An understanding of specific soil types can save time and effort during the engine cleaning process. The main categories of contaminants include water-soluble and organic soils, rust, and scale.
- Protective gloves and goggles should be worn when working with any type of cleaning solvent or chemical. Read the label carefully before using as well as all of the information provided on material safety data sheets.
- Parts washers, or solvent tanks, are a popular and inexpensive means of cleaning the metal surfaces of many automotive components and engine parts. Regardless of the type of solvent used, it usually requires some brushing, scraping, or agitation to increase the cleaning effectiveness.
- Cold soak tanks are used to clean carburetors, throttle bodies, and aluminum parts. Hot soak tanks, which can accommodate an entire engine block, use a heated cleaning solution to boil out dirt. Hot heat spray washers have the added benefit of moderate pressure cleaning.
- Alternatives to caustic chemical cleaning have emerged in recent years, including ultrasonic cleaning, salt baths, and citrus chemical cleaning. These methods are all growing in popularity.
- The main advantage of thermal cleaning is its total reduction of all oils and grease. The high temperatures inside the oven leave a dry, powdery ash on the parts. This is then removed by shot blasting or washing.
- Steel shot and glass beads are used for cleaning operations where etching or material removal is not desired. Grit, the other type of abrasive blaster, is used for more aggressive cleaning jobs.
- Some degree of manual cleaning is necessary in any engine rebuilding job. Very fine abrasive paper should be used to remove surface irregularities. A handheld or power wire brush is also helpful, though it can be time consuming.
- There are three common methods for detecting cracks in the metal casting of engine parts: using a magnet and magnetic powder (iron filings), using penetrant dye (especially for aluminum heads and blocks), and pressuring with air.
- Some engine repairs can be done while the engine is still in the vehicle. The procedures for doing these are very similar to performing the same service with the engine on an engine stand.

REVIEW QUESTIONS

Short Answer

1. What should be worn when working with any type of cleaning solvent or chemical?
2. Why should a memory saver be installed before disconnecting a vehicle's battery?

True or False

1. *True or False?* Many engines in FWD vehicles must be removed with the transmission still attached.
2. *True or False?* The first step in removing an engine is usually the removal of the intake and exhaust manifolds.
3. *True or False?* On many FWD vehicles, the suspension system must be partially disassembled to remove the radiator.

Multiple Choice

1. What is the best way to lift a vehicle when preparing to remove an engine?
   a. Frame contact hoist
   b. Drive on lift
   c. Hydraulic jack and safety stands
   d. Engine hoist

2. Which of the following statements is *not* true?
   a. When the engine is removed through the bottom of the vehicle, use an engine cradle and dolly to support the engine.
   b. If the manufacturer recommends engine removal through the hood opening, use an engine hoist.
   c. Regardless of the method of removal, the engine and transaxle in a FWD vehicle are usually removed as a unit.
   d. When removing an engine from a RWD vehicle, suspension disassembly is often required.
3. The buildup of minerals and deposits inside the cooling system is called ___.
   a. organic soil
   b. scale
   c. rust
   d. grime
4. Hydrocarbon solvents are ___ .
   a. flammable
   b. toxic
   c. both a and b
   d. neither a nor b
5. Which cleaning method uses high-frequency sound waves to create microscopic bubbles that loosen dirt from parts?
   a. Ultrasonic
   b. Salt bath
   c. Thermal
   d. Caustic
6. Parts must be ___ when they go into an abrasive blast machine.
   a. wet
   b. dry
   c. grease-free
   d. both b and c
7. An engine block should be mounted to an engine stand using a minimum of ___ bolts.
   a. four
   b. six
   c. three
   d. five
8. Which of the following is *not* considered part of the organic soil grouping?
   a. Petroleum by-products derived from crude oil, including tar, road oil, engine oil, gasoline, diesel fuel, grease, and engine oil additives
   b. Rust that is a product of coolant and aluminum
   c. By-products of combustion, including carbon, varnish, gum, and sludge
   d. Coatings, including such items as rust-proofing materials, gasket sealers and cements, paints, waxes, and sound-deadener coatings
9. Which of the following statements is *not* true about thermal cleaning?
   a. The main advantage of thermal cleaning is a total reduction of all oils and grease on and in blocks, heads, and other parts.
   b. After a part has been thermally cleaned, it should be submerged in water to cool it quickly.
   c. Thermal cleaning leaves behind a dry, powdery ash on the parts.
   d. After a part has been thermally cleaned, it should be washed or blasted with shot.
10. Which of the following is *not* a common way to identify the location of cracks in the engine block or cylinder head?
    a. Pressure checks
    b. Vacuum test
    c. Magnetic particle inspection
    d. Penetrant dye

ASE-STYLE REVIEW QUESTIONS

1. While working on an engine with an excessive amount of sludge buildup: Technician A says that the presence of sludge is a signal to look for wear on other components. Technician B says that excessive buildup can indicate a poor maintenance schedule. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

2. While discussing the common causes for cracks developing in a cylinder block or head: Technician A says that the chilling of a hot engine by a sudden rush of cold water or air over the surface may cause cracking. Technician B says that excessive overheating is a common cause. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. Technician A uses a crane to remove an engine from its compartment. Technician B uses an engine cradle to remove an engine from its compartment. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. While removing a cylinder head: Technician A keeps all rocker arms and pushrods in order. Technician B loosens each head bolt, starting with the center bolts and moving toward the ends. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. While discussing abrasive cleaners: Technician A says that shot is angular in shape and is used for aggressive cleaning. Technician B says that grit is an angular-shaped media and is used to peen metal surfaces. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. Technician A labels or marks all electrical wires before disconnecting them. Technician B labels or marks all vacuum hoses and verifies the connections to the underhood decal before disconnecting them. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. While discussing cleaning engine parts: Technician A says that the cleaning method used depends on the component to be cleaned and the type of cleaning equipment available. Technician B says a parts tumbler is good for cleaning aluminum components such as intake manifolds and cylinder heads. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. While loosening the axle shaft hub nuts on a FWD vehicle: Technician A says that a large breaker bar should be used to prevent damage to the bearings. Technician B says that these nuts should be loosened with the vehicle on the floor and the brakes applied. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. While preparing to remove an engine: Technician A turns the crankshaft pulley to set the engine at number 1 cylinder TDC. Technician B removes the drive belt and crankshaft pulley. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. After removing the vehicle's hood in preparation for removing the engine: Technician A places the hood on the roof of the vehicle. Technician B sets the hood aside in a safe place on fender covers or cardboard. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER 11

LOWER END THEORY AND SERVICE

OBJECTIVES

- Be able to disassemble and inspect an engine's cylinder block.
- List the parts that make up a short block and briefly describe their operation.
- Install an OHV camshaft and bearings. Inspect a crankshaft and determine the needed repairs.
- Explain the function of engine bearings, flywheels, and harmonic balancers.
- Be able to perform the common service and assembly techniques used in connecting rod and piston servicing.
- Be able to install pistons in their cylinder bores.
- Inspect, service, and install an oil pump.

The lower end of an engine is the cylinder block. This includes the block, crankshaft, bearings, pistons, piston rings, and oil pump (and sometimes the camshaft). Many of these parts are made by casting or forging. To cast is to form molten metal into a particular shape by pouring it into a mold. To **forge** is to form metal into a shape by heating it and pressing into a mold. Some forging is done with cold metals. These manufactured parts then undergo a number of machining operations. For example:

- The top of the block must be smooth so that the cylinder head can seal it.
- The bottom of the block is machined to allow for proper sealing of the oil pan.
- The cylinder bores are machined smooth and have the correct diameter to accept the pistons.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2010	**Make:** Honda	**Model:** Civic	**Mileage:** 59,919	**RO:** 17201
Concern:	Customer states oil light comes and oil level is low after about 900 miles since oil change.			
Given this concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

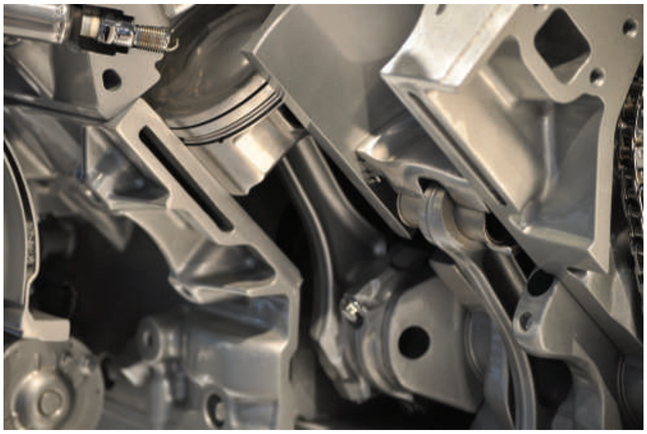


FIGURE 11-1 A cutaway showing the fit of the piston assemblies and crankshaft in an engine block.

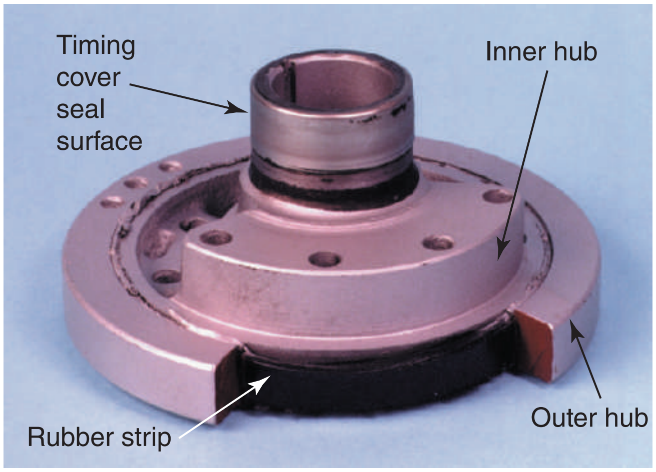


FIGURE 11-2 The construction of a harmonic balancer.

- The main bearing area of the block must be cut in a series of bores that are in a straight line and match the diameter of the journals on the crankshaft. Camshaft bearing bores must also be aligned.

When there is a major engine failure, shops either rebuild or replace the engine **(Figure 11–1)**. Most often the **short block** is repaired or replaced as an assembly. A short block consists of the block, crankshaft, bearings, connecting rods, pistons and rings, and oil gallery and core plugs. Parts related to the short block include the flywheel and harmonic balancer. A short block may also include the camshaft and timing gear. A **long block** is basically a short block with cylinder heads. These terms are commonly used by the industry.

Short Block Disassembly

This chapter begins with the assumption that the engine is on an engine stand and the cylinder head(s) are removed from the cylinder block. If the oil pan and water pump are still attached to the block, remove them before proceeding.

Remove the harmonic balancer, also called a vibration damper. The harmonic balancer has an inner hub bonded with rubber to an outer ring. Its purpose is to absorb the torsional vibrations of the crankshaft **(Figure 11–2)**. Removal of the balancer often requires the correct type puller. If an unsuitable puller is used, it is likely the rubber bonding will be damaged, which would make the balancer useless causing engine vibrations and crankshaft damage. Once the balancer is removed, carefully check the rubber for tears, separation of inner and outer sections, or other damage. If there are any faults, replace the balancer.

On OHV engines, remove the timing cover. Under the cover are the timing gears. The crankshaft's timing sprocket has a slight interference fit and can normally be pulled off by hand, as can the camshaft sprockets. The camshaft sprocket and chain must be removed with the crankshaft sprocket **(Figure 11–3)**.

Before removing the gears and chain, check the deflection of the timing chain. Depress the chain at its midway point between the gears and measure the amount that the chain can be deflected. If the deflection exceeds specifications, the timing chain and gears should be replaced.

Loosen the camshaft sprocket and pull the timing gears and chain from the engine. Be careful not to lose the keys in each shaft or any shims that may be behind the sprockets.

Often the timing chain assembly has tensioners and guides. Normally, the timing gear assembly is replaced during an engine overhaul, as are its tensioners and guides.

The timing belt or chain on OHC engines was already loosened before the cylinder head was removed. Remove it and unbolt the timing chain or belt cover and gently pry it away from the block and cylinder head. Remove the crankshaft position sensor, timing chain guide, chain tensioner slipper, and chain. On some engines, the oil pump is driven by

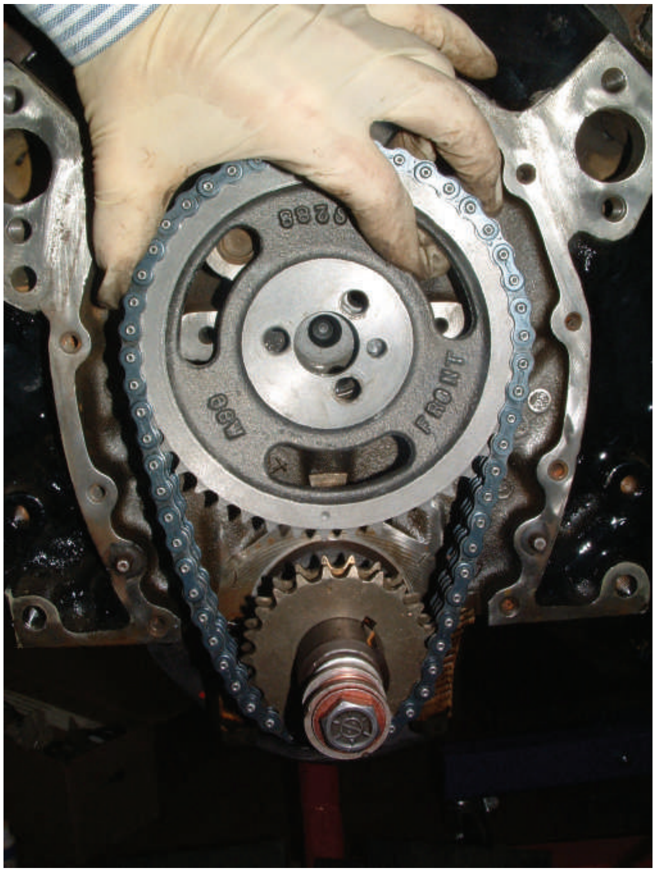


FIGURE 11-3 The timing gears and chain on a typical OHV engine.

the crankshaft at the front of the engine **(Figure 11–4)**. The pump should be unbolted and removed. Rotate the crankshaft counterclockwise to align the timing marks on the oil pump sprocket with the mark on the oil pump. Remove the bolt from the sprocket and the chain tensioner plate and spring. Then remove the oil pump sprockets and chain. Then, remove the oil screen from the oil pump.

If the lifters have not been removed, do so now. Place them on a bench in the order they were removed. Carefully pull the camshaft out of the block. Support the camshaft to avoid dragging its lobes over the surfaces of the camshaft bearings. This can damage the bearings and lobes.

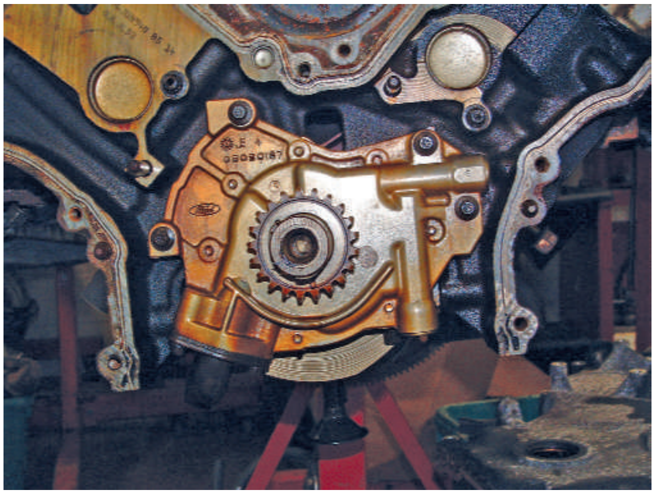


FIGURE 11-4 On most engines, the oil pump is driven by the crankshaft at the front of the engine.

Cylinder Block Disassembly

Rotate the engine on its stand so that the bottom is facing up. Remove the oil pan if it was not previously removed. Then remove the oil pump. Be careful not to lose the drive shaft while pulling the pump off the engine.

If the engine has balance shafts, check the thrust clearance of the shafts before removing the assembly. Set a dial indicator so that it can read the back-and-forth movement (end play) of the shaft. Measure the total distance that the shaft is able to move in the housing. Compare that reading to specifications. If the reading is more than the specified maximum, the balance shaft housing and bearings should be replaced. Unbolt the housing following the sequence given in the specifications **(Figure 11–5)**.

Lift the balance shaft(s) out of the housing. Inspect the bearings for unusual wear or damage. Keep the bearings in their original location. Check the journals on the balance shafts for scratches, pitting, and other damage. If a bearing or journal is damaged, replace the bearings and/or balance shaft.

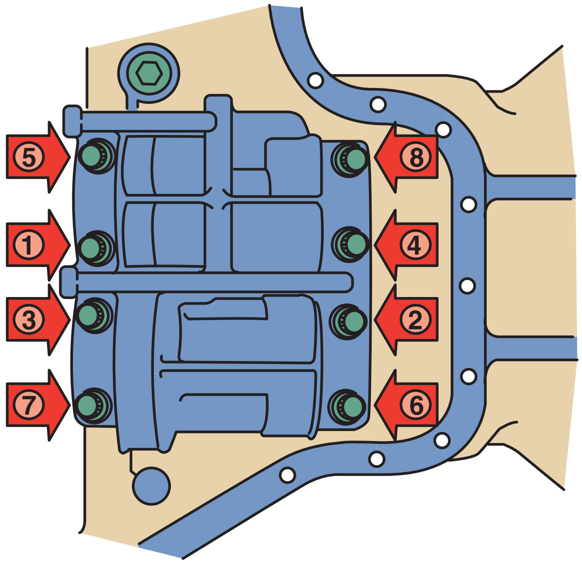


FIGURE 11-5 The balance shaft housing must be unbolted in the prescribed order to prevent shaft and housing warpage.

FIGURE 11–6 A ridge reamer should be used on all cylinders before removing the pistons.

Rotate the engine so that the bottom is at the bottom again. Rotate the crankshaft to put a cylinder at BDC. Carefully remove the cylinder ridge with a ridge reamer tool. Rotate the tool clockwise to remove the ridge **(Figure 11–6)**. Do not cut too deeply, because an indentation may be left in the bore. Remove just enough metal to allow the piston to slip out of the bore without causing damage to the bore.

The ridge is formed at the top of the cylinder. Because the top ring stops traveling before it reaches the top of the cylinder, a ridge of unworn metal is left **(Figure 11–7)**. Carbon also builds up above this ridge, adding to the problem. If the ridge is not removed, the piston's rings may be damaged as the piston is driven up in its bore.

FIGURE 11–7 Normal cylinder wear.

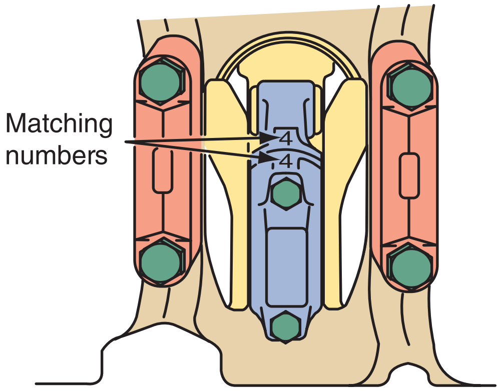


FIGURE 11–8 Check all connecting rods and main bearing caps for correct position and numbering. If the numbers are not visible, use a center punch or number stamp to number them.

Repeat the process on all cylinders. After removing the ridges, use an oily rag to wipe the metal cuttings out of the cylinder.

Rotate the engine to put the bottom side up. Check all connecting rods and main bearing caps for correct position and numbering. If the numbers are not visible, use a center punch or number stamp to number them **(Figure 11–8)**. Caps and rods should be stamped on the external flat surface. If the rods are already numbered or marked, make sure the marks designate the cylinder where the rods should be installed. If not, re-mark them to show their current location.

To remove the piston and rod assemblies, position the throw of the crankshaft at the bottom of its stroke. Remove the connecting rod nuts and cap. Remember that the caps and rods must remain as a set. To help remove the cap, tap the cap lightly with a soft hammer or wood block. Cover the rod bolts with protectors or pieces of rubber fuel line to avoid damage to the crankshaft journals. Carefully push the piston and rod assembly out with the wooden hammer handle or wooden drift and support the piston as it comes out of the cylinder. Be sure that the connecting rod does not damage the cylinder wall during removal.

Loosen and remove the main bearing cap bolts and main bearing caps. Keeping the main bearing caps in order is very important. The location and position of each cap should be marked. Many engines have a main bearing girdle or bearing support. These use at least four bolts at each main bearing. It is important that you follow the recommended bolt loosening sequence.

After removing the main bearing caps, carefully remove the crankshaft. Then store the crankshaft in a vertical position to avoid damage.

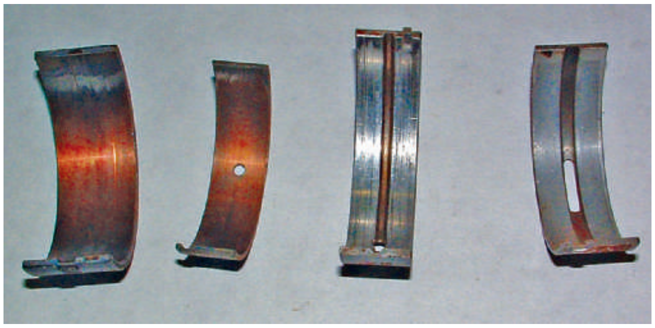


FIGURE 11–9 The bearings on the left have no babbitt left, and the ones on the right are slightly worn and scored.

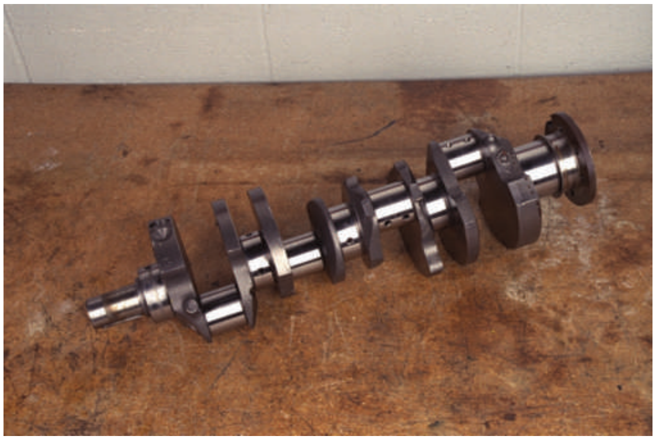
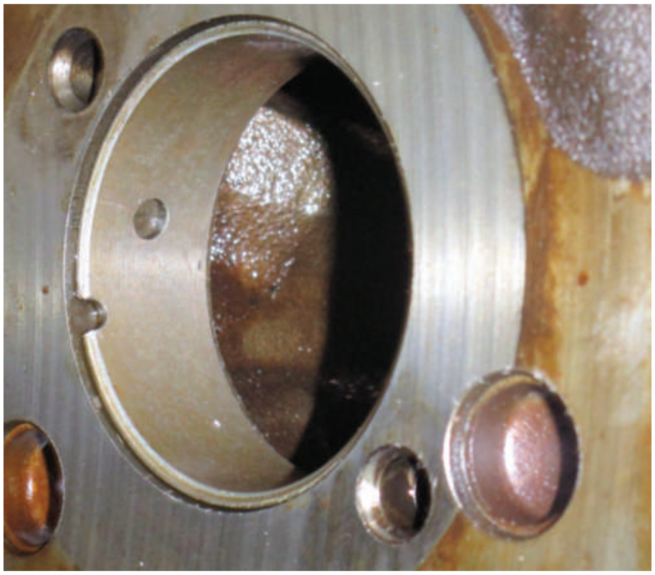


FIGURE 11–10 Inspect each crankshaft journal for damage and wear.

Remove the rear main oil seal and main bearings from the block and caps. Examine the bearing inserts for signs of unusual wear, embedded metal particles, lack of lubrication, antifreeze contamination, oil dilution, and uneven wear **(Figure 11–9)**. Then carefully inspect the main journals on the crankshaft for damage **(Figure 11–10)**.

Before removing the camshaft bearings, inspect the bearing surfaces for signs of scoring or other damage. Also note the location of where the oil holes are in relation to the block **(Figure 11–11)**. This is important for installing the new bearings correctly. To remove the camshaft bearings on an OHV block, you will need a cam bearing tool. Insert the correct adaptor onto the tool and tighten against the bearing. Use a hammer to drive the tool and bearings from each bore.

Engine blocks have **core plugs**, also called expansion plugs. When the block is made, sand cores are used to provide the various passages inside the block. The sand is partly broken and dissolved when the hot metal is poured into the mold. To remove the remaining sand, holes are bored into the block. These core holes are machined and core plugs installed to seal them **(Figure 11–12)**. Blocks



(A)

(B)

FIGURE 11–11 (A) Incorrect bearing alignment. (B) Verifying cam bearing oil hole alignment with a pick.

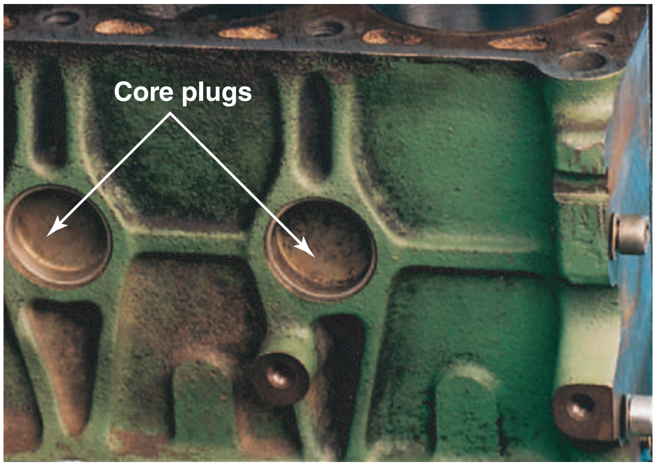


FIGURE 11–12 Core plugs in an engine block.

SHOP TALK

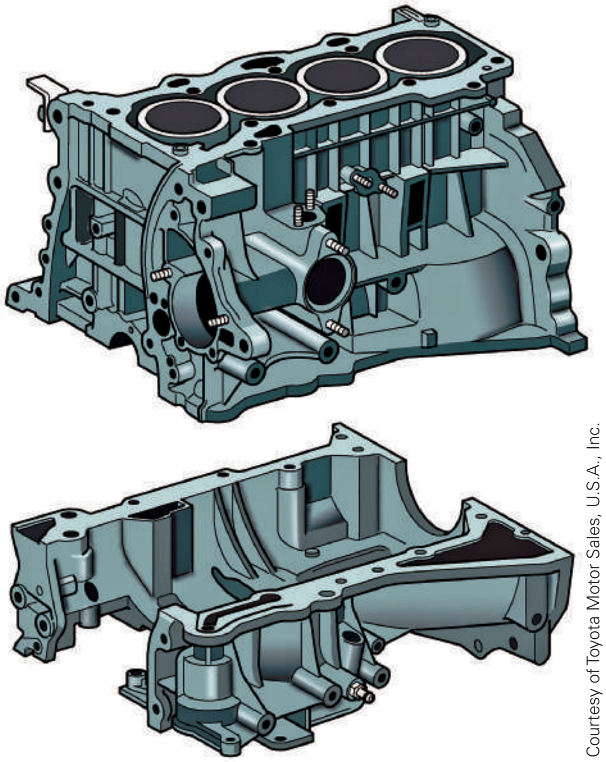
Using heat to melt paraffin into the threads of oil plugs will make removal much easier. As the part is heated, it will expand and the paraffin will leak down between the threads. Because the paraffin serves as a lubricant, you will be able to loosen the plug. Hot paraffin burns, so wear gloves when handling it.

are also made with passageways for oil. These are machined in the block and are sealed with plugs.

The block cannot be thoroughly cleaned unless all core plugs and oil plugs are removed. To remove cup-type "freeze"/core plugs, drive them in on a slant and use channel lock pliers to pull them out. Flat-type plugs can be removed by drilling a hole near the center and inserting a slide hammer to pull it out. On some engines, the cup-type plug can be removed by driving the plug out from the backside with a long rod.

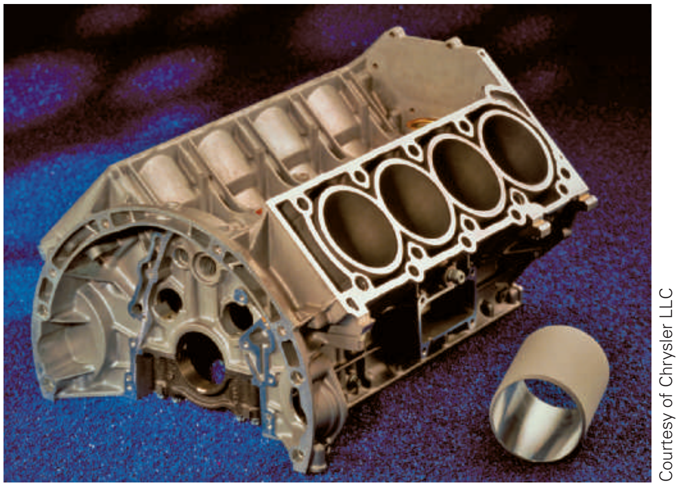
Sometimes removing threaded front and rear oil gallery plugs can be difficult. Using a drill and screw extractor can help.

After cleaning, the block and its parts must be visually checked for cracks or other damage.



Courtesy of Toyota Motor Sales, U.S.A., Inc.

FIGURE 11–13 Aluminum engine blocks are often two-piece units.



Courtesy of Chrysler LLC

FIGURE 11–14 A cylinder block and cylinder liner for a late-model aluminum V8 engine.

Cylinder Block

The cylinder blocks are normally a one-piece casting. They may be cast from different materials such as iron, aluminum, magnesium, or possibly, in the future, plastic. A few engine blocks have a magnesium exterior with cast-iron inserts to serve as cylinders, coolant passages, etc. Some late-model blocks are made of two pieces: an upper unit that contains the cylinders and a lower one that surrounds the crankshaft **(Figure 11–13)**.

Cast-iron blocks are very strong but heavy. Many engines have an aluminum block to reduce the vehicle's overall weight. Certain materials are added to aluminum to make it stronger and less likely to warp from the heat of combustion.

Cylinder Liners

The cylinder walls of aluminum blocks may be treated with a special coating or have a sleeve or liner to serve as cylinder walls **(Figure 11–14)**. The liners are normally made of a cast-iron alloy. On some engines, the liners can be replaced and/or machined if they are damaged. Most are very thin and cannot be serviced and the block must be replaced if the walls are damaged. Liners are pressed into the block or are placed in the mold before the block is cast. The liners have ribs on their outside diameter. These ribs hold the liner in place and increase its ability to dissipate heat. There are two types of sleeves: wet and dry. The dry sleeve is

supported from top to bottom by the block. The wet sleeve is supported only at the top and bottom. Coolant passes over the center part of a wet sleeve.

Lubrication and Cooling

A cylinder block has a series of oil passages that allow engine oil to be pumped through the block and crankshaft and on to the cylinder head. Water jackets are also cast in the block around the cylinder bores. Coolant circulates through these jackets to transfer heat away.

Some engine blocks are cast with a plastic spacer for the water jackets. The spacers provide a uniform distribution of heat throughout the cylinders by directing the flow of coolant toward the normally hotter areas.

An engine block has machined areas on which other parts are mounted. These include threaded bores. Brackets and housings may also be cast onto the basic block.

Cylinder Block Reconditioning

Before doing any service to the block, clean all threaded bores with the correct-size thread chaser to remove any burrs or dirt. Use a bottoming tap in any blind holes. The bores should be slightly **chamfered** to eliminate thread pulls and jagged edges. If there is damage to the threads, they should be repaired. To restore damaged threads in an aluminum part, a threaded insert should be installed.

Check the block for cracks and other damage. Cast-iron blocks can be checked by magnafluxing. Aluminum blocks are checked for cracks with penetrant dye and a black light. Some cracks can be repaired; however, if they are in critical areas, the block should be replaced.

Deck Flatness

The top of the block is called the **deck**. To check deck warpage, use a precision straightedge and feeler gauge. With the straightedge positioned diagonally across the deck, the amount of warpage is determined by the size of feeler gauge that fits into the gap between the deck and the straightedge **(Figure 11–15)**.

Some engines have special deck flatness requirements. Always refer to the manufacturer's specifications. If the deck is warped beyond limits, the block should be decked or replaced. Decking requires a special grinder that will shave off small amounts of metal, leaving a flat surface. Some manufacturers do not recommend decking, especially if the block is aluminum. If the block has more than one deck surface (such as a V-type engine), each deck must be machined to the same height. If the deck is warped and not corrected, coolant and combustion leakage can occur.

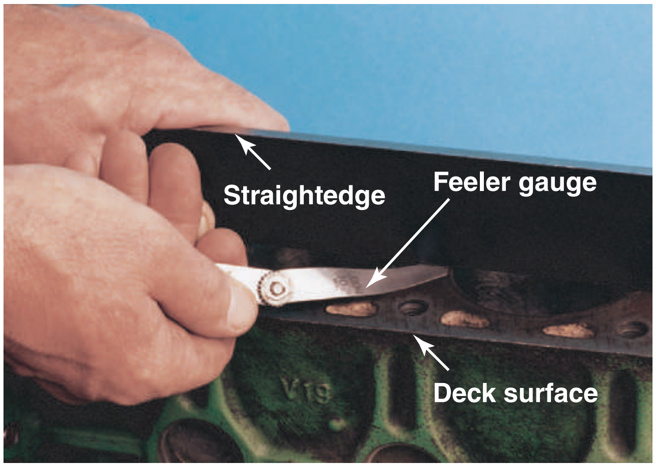


FIGURE 11–15 Checking for deck warpage with a straightedge and feeler gauge.

Cylinder Bore Inspection

Inspect the cylinder walls for scoring, roughness, or other signs of wear. Dirt can accelerate ring and cylinder wall wear. Scuffed or scored pistons, rings, and cylinder walls **(Figure 11–16)** can act as passages for oil to bypass the rings and enter the combustion chamber. Scuffing and scoring occur when the oil film on the cylinder wall is ruptured, allowing metal-to-metal contact of the piston rings on the cylinder wall. Cooling system hot spots, oil contamination, and fuel wash are typical causes of this

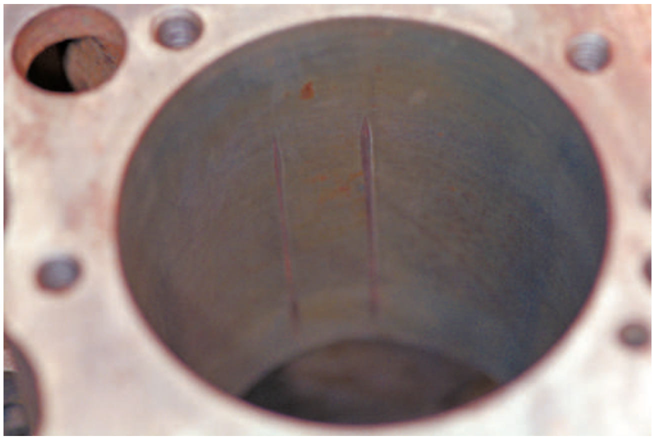


FIGURE 11–16 A scored cylinder wall.

problem. If the cylinder walls show light scratches, inspect the air induction system for leaks. Unfiltered air can allow dirt to enter the cylinders and damage the walls.

Most cylinder wear occurs at the top of the ring travel. Pressure on the top ring is at a peak and lubrication at a minimum when the piston is at the top of its stroke. A ridge of unworn material builds above the upper limit of ring travel. Below the ring travel area, wear is negligible because only the piston skirt contacts the cylinder wall.

A cylinder should have the correct diameter, no taper or out-of-roundness, and the surface finish must be such that the piston rings will seat to form a seal that will control oil and minimize blowby.

Taper is the difference in diameter between the bottom of the cylinder bore and the top of the bore just below the ridge **(Figure 11–17)**. Subtracting the smaller diameter from the larger one gives the cylinder taper. Some taper is permissible, but normally not more than 0.006 inch (0.1524 mm).

Cylinder out-of-roundness is the difference of the cylinder's diameter when measured parallel with the crank and then perpendicular to the crank **(Figure 11–18)**. Out-of-roundness is measured at the top of the cylinder just below the ridge. Typically the maximum allowable out-of-roundness is 0.0015 inch (0.0381 mm). Normally the cylinder bore is checked for out-of-roundness with a dial bore gauge **(Figure 11–19)**. However, a telescoping gauge can also be used.

When using a dial bore gauge or a telescoping gauge, make sure the measuring arms are parallel to the plane of the crankshaft. The best way to do this is to rock the gauge until the smallest reading is obtained.

A block with cylinders that exceed taper or out-of-round specifications may need to be replaced or bored oversize. Reboring an engine requires installing oversized pistons to match the larger cylinder diameter.

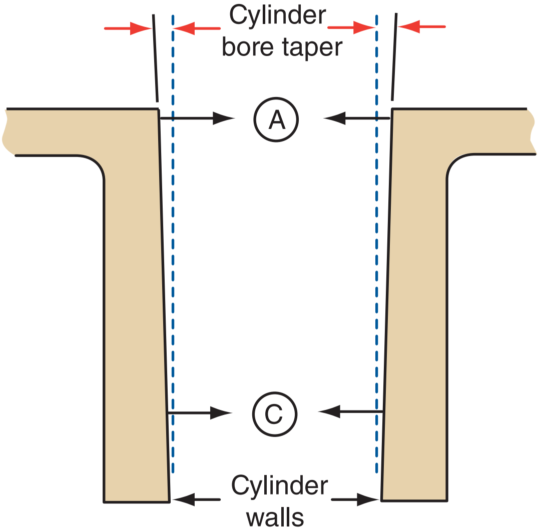


FIGURE 11–17 To check for taper, measure the diameter of the cylinder at A and C. The difference between the two readings is the amount of taper.

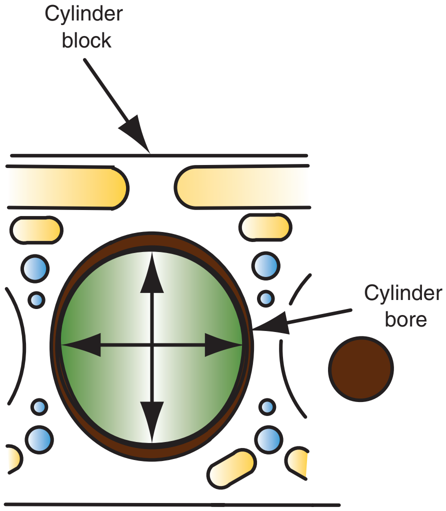


FIGURE 11–18 To check cylinder out-of-roundness, measure the bore in different locations.

FIGURE 11–19 Cylinder bore is checked for out-of-roundness with a dial bore gauge.

Cylinder Bore Surface Finish

The surface finish on a cylinder wall should act as an oil reservoir to lubricate the piston rings and prevent piston and ring scuffing. Piston ring faces can be damaged and wear prematurely if the wall is too rough. A surface that is too smooth will not hold enough oil and scuffing may occur.

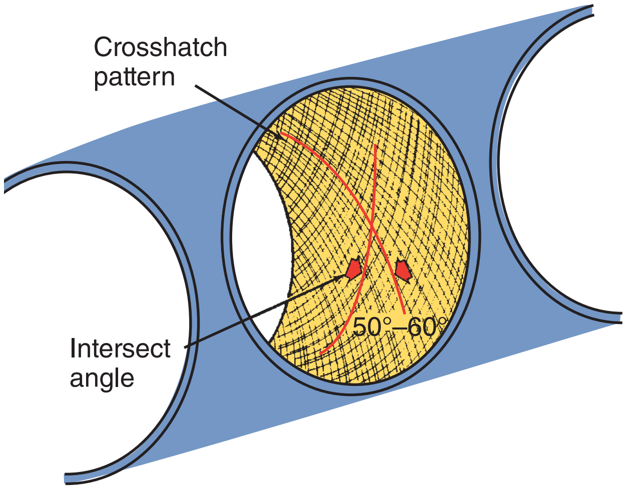


FIGURE 11–20 Ideal crosshatch pattern for cylinder walls.

The desired finish has many small crisscross grooves **(Figure 11–20)**. Ideally, these grooves cross at 50- to 60-degree angles, although anything from 20 to 60 degrees is acceptable. This finish leaves millions of tiny diamond-shaped areas to serve as oil reservoirs **(Figure 11–21)**. It also provides flat areas or plateaus on which an oil film can form to separate the rings from the wall. If the angle of the crosshatch is too steep, the oil film will be too thin, causing scuffing. If the angle is too flat, the pistons may hydroplane and excessive oil consumption will result.

Cylinder Deglazing If the inspection and measurements of the cylinder wall show that surface conditions, taper, and out-of-roundness are within acceptable limits, the walls may only need to be deglazed. Combustion heat, engine oil, and piston movement combine to form a thin residue, **glaze**, on the cylinders. Glazed walls allow the piston rings to slide and prevent a positive seal between the walls and the rings.

Often, glazing can be removed by wiping the cylinders with denatured alcohol or lacquer thinner. Fine honing stones will also remove glaze and leave the walls with a desired finish. Often, technicians use a ball hone to deglaze **(Figure 11–22)** and create the desired pattern on the walls of the cylinder. On many newer engines, deglazing with a ball hone or stones is not recommended.

After servicing the walls, use hot, soapy water; a stiff-bristle brush; and a soft, lint-free cloth to clean the walls. Then rinse the block with water and allow it to thoroughly dry. Put a light coat of clean engine oil on the walls to prevent rust.

Lifter Bores

Carefully check each valve lifter bore for cracks and evidence of excessive wear. Oblong or egg-shaped bores indicate wear. If the bores are rusted, glazed, or have burrs and high spots, they can be honed

FIGURE 11–21 The desired cylinder wall finish for most types of piston rings.

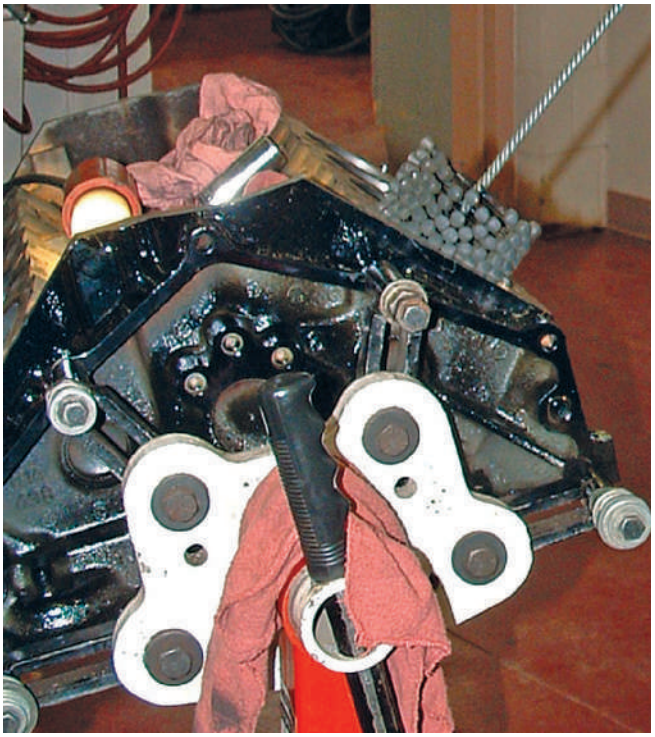


FIGURE 11–22 Using a resilient-based, hone-type brush, commonly called a ball hone.

with a brake wheel cylinder hone. Be careful not to remove more than 0.0005 inch of metal while honing. If the bores exceed allowable wear limits or are damaged, the engine block should be replaced.

Installing Core Plugs

After the block has been serviced and cleaned, new oil and core plugs should be installed. Make sure the plugs are the correct size and type. Coat the plug or bore lightly with a nonhardening oil-resistant (oil gallery) or water-resistant (cooling jacket) sealer. If the threads for the oil plugs are damaged, run a tap through the bore.

If the bore for a core plug is damaged, it should be bored out for an oversized plug. Oversize (OS) plugs are identified by the OS stamped on the plug. The correct way to install a core plug depends on the type of plug.

Disc- or Dished-Type These fit in a bore with the dished side facing out **(Figure 11–23A)**. With a hammer, hit the center of the disc's crown and drive the plug in until just the crown becomes flat. This expands the plug so that it can make a good seal.

Cup-Type These are installed with the flanged edge outward **(Figure 11–23B)**. The bore for these plugs has its largest diameter at the outer edge. The outside of the cup must be positioned behind the chamfered edge of the bore to effectively seal the bore.

Expansion-Type These are installed with the flanged edge inward **(Figure 11–23C)**. The bore for these plugs has its largest diameter at the back of the bore. The base of the plug must be positioned at the rear of the bore to seal it.

Camshaft Bearings

The camshaft is supported by several bearings, or bushings. OHV camshaft bearings are one-piece plain bearings pressed into the camshaft bore **(Figure 11–24)**. Inspect the bearing bores for wear and out-of-roundness. With the main bearing caps installed and torqued, use a bore gauge or telescoping gauge to measure bore diameter vertically and horizontally with the block. Severely out-of-round bores indicate a distorted block. If the bearing bores are in good condition, new camshaft bearings can be installed.

Balance Shafts

Many late-model engines have one or more balance (silence) shafts to smoothen engine operation. An engine's crankshaft is one of the main sources of

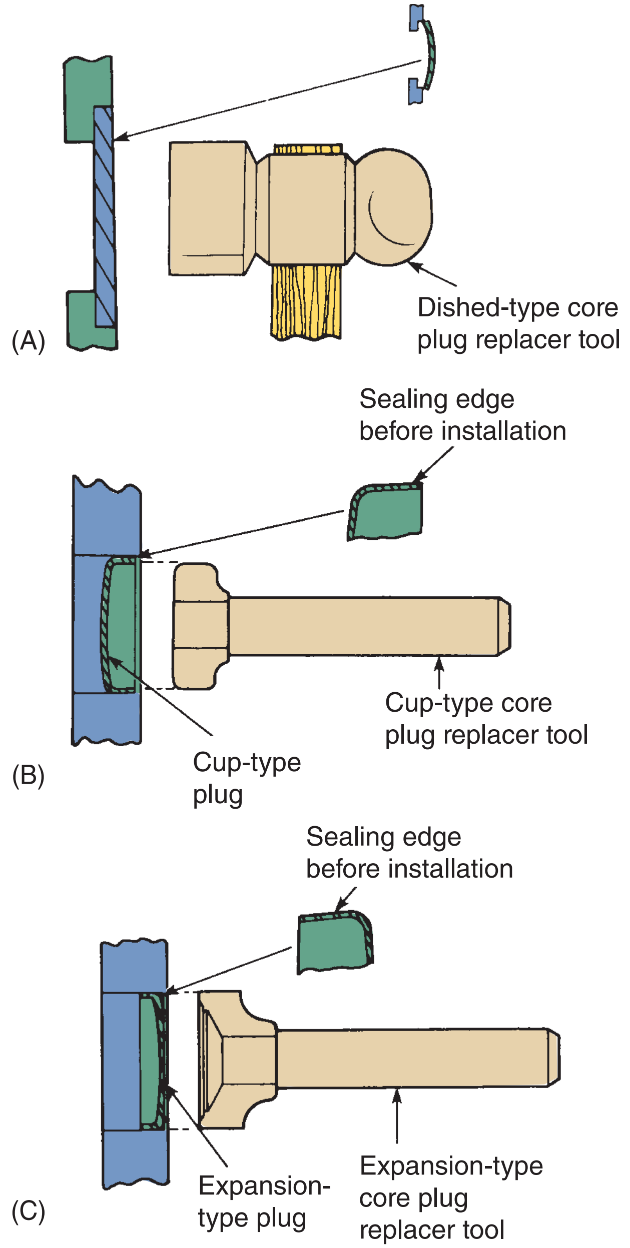


FIGURE 11–23 Core plug installation methods: (A) dished, (B) cup, and (C) expansion.

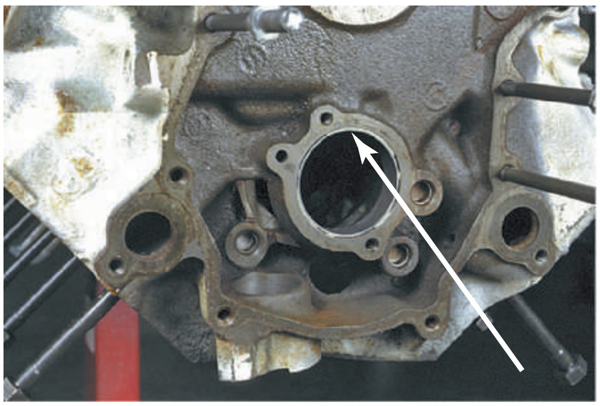


FIGURE 11–24 The typical camshaft bearing is a full round design.

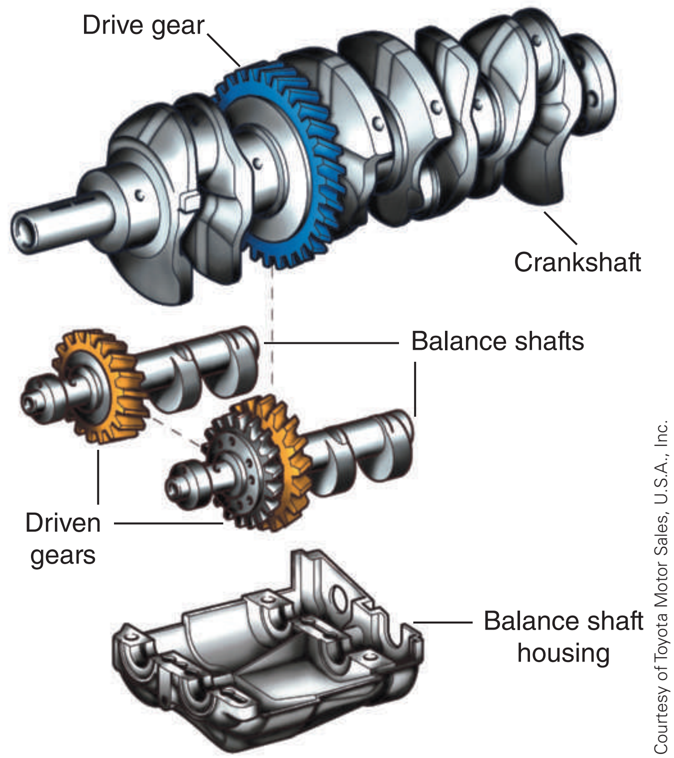


FIGURE 11–25 Balance shaft assemblies for a four-cylinder engine.

engine vibration because it is inherently out of balance. Balance shafts are designed to cancel out these vibrations.

A balance shaft has counterweights designed to mirror the throws of the crankshaft. These weights are positioned to the opposite side of the weight of the crankshaft and are rotated in the opposite direction as the crankshaft. As the engine turns, the opposing weights cancel out any vibrations. Balance shafts are timed to the rotation of the crankshaft. If the balance shaft(s) are not timed to the crankshaft, the engine may vibrate more than it would without a balance shaft.

Balance shafts are located in the engine block on one side of the crankshaft, in the camshaft bore, or in a separate assembly bolted to the engine block **(Figure 11–25)**.

Balance shafts' journals and bearings need to be checked for wear, damage, and proper oil clearances. Check the bolts for the housing. If they are damaged, replace them. Use a vernier caliper to measure the length of the bolts from their seat to the end. Compare the length to specifications. If the bolts are too long, replace them. The drive chain for the shaft(s) should also be checked for stretching. This is done by pulling on two ends of the chain and measuring that length. If the length is greater than specifications, the chain should be replaced.

Crankshaft

Crankshafts are made of cast iron, forged cast steel, or nodular iron, and then machined. At the centerline of the crankshaft are the main bearing journals. These journals are machined to a very close tolerance because the weight and movement of the crankshaft are supported at these points. The number of main bearings varies with engine design. V-type engines have fewer main bearings than an inline engine with the same number of cylinders. A V-type engine uses a shorter crankshaft.

Offset from the crankshaft's centerline are connecting rod journals. The degree of offset and number of journals depends on engine design **(Figure 11–26)**. An inline six-cylinder engine has six connecting rod journals. A V6 engine may have only three. Each journal has two rods attached to it, one from each side of the V. A connecting rod journal is also called a crankpin.

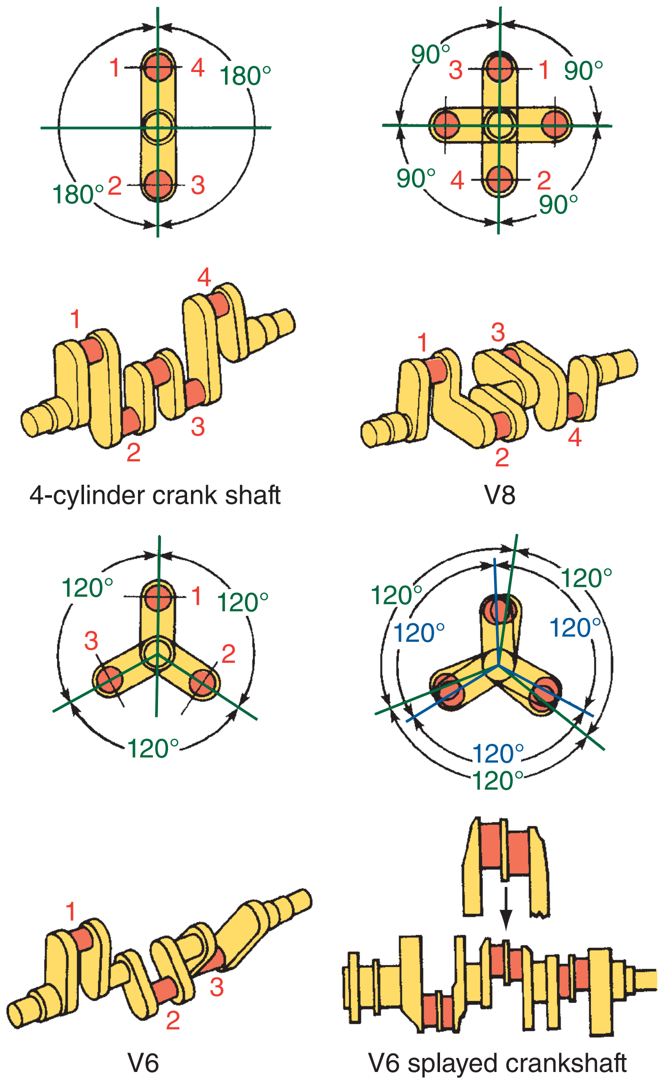


FIGURE 11–26 Various crankshaft configurations.

The position of the rod journals places the weight and pressure from the pistons away from the center of the crankshaft. This creates an imbalanced condition. To overcome this imbalance, counterweights are built into the crankshaft to offset the weight of the pistons and connecting rods. These are positioned opposite the connecting rod journals.

Some engines use flat-plane crankshafts. All inline four-cylinder engines are flat-plane motors and a few high-performance V-8s are also. A flat-plane crank spaces the connecting rod journals 180 degrees apart. This reduces the size and mass of the counterweights allowing for high-revving engines and increased power output.

The main and rod bearing journals must have a very smooth surface. A clearance between the journal and bearing is needed to allow a film of oil to form. The crankshaft rotates on this film. If the crankshaft journals become out of round, tapered, or scored, the oil film will not form properly and the journal will contact the bearing surface. This causes early bearing or crankshaft failure. The main and rod bearings are generally made of lead-coated copper or tin, or aluminum. These materials are softer than the crankshaft. This means that wear will appear first on the bearings.

It is important that the journals receive an ample supply of clean oil. Each main bearing journal has a hole drilled into it with a connecting bore or bores leading to one or more rod bearing journals. Pressurized oil moves in, over, and out of the journals.

A crankshaft has two distinct ends. One is called the flywheel end. The front end or belt drive end of the crankshaft has a snout for mounting the crankshaft timing gear and damper.

Crankshaft Torsional Dampers

Combustion causes an extreme amount of pressure in a cylinder (more than 2 tons each time a cylinder fires). This pressure is applied to the pistons and moves through the connecting rods to the crankshaft. This downward force causes the crankshaft to rotate. In an engine with more than one cylinder, this pressure is exerted at different places on the crankshaft and at different times. As a result, the crankshaft tends to twist and deflect, causing torsional harmonic vibrations. These vibrations constantly change but there are specific engine speeds where these harmonics are amplified. This increase in torsional vibration can cause damage to the crankshaft, the engine, and/or any accessories that are driven by the crankshaft.

These harmful vibrations are often limited by the torsional (harmonic) damper located at the front of the crankshaft. The hub of the harmonic balancer is pressed onto the snout of the crankshaft. The inertia ring is heavy and is machined to serve as a counterweight for the crankshaft. As the crankshaft twists, the hub applies a force to the rubber. The rubber then applies this force to the inertia ring. The counterweight is snapped in the direction of crankshaft rotation to counterbalance the torsional vibrations from the pulsating crankshaft.

To allow the outer ring to move independently of the hub, the rubber sleeve deflects slightly. The condition of this sleeve is critical to the effectiveness of the balancer. Check the condition of the rubber; look for any broken areas or tears. If it looks good, press on the rubber; it should spring back. If the balancer fails the checks, it should be replaced.

Flywheel

The **flywheel** also helps the engine run smoother by applying a constant moving force to carry the crankshaft from one firing stroke to the next. Once the flywheel starts to rotate, its weight tends to keep it rotating. The flywheel's inertia keeps the crankshaft rotating smoothly in spite of the pulses of power from the pistons.

Because of its large diameter, the flywheel also makes a convenient point to connect the starter to the engine. The large diameter supplies good gear reduction for the starter, making it easy for it to turn the engine against its compression. The surface of a flywheel may be used as part of the clutch **(Figure 11–27)**. On a vehicle with an automatic transmission, a lighter **flexplate** is used. The torque

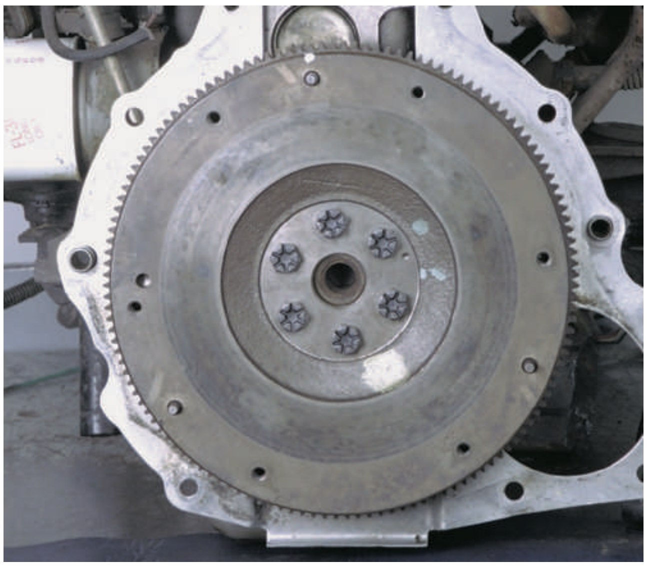


FIGURE 11–27 A flywheel attached to an engine.

converter provides the weight required to attain flywheel functions.

Flywheel Inspection Check the runout of the flywheel and carefully inspect its surface. Replacement or resurfacing may be required. Excessive runout can cause vibrations, poor clutch action, and clutch slippage. With both manual shift and automatic transmissions, inspect the flywheel for a damaged or worn ring gear. Many ring gears can be removed and flipped over if they are damaged on one side.

Some engines have the crankshaft sensor reluctor build into the flywheel. Inspect the reluctor for cracks and damage.

Crankshaft Inspection and Rebuilding

To measure the diameter of the journals, use an outside micrometer **(Figure 11–28)**. Measure them for size, out-of-roundness, and taper **(Figure 11–29)**. Taper is measured from one side of the journals to the other. The maximum taper is 0.001 inch.

Compare these measurements to specifications to determine if the crankshaft needs to be reground or replaced. If the journals are within specifications, the journal area needs only to be cleaned.

Check and clean the crankshaft oil passages using a small diameter bore brush. Insert the brush through each oil passage to make sure it is not restricted. Use compressed air to blow any dirt from the passages after brushing.

Inspect the snout of the crank for wear and damage along the keyway where the timing sprocket, front seal, and harmonic balancer are attached. Check the sealing surface for the rear main seal. A worn or grooved seal flange can cause an oil leak even with a new seal installed.

FIGURE 11–28 Measure the diameters of the crank journals with an outside micrometer.

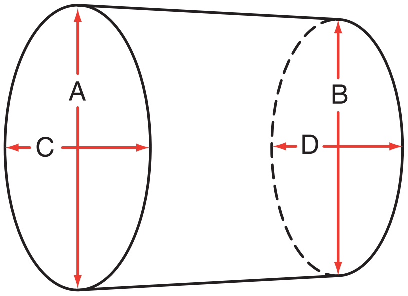


FIGURE 11–29 Measure crank journals for size, out-of-round, and taper.

Crankshaft Reconditioning

If the crankshaft is severely damaged, it should be replaced. A crankshaft with journal taper or grooves, burnt marks, or small nicks in the journal surfaces may be reusable after the journals are refinished. This process grinds away some of the metal on the journals to provide an even and mar-free surface.

Minor journal damage may be corrected by polishing the journals with very fine sandpaper. A polishing tool rotates a long loop of sandpaper against the journals as the crankshaft is rotated by a stand. The constant movement of the sandpaper and the rotation of the crankshaft prevent the creation of flat spots on the journals.

Checking Crankshaft Straightness

To check the straightness of the crankshaft, ensure that it is supported on V-blocks positioned on the end main bearing journals. Position a dial indicator at the 3 o'clock position on the center main bearing journal.

USING SERVICE INFORMATION Crankshaft specifications can be found in the engine specification section of the service information.

Set the indicator at 0 (zero) and turn the crankshaft through one complete rotation. The total deflection of the indicator, the amount greater than zero plus the amount less than zero, is the **total indicator reading (TIR)**. Bow is 50 percent of the TIR. Compare the bow of the crankshaft to the acceptable alignment/bow specifications.

A special machine is used to straighten crankshafts but will only be found in serious engine rebuilding shops. In most cases if the crankshaft is warped, it is replaced.

Crankshaft Bearings

Bearings are a major wear item and require close inspection. Main bearings support the crankshaft journals. Connecting rod bearings connect the crankshaft to the connecting rods.

Crankshaft bearings are known as insert bearings. There are two basic designs. A **full-round** (one-piece) **bearing** is used in bores that allow the shaft's journals to be inserted into the bearing, such as a camshaft. A **split** (two halves) **bearing** is used where the bearing must be assembled around the journal. Crankshaft bearings are the split type **(Figure 11–30)**.

Many crankshafts have a main bearing with flanged sides. This is called a thrust bearing and is used to control the horizontal movement or end play of the shaft. Most thrust main bearings are double flanged **(Figure 11–31)**. Some crankshafts use flat insert thrust bearings.

Some late-model engines do not have separate main bearing caps; rather, they are fitted with a lower engine block assembly. This assembly works like a bridge and contains the lower half of the main bearing bores. The assembly is torqued to the block.

FIGURE 11–30 Examples of split-type main bearings.

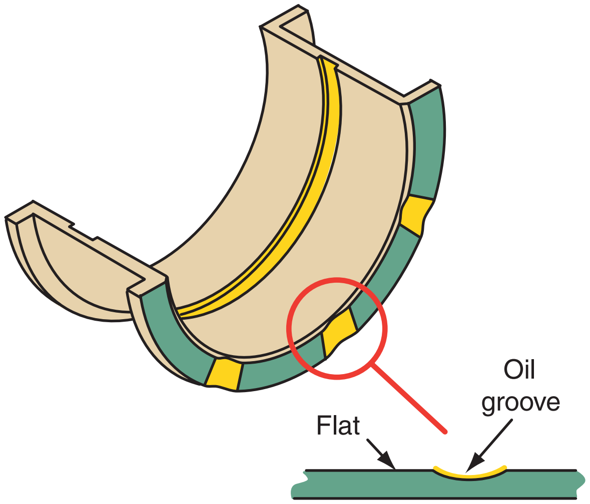


FIGURE 11–31 A thrust bearing with grooves cut into its flange to provide for better lubrication.

On some engines, the main bearing caps and lower block assemblies are given additional strength through the use of additional bolts. The main caps are secured by four bolts, two on each side of the cap. Other designs may have additional side bolts to fasten the side of the cap to the engine block. Regardless of the number and position of the bolts, proper tightening sequences **(Figure 11–32)** must be followed.

Bearing Materials

Bearings can be made of aluminum, aluminum alloys, copper and lead alloys, and steel backings coated with babbitt. Each has advantages in terms of

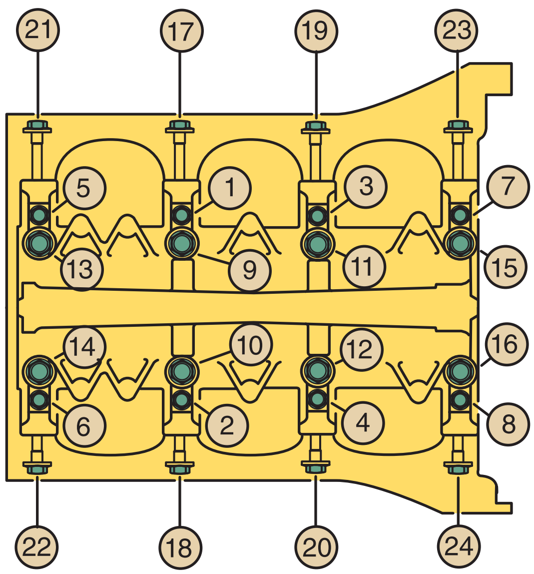


FIGURE 11–32 Six bolts secure each main cap in this engine. Each bolt must be tightened in correct sequence and to the correct torque.

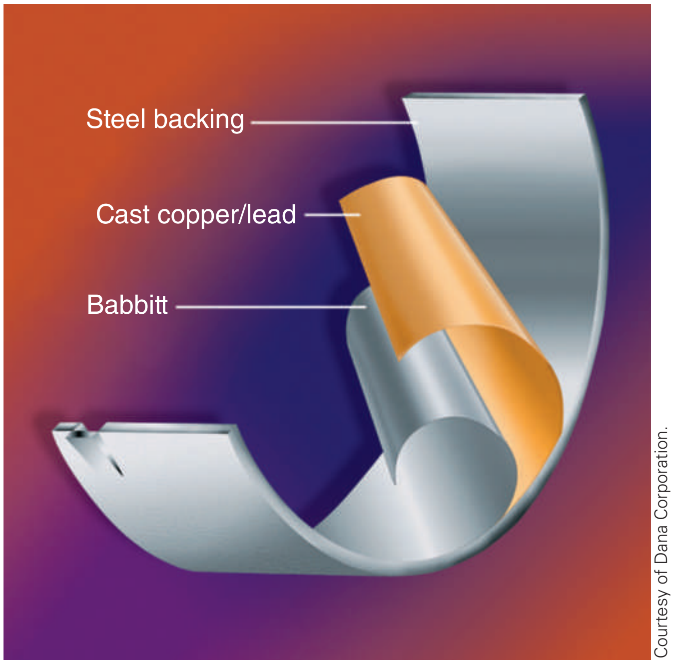


FIGURE 11-33 The basic construction of a bearing composed of three metals.

resistance to corrosion, rate of wear, and fatigue strength. Aluminum alloy bearings are the most commonly used. These bearings contain silicon, which helps to reduce wear. Some bearings use a combination of metals, such as a layer of copper-lead alloy on a steel backing, followed by a thin coating of babbitt **(Figure 11–33)**. This design takes advantage of the excellent properties of each metal.

Bearing Spread

Most main and connecting rod bearings have "spread." This means the distance across the outside parting edges of the bearing insert is slightly greater than the diameter of the housing bore. To position a bearing half with spread, it must be snapped into place **(Figure 11–34)**. This provides a good fit inside the bore and helps keep the bearings in place during assembly.

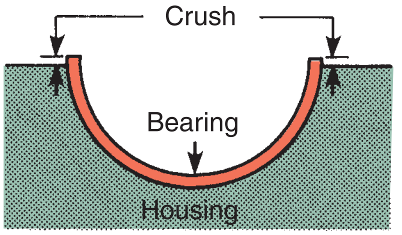


FIGURE 11-35 Crush ensures good contact between the bearing and the housing.

Bearing Crush

Each half of a split bearing is made slightly larger than an exact half. This can be seen quite easily when a half is snapped into place. The parting faces extend a little beyond the seat **(Figure 11–35)**. This extension is called crush. When the two halves are assembled and the cap tightened, the crush forces the bearing halves into the bore. Bearing crush increases the contact area between the bearing and bore, allowing for better heat transfer, and compensates for slight bore distortions.

Bearing Locating Devices

Engine bearings must not be able to rotate or shift sideways in their bores. Many different methods are used to keep the bearings in place. The most common way is the use of a locating lug. As shown in **Figure 11–36**, this is a protrusion at the parting face of the bearing. The lug fits into a slot in the bearing's bore.

Oil Grooves

To ensure an adequate oil supply to the bearing's surface, an oil groove is added to the bearing. Most bearings have a full groove around the entire circumference of the bearing, and others have a groove only in the upper bearing half.

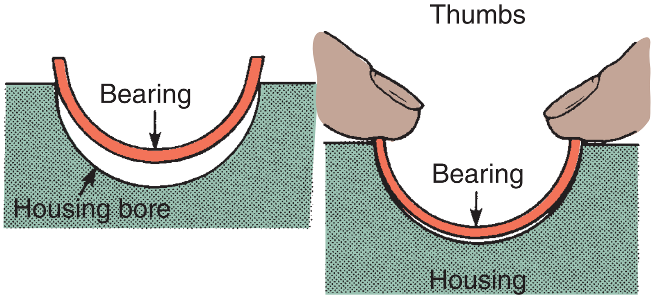


FIGURE 11-34 Spread requires a bearing to be lightly snapped into place.

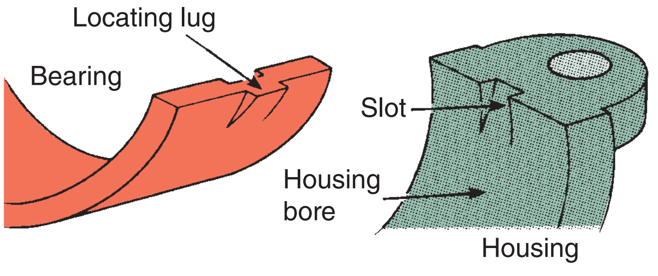


FIGURE 11-36 The locating lug fits into the slot in the housing.

Oil Holes

Oil holes in the bearings allow oil to flow through the block and into the bearing's oil clearance. These holes control the amount of oil sent to the connecting rod bearings and other parts of the engine. For example, oil squirt holes in connecting rods are used to spray oil onto the cylinder walls. The oil hole normally lines up with the groove in a bearing. When installing bearings, make sure the oil holes in the block line up with holes in the bearings.

Bearing Failure and Inspection

As shown in **Figure 11–37**, bearings can fail for many reasons. Dirt and oil starvation are the major reasons for bearing failure. Other engine problems, such as bent or twisted crankshafts or connecting rods or out-of-shape journals, can also cause bearings to wear irregularly.

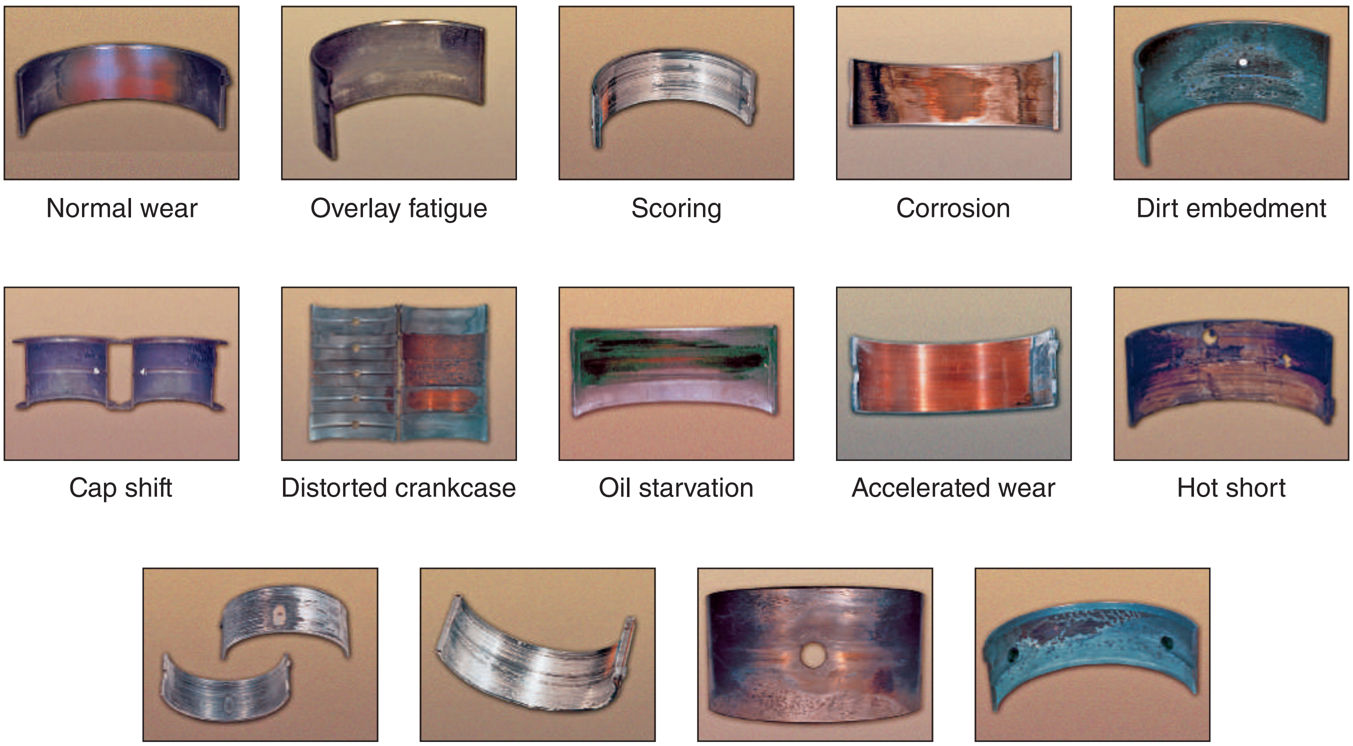
Installing Main Bearings and Crankshaft

Before assembling the short block, make sure the engine is thoroughly cleaned. A gap or clearance between the outside diameter of the crankshaft journals and the inside diameter of its bearings is necessary. This clearance allows for the building and maintenance of an oil film. Scored bearings, worn crankshaft, excessive cylinder wear, stuck piston rings, and worn pistons can result from too small an oil clearance. If the oil clearance is too great, the crankshaft might pound up and down, overheat, and weld itself to the insert bearings.

During an engine rebuild, if there is little or no wear on the journals, the proper oil clearance can be restored with the installation of standard-size bearings. However, if the crankshaft is worn to the point where standard-size bearings will leave an excessive oil clearance, a bearing with a thicker wall must be used. Although these bearings are thicker, they are known as undersize because the journals and crankpins are smaller in diameter. In other words, they are under the standard size.

With undersized bearings, the difference in bearing thickness is normally stamped onto the backside of the bearing. Bearings may also be color-coded to indicate their size. Often engines are manufactured with other than standard journal sizes. The crankshaft is marked to show the size of bearing used.

If the housing bores have been machined larger by align boring or align honing, oversized bearings are used to take up this space.



Normal wear · Overlay fatigue · Scoring · Corrosion · Dirt embedment

Cap shift · Distorted crankcase · Oil starvation · Accelerated wear · Hot short

Dirt on bearing back · Wiped · Fretting · Fatigue

Courtesy of Dana Corporation.

FIGURE 11–37 Common forms of bearing distress.

Make sure the new bearings match the crankshaft journal diameters and main bearing bores. Before the bearings are installed, make sure the bore is clean and dry. Use a clean, lint-free cloth to wipe the bearing back and bore surface.

Put the new main bearings into each main bearing cap and the bearing bores in the cylinder block. Make sure all holes are aligned. The backs of the bearing inserts should never be oiled or greased. Place the crankshaft onto the bearings. The oil clearance is now measured with Plastigage. Make sure the journals are clean and free of oil. The presence of oil will give inaccurate clearance measurements.

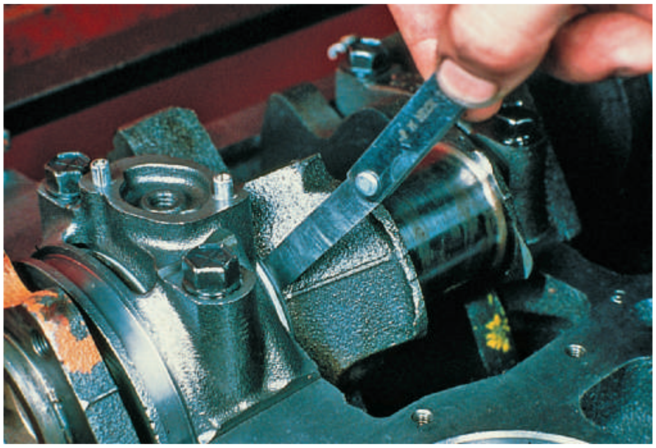
Plastigage is fine, plastic string that flattens out as the caps are tightened on the crankshaft. The procedure for using Plastigage is shown in Photo Sequence 7.

One side of the Plastigage's package is used for inch measurements, the other for metric measurements. The string can be purchased to measure different clearance ranges. Usually, the smallest clearance range is required for engine work.

If the oil clearance is not within specifications, the crankshaft needs to be machined or replaced, or undersized bearings should be installed.

Crankshaft End Play

Crankshaft end play can be measured with a feeler gauge by prying the crankshaft rearward and measuring the clearance between the thrust bearing flange and a machined surface on the crankshaft. Insert the feeler gauge at several locations around the rear thrust bearing face **(Figure 11–38)**. You may also position a dial indicator so that the fore and aft movement of the crankshaft can be measured.



Courtesy of Federal-Mogul Corp.

FIGURE 11-38 Crankshaft end play can be checked with a feeler gauge.

SHOP TALK

If the journals measure within specifications but they are pitted or gouged, polish the worst journal to determine whether or not grinding is necessary. If polishing achieves smoothness, then grinding is probably not necessary.

If the end play is less than or greater than the specified limits, the main bearing with the thrust surface must be exchanged for one with a thicker or thinner thrust surface. If the engine has thrust washers or shims, thicker or thinner washers or shims must be used.

Most engines require the installation of main bearing seals during the final installation of the crankshaft.

Connecting Rod

The connecting rod is used to transmit the pressure applied on the piston to the crankshaft **(Figure 11–39)**. Connecting rods must be able to swivel at the piston and the crankshaft. This allows them to freely move

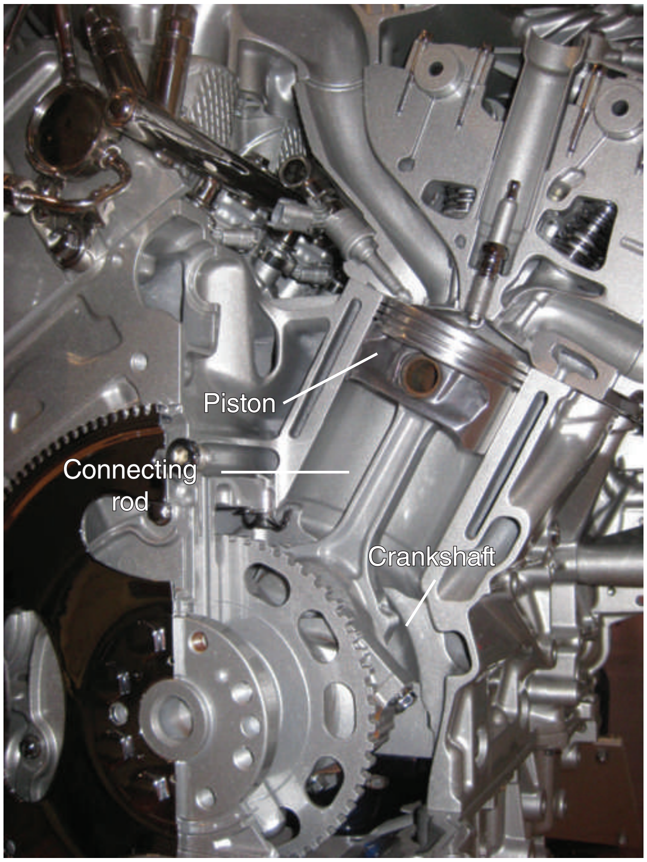
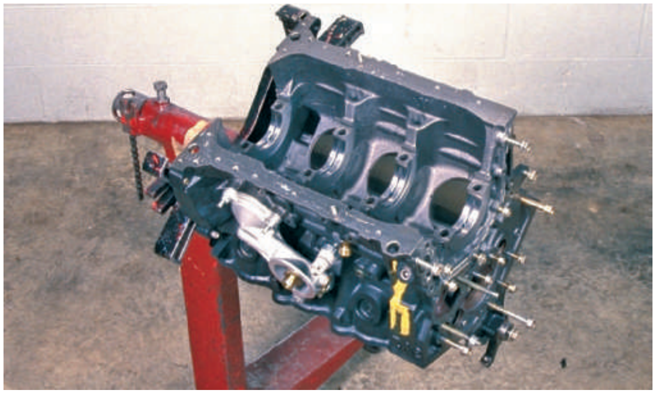


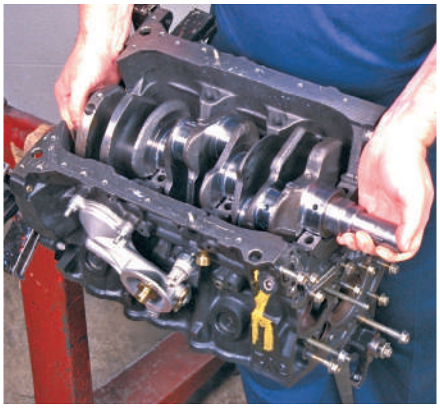
FIGURE 11-39 A piston and connecting rod assembly.

Checking Main Bearing Clearance with Plastigage

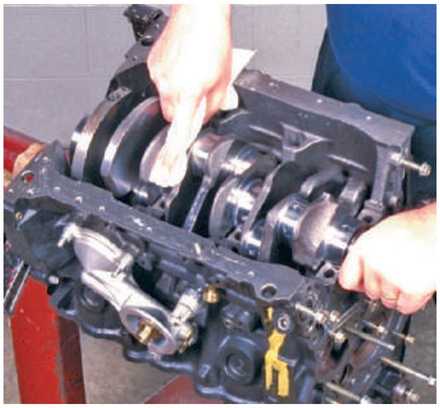


P7-1 Checking the main bearing clearance begins with mounting the engine block upside down on an engine stand.

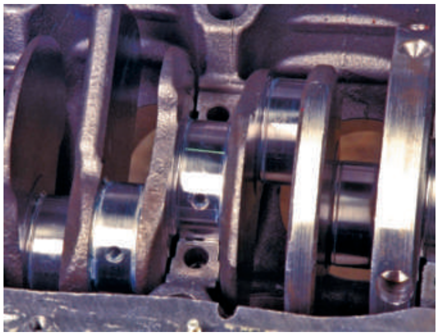
P7-2 Install main bearings into bores, being careful to properly seat them. Wipe the bearings with a clean lint-free rag.



P7-3 Carefully install the crankshaft into the bearings. Try to keep the crankshaft from moving on the bearing surfaces.

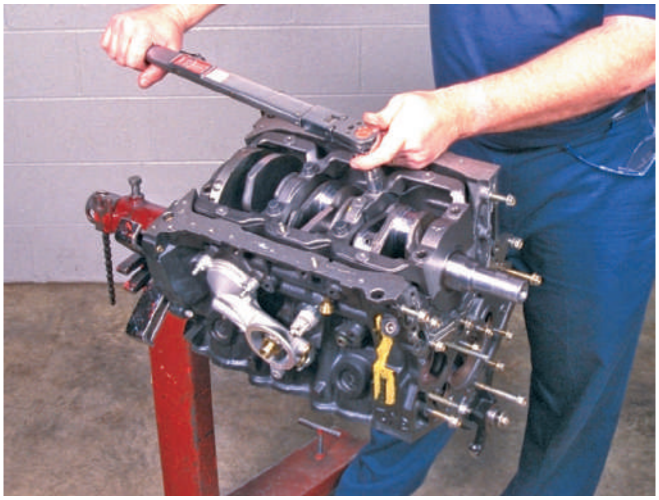


P7-4 Wipe the crankshaft journals with a clean rag.



P7-5 Place a piece of Plastigage on the journal. The piece should fit between the radius of the journal.

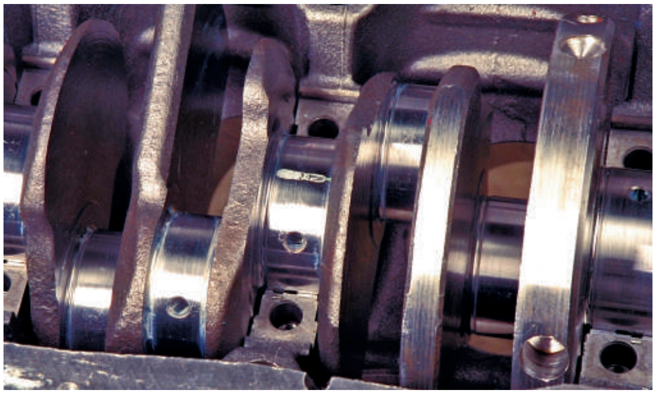
P7-6 Install the main caps in their proper locations and directions. Wipe the threads of the cap bolts with a clean rag.



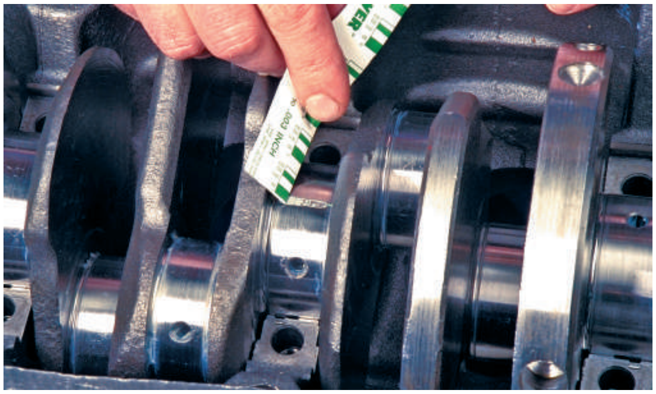
P7-7 Install the cap bolts and tighten them according to the manufacturer's recommendations.

PHOTO SEQUENCE 7

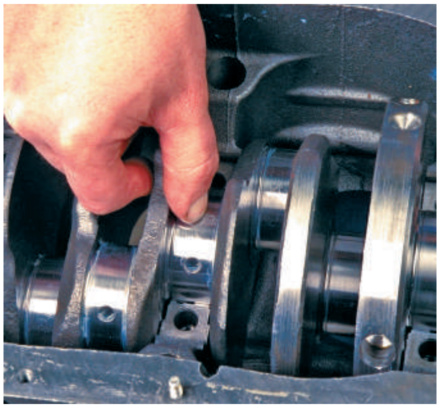
Checking Main Bearing Clearance with Plastigage *(continued)*



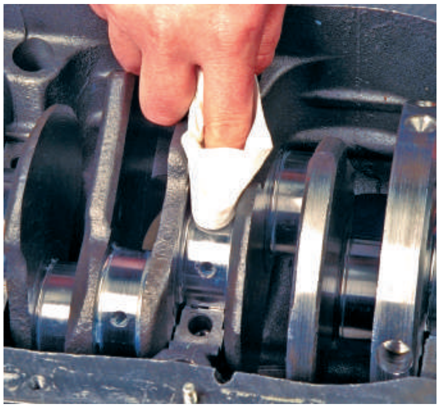
P7-8 Remove the main caps and observe the spread of the Plastigage. If the gage did not spread, try again with a larger gage.



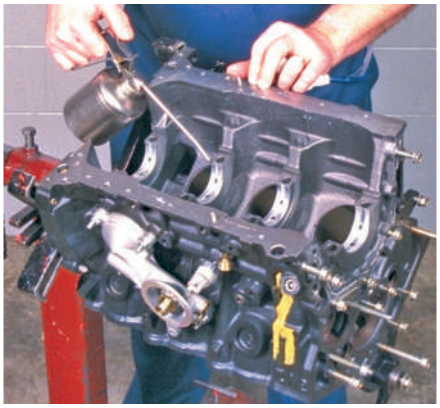
P7-9 Compare the spread of the gage with the scale given on the Plastigage container. Compare the clearance with the specifications.



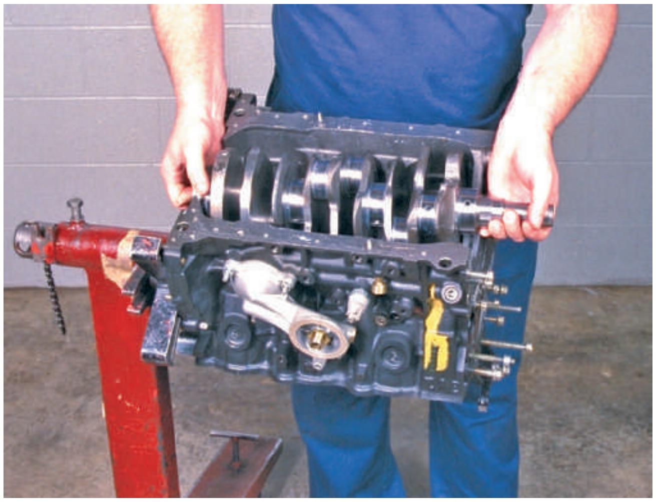
P7-10 Carefully scrape the Plastigage off the journal surface.



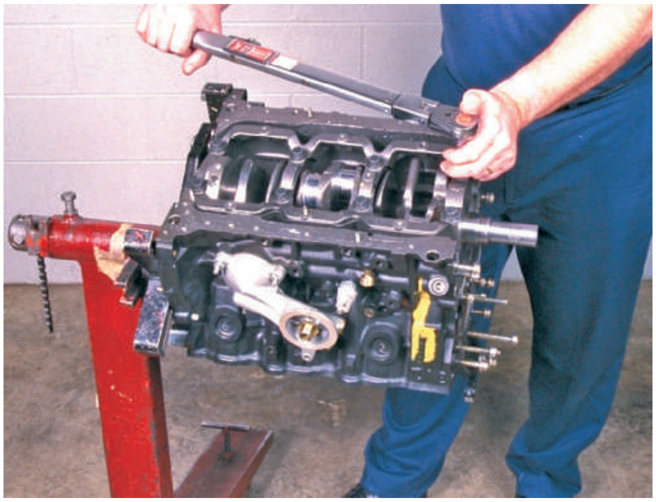
P7-11 Wipe the journal clean with a rag.



P7-12 If the clearance was within the specifications, remove the crankshaft and apply a good coat of fresh engine oil to the bearings.



P7-13 Reinstall the crankshaft and apply a coat of oil to the journal surfaces.



P7-14 Reinstall the main caps and tighten according to specifications.

the pistons up and down while they rotate around the crankshaft. The force applied during the power stroke is applied to the connecting rod as it moves through a variety of angles. The rod has great force applied to it from the top and has great resistance to movement at the bottom. The center section of a rod is basically an "I-beam." This provides maximum strength with minimum weight.

Connecting rods are kept as light as possible. They are generally forged from high-strength steel or made of nodular steel or cast iron. Cast iron is rarely used in automotive engines. Aluminum and titanium connecting rods are also used. Aluminum rods are light and have the ability to absorb high-pressure shocks, but they are not as durable as steel rods. Titanium rods are very strong and light but are rather expensive. Some late-model engines, such as the Ford 4.6–liter and the Chrysler 2.0–liter engines, have powdered (sintered) metal connecting rods. These rods are light and strong and are easily identified by their smoothness.

The **piston pin** is inserted into the small end or piston pin end, which connects the piston to the rod. The piston pin can be pressed-fit in the piston and free fit in the rod. When this is the case, the small end of the rod will be fitted with a bushing. The pin can also be a free fit in the piston and pressed-fit in the rod. In this case no bushings are used. The pin simply moves in the piston using the piston hole as a bearing surface.

The "big" end of the rod is attached to the crankshaft. It is made in two pieces. The upper half is part of the rod. The lower half is called the rod cap. The connecting rod and its cap are manufactured as a unit. During production, the rod caps are either machined off the rod or are scribed and broken off. Since the cap of a powdered metal rod is broken away from the rod during manufacturing, there is an uneven mating surface due to the break and the grain of the powdered metal. These imperfections ensure that the cap is positioned exactly where it was before it was broken off. With other rods, there is the possibility that the rod and cap will be slightly misaligned when they are bolted together.

The big end is fitted with bearing inserts made of the same material as the main bearings. Many connecting rods have a hole drilled through the big end to the bearing area. The bearing insert may have a hole that is aligned with the hole in the rod's bore. This hole supplies oil for lubricating. Some rods have an oil squirt hole. This hole sprays oil onto the cylinder wall to lubricate and cool the piston skirt. When the rod is properly installed, this squirt hole is pointed to the major thrust area of the cylinder wall.

Inspection Closely examine all piston skirts and bearings for unusual wear patterns that may indicate a twisted rod. Rods suspected of being bent or distorted can be checked with a rod alignment checker. Normally a damaged rod is replaced. Many manufacturers recommend a check of the rod bolts before reusing them. The typical procedure involves measuring the diameter of the bolt at its tension portion. If the diameter is less than the minimum, it should be replaced.

Piston and Piston Rings

The piston forms the lower portion of the combustion chamber. The pressures from combustion are exerted against the top of the piston, called the head or **dome**. A piston must be strong enough to face this pressure; however, it should also be as light as possible. This is why most pistons are made of aluminum or aluminum alloys though some newer designs have a steel insert to support the top compression ring. To remove heat from the piston, some manufacturers are looking at adding oil channels under the dome.

There are three basic types of aluminum silicon alloys used in pistons: hypoeutectic, eutectic, and hypereutectic. Hypoeutectic pistons have about 9 percent silicon and most eutectic pistons have 11 percent to 12 percent silicon. **Hypereutectic** pistons have a silicon content above 12 percent. They offer low thermal expansion rates, improved groove wear, good resistance to high temperatures, and greater strength and scuff and seizure resistance.

Late-model engines that are capable of running to fairly high rpm use pistons that have skirts only on the thrust sides. Often these skirts special patches or coatings to reduce friction and wear **(Figure 11–40)**.

The head of the piston can be flat, concave, convex, crowned, raised and relieved for valves, or notched for valves. Newer pistons are typically flat, flat with valve notches, or have a slightly dished crown. The dished crown concentrates the pressure of combustion at the thickest part of the piston head, right above the top of the piston pin boss. The piston pin boss is a built-up area around the bore for the piston pin, sometimes called the **wrist pin (Figure 11–41)**. The pin bore can be offset toward the major thrust side of the piston, which is the side that will contact the cylinder wall during the power stroke.

Piston heads are often coated with hard anodizing, ceramics, or electroplating. These coatings increase

FIGURE 11–40 These pistons are coated with a special compound to reduce friction.

the hardness and resistance to corrosion, cracking, wear, and scratching. New ceramic coatings offer nearly three times the surface hardness of traditional hard-anodized coatings. Ceramic coatings also help protect against spontaneous detonation.

Just below the dome, around the sides of the piston, are grooves. These are used to hold the piston rings. The areas between the grooves are called **ring lands**. Some pistons have a ceramic coating in the top ring groove to prevent the ring from being "welded" inside the groove. Normally there are two compression and one oil control groove. The compression grooves are located toward the top of the piston. The depth of grooves varies with the size of the piston and the type of rings used. The oil control groove is the lowest groove on the piston. They are normally wider than the compression ring grooves and have holes or slots to allow oil to drain. The positions of the ring grooves vary with engine design. Many newer engines have the top compression ring as close as possible to the piston head. This reduces the amount of fuel that can drop down the sides of the piston before combustion. This hidden fuel leaves as unburned hydrocarbons during the exhaust stroke.

The area below the piston pin is called the piston skirt. The area below the bottom ring groove and the tip of the skirt is the piston thrust surface. There are two basic types of piston skirts: a full skirt is used primarily in truck and commercial engines. A slipper type is used in automobile engines and allows for a lighter piston and less material that can hold heat.

To make sure the piston is installed correctly, the top of the piston has a mark. A common mark is a notch machined into the top edge of the piston. Always check the service information for the correct direction and position of the mark. The front of the piston must match the front of the connecting rod **(Figure 11–42)**.

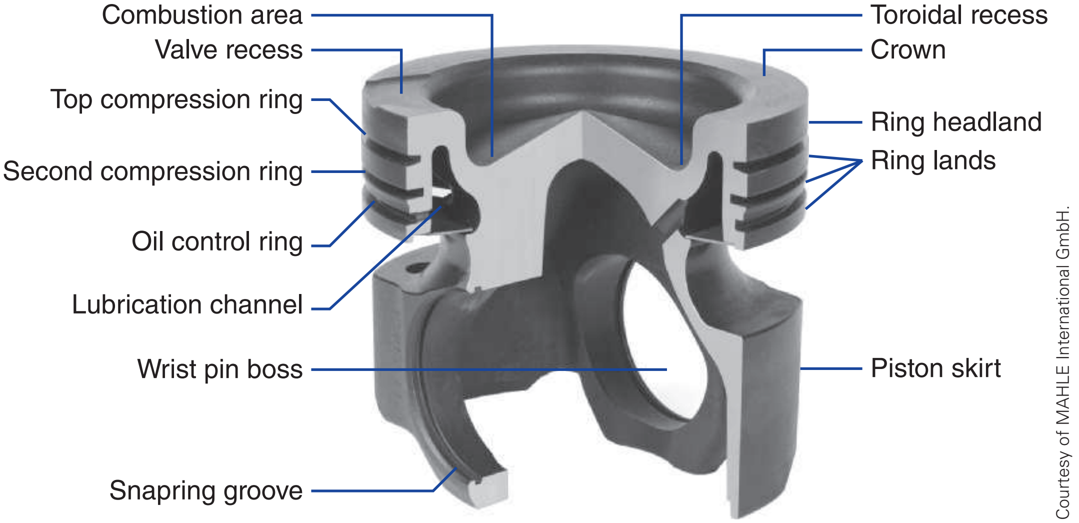


FIGURE 11–41 The features and terminology used to describe a piston.

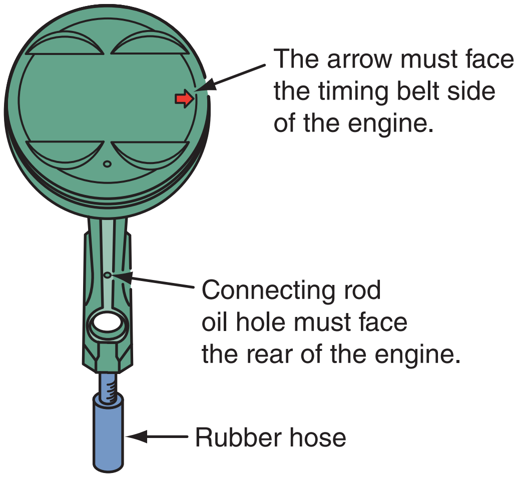


FIGURE 11–42 Always make sure that the markings on the piston and connecting rod are in the correct relationship to each other and they face the correct direction.

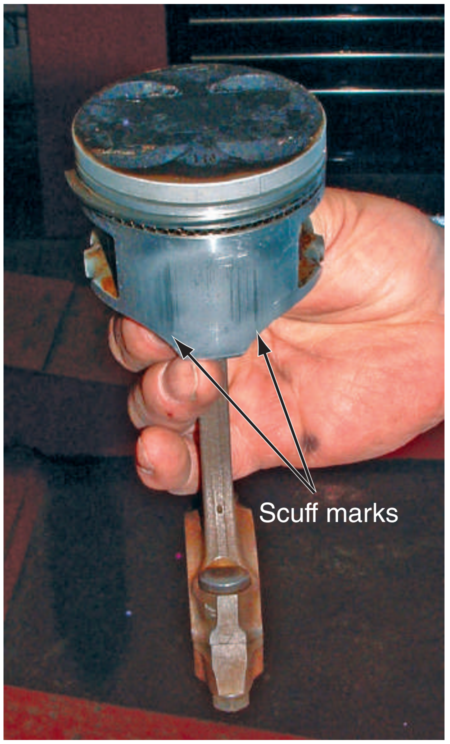


FIGURE 11–43 Each piston should be carefully checked for scuffing on the sides of the piston.

When an engine is designed, piston expansion determines how much piston clearance is required in the cylinder bore. Too little clearance will cause the piston to bind at operating temperatures. Too much will cause piston slap. The clearance is measured between the piston skirt and the cylinder wall.

Inspection Each piston should be carefully checked for damage and cracks. Pay attention to the ring lands and the pin boss area. Look for scuffing on the sides of the piston **(Figure 11–43)**. Minor up and down scuffing is normal. Excessive, irregular, or diagonal scuff marks indicate lubrication, cooling system, or combustion problems. Scuffing may also be caused by a bent connecting rod, seized piston pin, or inadequate piston-to-wall clearance. If any damage is evident, the piston should be replaced.

Remove the piston rings. A ring expander should be used to remove the compression rings. Normally the oil control ring can be rolled off by hand. Remove the carbon from the top of the piston with a gasket scraper. Remove all carbon and oil build up in the back part of the groove. The dirt will prevent the rings from seating properly. Clean the grooves of the piston with a groove cleaning tool or a broken piston ring—make sure no metal is scraped off. The oil control ring groove has slots or holes, which should also be cleaned. Once the grooves are clean, use a brush and solvent to thoroughly clean the piston. Do not use a wire brush.

Ring side clearance is the difference between the thickness of the ring and the width of its groove and it should be measured. To measure this, place a new ring in its groove and, with a feeler gauge, measure the clearance between the ring and the top of the groove **(Figure 11–44)**. If the clearance is not within the specified range, the piston should be replaced.

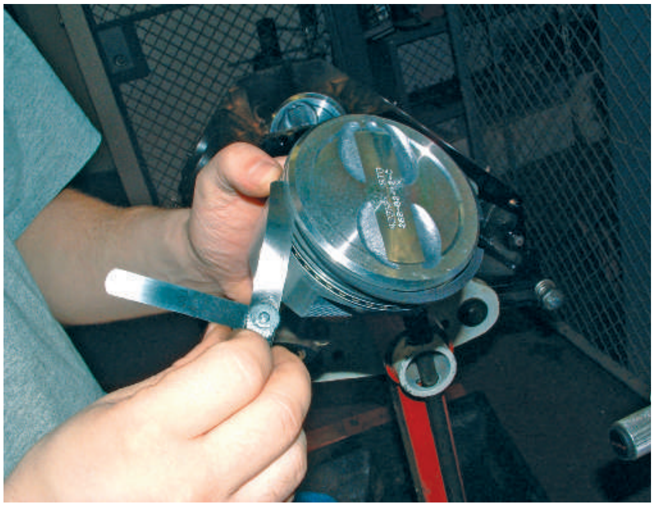


FIGURE 11–44 Ring side clearance should be checked on each piston.

The diameter of the piston should be measured. This measurement is normally taken across specific points on the skirt **(Figure 11–45)**. If the diameter is not within specifications, the piston should be replaced. Some engine rebuilders knurl the skirts if the diameter is slightly less than specifications.

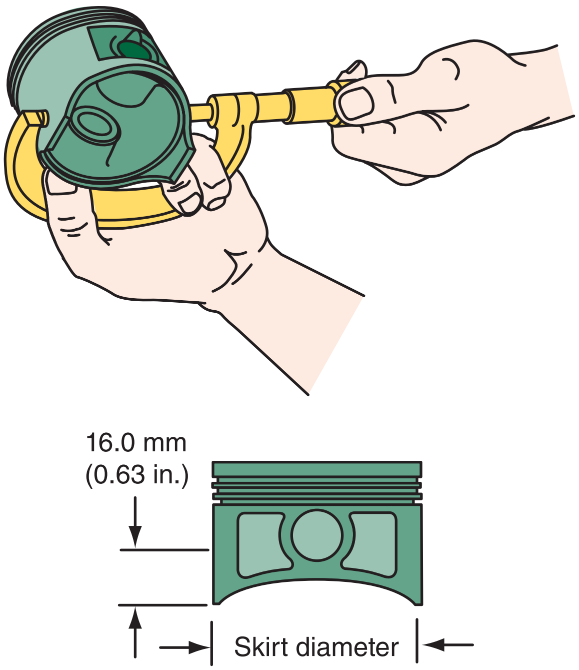


FIGURE 11–45 The diameter of the piston is measured across specific points on the skirt.

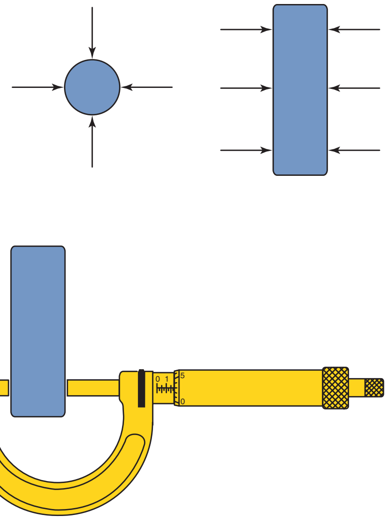


FIGURE 11–46 The piston pin is measured at a variety of spots and its diameter compared to the ID of the piston's pin bore and the small end of the connecting rod.

Piston Pins

Piston pins are basically thick-walled hollow tubes. Most are made from alloy steel and are plated with chrome, carburized, and/or heat-treated to provide good wear resistance. Piston pins are lubricated by oil fed through passages in the connecting rods, oil splashing in the crankcase, or spray nozzles in the rods or pistons.

A piston pin fits through the connecting rod and the piston's pin bore. Inspect the pin boss area on the piston for signs of pin wobble. Then remove the pin to inspect it. With full-floating pins, the retaining clips are removed and the pin pushed out. A pin press is used to remove and install pressed-fit pins. Inspect the pin and pin bore closely for signs of wear. Full-floating pins should have an even wear pattern. If there are signs of uneven wear, suspect a lubrication or connecting rod problem.

Check the fit of the pin. It should move freely through the bores. Also attempt to move the pin up and down in its bores. Any movement means the piston bore or pin is worn. To determine if the bore or pin is worn, measure the diameter of the pin bore. If the bore is not within specifications, replace the piston. Then measure the diameter of the pin **(Figure 11–46)**. If the pin is not within specifications, replace it. If the piston bore and pin meet specifications, measure the small end bore of the connecting rod. If the diameter is not within specifications, replace the connecting rod.

Connecting rods may have a piston pin bushing. Measure the inside diameter of the bushing and compare the reading to specifications. If the bushing is worn or damaged, it should be replaced. The bushing is pressed out of and in the rod with a pin press. Before applying pressure on the pin, make sure it is set squarely above the bore.

Piston Rings

Piston rings fill the gap between the piston and cylinder wall. Piston rings seal the combustion chamber at the piston. They must also remove oil from the cylinder walls to prevent oil from entering the combustion chamber and carry heat from the piston to the cylinder walls to help cool the piston.

Compression Rings Compression rings use combustion pressure to force them against the cylinder wall. During the power stroke, pressure is applied between the inside of the ring and the piston ring groove forcing the ring into full contact with the cylinder walls. This pressure also forces the ring against the bottom of the ring groove. Both of these actions help to form a tight ring seal.

Compression rings are made of cast iron, cast iron coated with molybdenum (moly), and cast iron coated with chrome **(Figure 11–47)**. Moly coatings are porous and can hold oil, and therefore have very high resistance to scuffing. Chrome also has good resistance to scuffing but does not have the oil retention capabilities of moly. Chrome coatings will push away the dirt that enters the cylinder on the intake stroke. Therefore, a moly ring is used as the

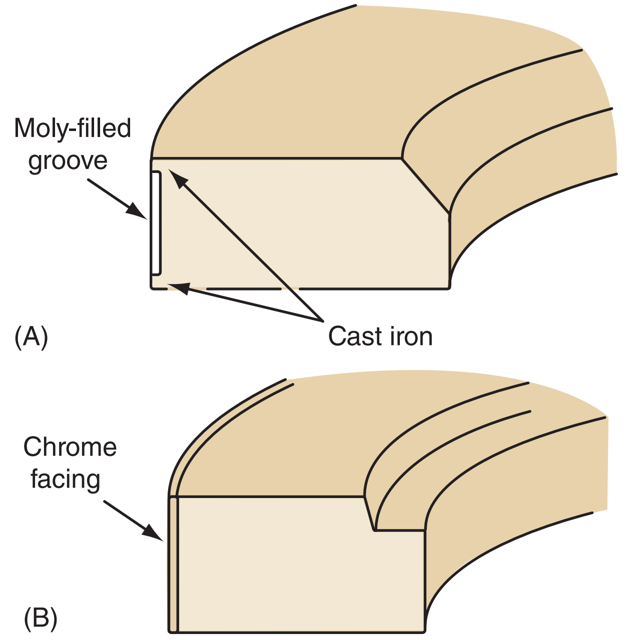


FIGURE 11–47 (A) A moly-coated compression ring. (B) A chrome-faced compression ring.

top ring with a cast iron or chrome ring in the second groove.

Oil Control Rings Oil is constantly applied to the cylinder walls. The oil lubricates and cleans the cylinder wall and helps cool the piston. Controlling this oil is the primary purpose of the oil ring. The two common types of oil rings are the segmented oil ring and the cast-iron oil ring. Both are slotted so that excess oil from the cylinder wall can pass through the ring. The piston's oil ring groove is also slotted.

Segmented oil rings have an upper and a lower scraper rail and an expander. The scraper rings are often chrome rings. The expander pushes the two scrapers out against the cylinder wall.

Installing the Rings

Before installing the rings onto a piston, check the rings' end gap. Place a compression ring into a cylinder. Use an upside-down piston to square the ring in the bore. Measure the gap between the ends of the ring with a feeler gauge **(Figure 11–48)**. Compare the reading to specifications. If the gap exceeds limits, oversized rings should be used. If the gap is less than specifications, the ends of the ring can be filed with a special tool.

Piston ring gap is critical. Excessive gap allows combustion gases to leak into the crankcase. This is commonly called blowby. Too little clearance can score the cylinder walls as the ends of the rings

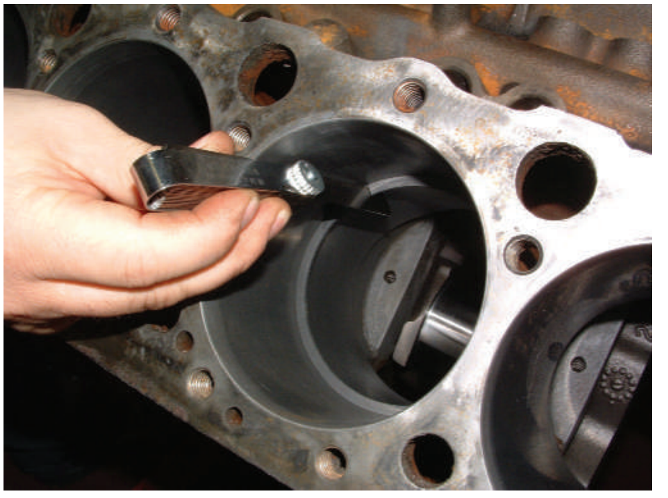


FIGURE 11–48 Check piston ring gap before installing the piston into the cylinder.

come in contact with each other when the engine heats up. Because each ring is subject to different temperatures and pressures, the manufacturer may have different end gap specifications for the various piston rings. The gap of the top compression ring allows some combustion pressure to leak onto the second compression ring, which helps the ring seal.

Apply a light coat of oil on the rings. The oil control ring is installed first. Insert the expander; position the ends above a pin boss but do not allow them to overlap. Then install the rails. Stagger the ends of the three parts. The oil control ring assembly can be installed by hand.

Use a piston expander to install the top and second compression rings **(Figure 11–49)**. Install the second ring first. Make sure the rings are installed in the right position. This includes making sure that the

FIGURE 11–49 Use a ring expander to install the compression rings.

correct side of the ring is facing up. Rings have some sort of mark to show which side should be up. Check the instructions of the ring manufacturer.

Installing Pistons and Connecting Rods

Before installing the piston and connecting rod assemblies, check the marks on the connecting rod caps and the connecting rods to make sure they are a match. Snap the bearing inserts into the connecting rods and rod caps. Make sure the tang on the bearing fits snugly into the matching notch. Check the clearance of the connecting rod bearings with Plastigage or a micrometer. If the clearance is not within specifications, the connecting rod may need to be machined or replaced, or undersized bearings should be installed.

Wipe a coat of clean oil on the cylinder walls. Make sure that the end gaps of the piston rings are staggered **(Figure 11–50)** prior to installing the piston assembly. Then install the piston and rod as shown in Photo Sequence 8.

Coat the crankshaft with clean lubricant or engine oil. After each piston is installed, rotate the crankshaft and check its freedom of movement. If the crankshaft is hard to rotate after a piston has been installed, remove it and look for signs of binding.

After the pistons and rods have been installed, check the connecting rod side clearances **(Figure 11–51)**. Side clearance is the distance between the crankshaft and the side of the connecting rod. It is measured with a feeler gauge. If the clearance is not correct, the rods may need to be machined or replaced.

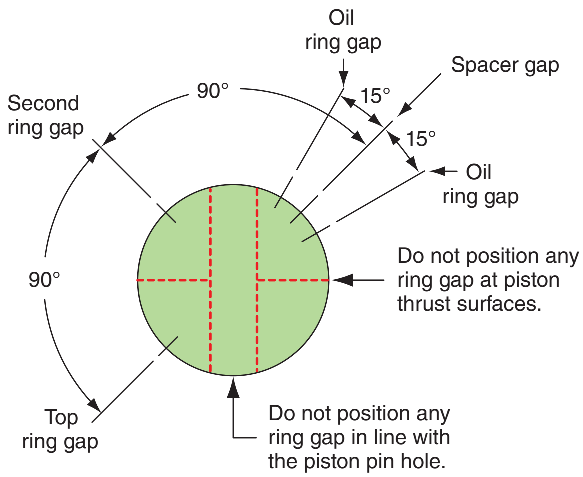


FIGURE 11–50 Make sure that the ring end gaps are arranged according to specifications.

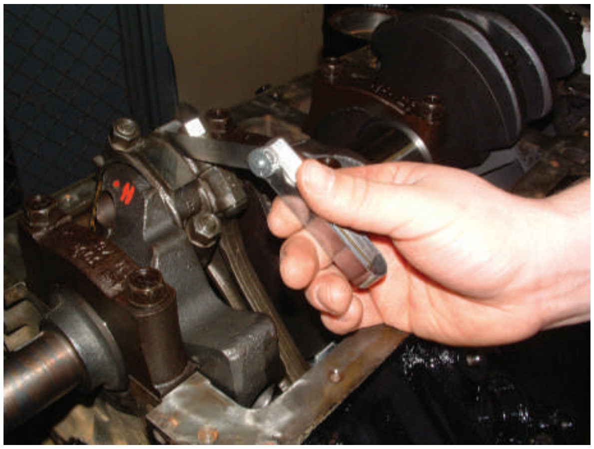


FIGURE 11–51 Measuring connecting rod side clearance.

Timing Components

The timing belt or chain and crankshaft/camshaft gears (sprockets) should be inspected and replaced if damaged or worn. A timing gear with cracks, spalling, or excessive tooth wear is an indication of improper **backlash** (either insufficient or excessive). Excess backlash causes accelerated tooth wear and breakage. Insufficient backlash can cause the gears to bind, which can cause spalling and wear.

Gear backlash is checked with a dial indicator. Check the movement between the camshaft and crankshaft gears at six equally spaced teeth. Firmly hold the gear against the block while making the check. Refer to specifications for backlash limits.

Lifters

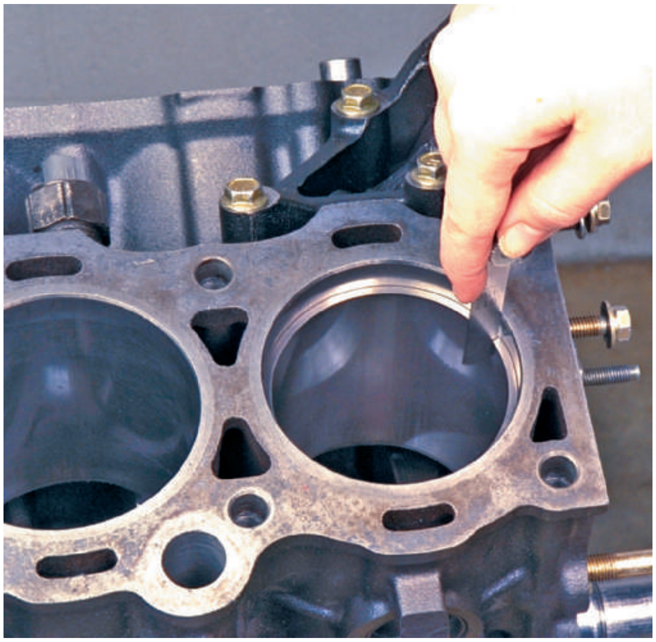
When inspecting lifters, carefully check their bottoms and pushrod sockets. Bottom wear should be off the center on the lobe and with no signs of edge contact. If they show abnormal wear, scoring, or pitting, they should be replaced. Any lifter that has its contact face worn flat or concave must also be replaced **(Figure 11–52)**.

Courtesy of TRW, Inc.

FIGURE 11–52 The possible wear patterns of a lifter that does not spin in its bore.

PHOTO SEQUENCE 8

Installing a Piston and Rod Assembly



P8-1 Insert a new piston ring into the cylinder. Use the head of the piston to position the ring so that it is square with the cylinder wall. Use a feeler gauge to check the end gap. Compare end-gap specifications with the measured gap. Correct as needed. Normally, the gaps of the piston rings are staggered to prevent them from being in line with each other. Piston rings are installed easily with a ring expander.

P8-2 Before attempting to install the piston and rod assembly into the cylinder bore, place rubber or aluminum protectors or boots over the threaded section of the rod bolts. This will help prevent bore and crankpin damage.

P8-3 Lightly coat the piston, rings, rod bearings, cylinder wall, and crankpin with an approved assembly lubricant or a light engine oil. Some technicians submerge the piston in a large can of clean engine oil before it is installed.

P8-4 Stagger the ring end gaps and compress the rings with the ring compressor. This tool is expanded to fit around the piston rings. It is tightened to compress the piston rings. When the rings are fully compressed, the tool will not compress any further. The piston will fit snugly but not tightly.

Installing a Piston and Rod Assembly *(continued)*

P8-5 Rotate the crankshaft until the crankpin is at its lowest level (BDC). Then place the piston/rod assembly into the cylinder bore until the ring compressor contacts the cylinder block deck. Make sure that the piston reference mark is in correct relation to the front of the engine. Also, when installing the assembly, make certain that the rod threads do not touch or damage the crankpin.

P8-6 Lightly tap on the head of the piston with a mallet handle or block of wood until the piston enters the cylinder bore. Push the piston down the bore while making sure that the connecting rod fits into place on the crankpin. Remove the protective covering from the rod bolts.

P8-7 Position the matching connecting rod cap and finger tighten the rod nuts. Make sure the connecting rod blade and cap markings are on the same side. Gently tap each cap with a plastic mallet as it is being installed to properly position and seat it. Torque the rod nuts to the specifications given in the service information. Repeat the piston/rod assembly procedure for each assembly.

Hydraulic lifters should be removed, disassembled, cleaned, and checked. Check the lifter with a leakdown tester. If the lifters leak down too quickly, noisy operation will result. If the lifters' leakdown does not meet specifications, they should be replaced, along with the camshaft.

Installation of Camshaft and Related Parts

Before installing the camshaft and balance shafts, coat them, including the bearings, with an extreme pressure (EP) lubricant. This helps prevent scuffing and galling during installation and initial startup.

Camshaft Bearings

The bearings are either aluminum or steel with a lining of babbitt. **Babbitt** is a soft slippery material made of mostly lead and tin. Alloys of aluminum are commonly used in late-model engines. Aluminum bearings have a longer service life because they are harder than babbitt, but they are more susceptible to damage from dirt and poor lubrication.

OHV cam bearings are one piece, often called full-round bearings, and are press-fit into the block using a bushing driver and hammer **(Figure 11–53)**. Wipe each cam bearing with a lint-free cloth, then thoroughly coat the camshaft lobes and bearing journals with assembly lube. The bearing at the rear of the block should be installed first. The camshaft journals may have different diameters, with the smallest being on the rear of the block and each journal being progressively larger. Once all of the camshaft bearings have been installed, it is important to make sure that the holes in the bearings are properly aligned with the oiling holes in the cylinder block. The alignment may be checked using a small wire or a squirt can of engine oil. To check the alignment using the wire, carefully pass the wire through the hole in each camshaft bearing. If the wire easily passes through, the bearing is properly aligned. If the wire meets resistance or will not pass through the hole, oil will not be able to reach the camshaft. Alternatively, using the oil can, squirt oil into the hole in each camshaft bearing. The oil should easily pass through. Again, if resistance is met or the oil does not flow, the camshaft will not receive proper lubrication once installed.

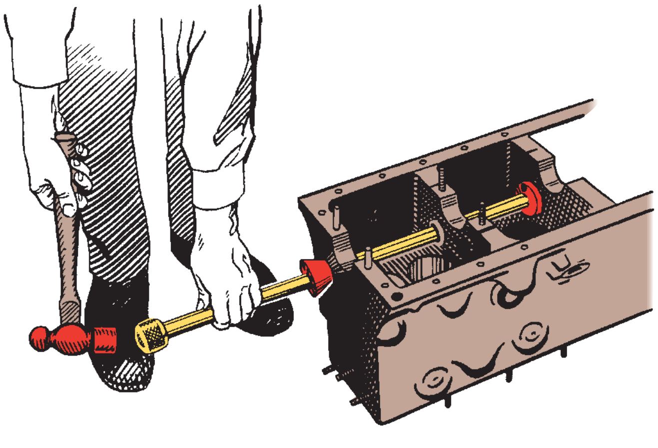


FIGURE 11–53 Cam bearings are normally press-fit into the block or head using a bushing driver and hammer.

While driving the bearings into their bore, be careful not to shave metal off the backs of the bearings. This galling may cause a buildup of metal between the outside of the bearing and the housing bore and result in less clearance. To prevent galling, housing bores should be chamfered.

Camshaft

Install the camshaft, taking care not to damage the bearings with the edge of a cam lobe or journal. Keep it straight while installing it. A threaded bolt in the front of the camshaft helps guide the cam in place.

When the camshaft is in place, install the thrust plate and the timing gear. Align the thrust plate with the woodruff key. Never hammer a gear or sprocket onto the shaft. Heating steel gears helps with installation, but do not heat fiber gears. When installing the gears, keep the gear square and aligned with the keyway at all times.

Once the shaft is in the block, it should be able to be turned by hand. If it does not turn, check for a damaged bearing, a nick on a cam's journal, or a slight misalignment of the block journals.

Lubricate the valve lifters before installing them in their bores. Most cam wear happens within the first few minutes of operation. Prelubrication helps to prevent this.

Crankshaft and Camshaft Timing

During most engine rebuilds, a completely new timing assembly is installed. The camshaft drive must be installed so that the camshaft and crankshaft are in time with each other. Both sprockets are held in position by a key or possibly a pin. There are factory timing marks on the crankshaft and camshaft gears or sprockets **(Figure 11–54)**.

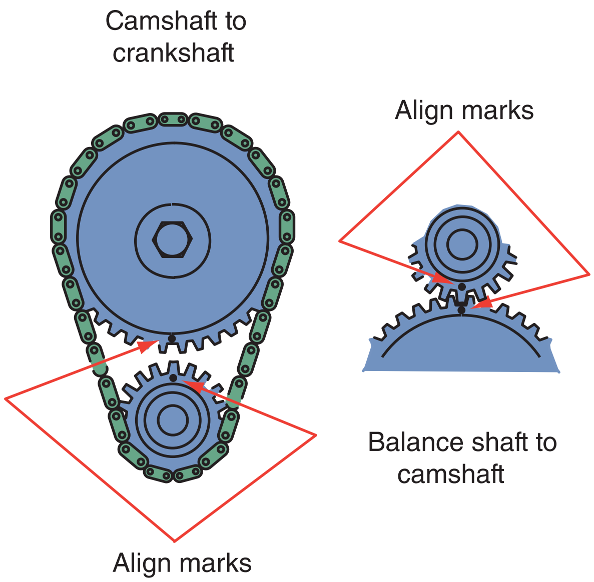


FIGURE 11-54 Camshaft-to-crankshaft and camshaft-to-balance shaft timing marks.

SHOP TALK

Make sure the timing marks are precisely matched. If the gears are misaligned by one gear tooth, the timing will be off by about 17 degrees.

Install the chain onto the crankshaft gear and then around the camshaft sprocket. Carefully place the entire assembly, as a unit, onto the shafts by evenly pressing both gears while keeping the keyways aligned. Then gently tap them in place.

Some manufacturers recommend a check of the clearance between the camshaft gear and its backing plate. This check is done with a feeler gauge. This clearance can often be corrected by repositioning the camshaft gear.

Camshaft end play should also be measured with a dial indicator. As the camshaft is moved back and forth in the block, the indicator will read the amount of movement. Compare this to specifications. End play can be corrected by changing the size of the shim behind the thrust plate or by replacing the thrust plate. Some engines limit the end play with a cam button.

SHOP TALK

There are some OHV engines that are interference engines. If the crankshaft-to-camshaft timing is not correct, the pushrods can bend when the engine is started. Double-check the alignment.

Balance Shafts

Balance shafts are serviced in the same way as crankshafts. Each bearing and journal should be cleaned and carefully inspected. All worn or damaged parts should be replaced. The oil clearance between the shafts and bearings should be checked with Plastigage. Place the balance shaft half bearings into the crankcase and then position the balance shaft(s) onto the bearings. Lay a strip of Plastigage across each journal. Insert the matching bearing halves into the balance shaft housing and tighten the housing bolts to specifications. Now remove the housing bolts and housing. Measure the Plastigage at its widest point. Compare the readings to specifications. Determine the cause of excessive clearances and replace the bearing or balance shaft. Remove the Plastigage completely after measuring.

To install the balance shaft assembly, install the bearings in the crankcase and housing. Apply a light

Performance TIP

A camshaft is designed to open and close the valves at a precise time. The camshaft, crankshaft, timing gears or sprockets, and timing chains or belts are also made to specifications. Those specifications will include a range of acceptable tolerances. However, there is no guarantee the timing assembly will provide exactly what the camshaft was designed to do. Overall engine performance can be affected by a few degrees of misalignment. Many engine builders degree the camshaft to precisely match the position of the camshaft with the crankshaft. Degreeing a cam is recommended when installing a performance camshaft. An engine with a properly degreed camshaft will be more efficient than one without a degreed cam.

The exact procedure for degreeing camshafts varies with each engine design. Doing this requires a degree wheel, a stable pointer attached to the block, a dial indicator with a mount, a positive TDC stop tool, the camshaft's specification sheet, and the parts necessary to adjust the mounting of the timing gears.

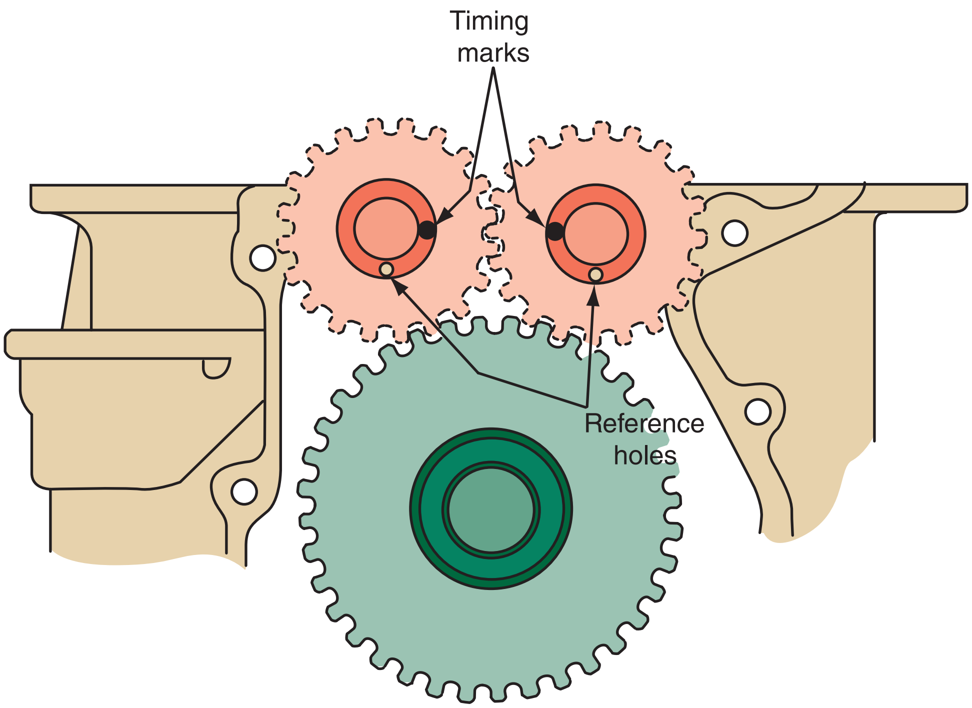


FIGURE 11–55 Balance shafts must be timed to each other and the crankshaft.

coat of engine oil on the bearings. The shafts must be properly timed to the crankshaft. On some engines there are two balance shafts; these must be timed to each other, in addition to the crankshaft **(Figure 11–55)**. Align the timing marks of the balance shaft(s). Set the shaft(s) into position in the block. Place the housing with bearings over the shafts. Install and tighten the housing bolts, according to specifications.

Lifters

Before installing the lifters into the lifter bores, coat the lifter bores with assembly lube. Coat the lifters and/or followers one at a time as they are being installed. After they have been installed, rotate the camshaft to check for binding or misalignment.

Oil Pump

After an engine is rebuilt, a new or rebuilt oil pump is often installed. If the old pump is to be reused, it should be carefully inspected for wear and thoroughly cleaned. The oil pump may be located in the oil pan or mounted to the front of the engine **(Figure 11–56)**. Its installation depends on the engine's design, but it is typically driven by the crankshaft and creates suction to draw oil from the oil pan through a strainer. The pump's suction creates

SHOP TALK

Some technicians submerge the hydraulic lifters in clean oil to allow them to fill with oil before installing them.

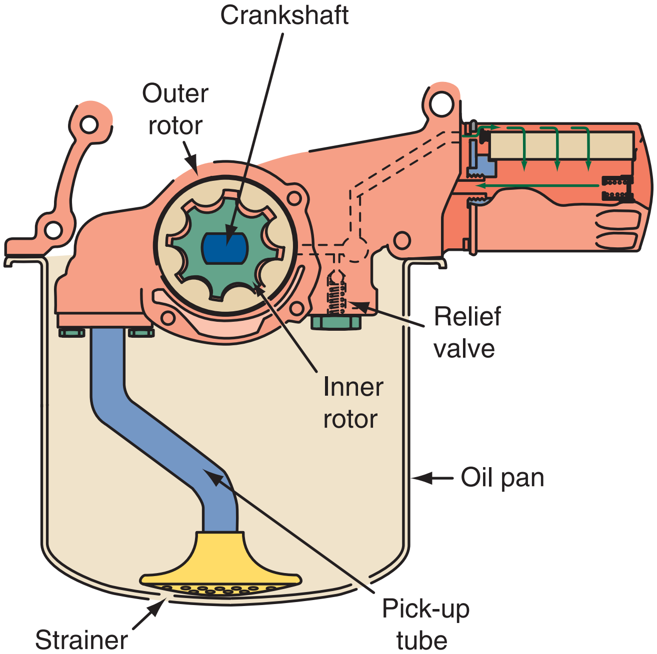


FIGURE 11–56 A typical oil pump driven by the crankshaft.

pressure that forces the oil through the oil filter to various passages. The oil then returns to the oil pan.

Oil Pump Service

An oil pump is seldom the cause of lubrication problems. However, it can go bad. The best way to check an oil pump is to conduct an oil pressure test. This test will not only check the oil pump, but it also will evaluate the rest of the lubrication system.

GO TO Chapter 9 for the correct procedure for conducting and interpreting an oil pressure test.

A new or rebuilt oil pump is normally installed when an engine is rebuilt. Although the oil pump is the best lubricated part of an engine, it is lubricated before the oil passes through the filter. Therefore, it can experience premature failure due to dirt or other materials entering the pump.

Inspection

The oil pump should be carefully inspected. Carefully remove the pressure relief valve and note the direction it is pointing to so that it can be reinstalled in its proper position. If the relief valve is installed backward, the pump will not be able to build up pressure. Inspect the relief valve spring for signs of collapsing or wear. Check the tension of the spring according to specifications. Also check the piston for scores and free operation in its bore. Remove the housing bolts, then remove the cover from the housing.

Mark the gear teeth so that they can be reassembled with the same tooth indexing **(Figure 11–57)**. The gears and rotors of some pumps are marked by the factory. Once all parts have been removed, clean them and dry them off with compressed air.

Inspect the pump gears or rotors for chipping, galling, pitting, or signs of abnormal wear. Galling is the transfer of material between mated and moving components. This can be due to the microscopic welding of the two parts together followed by the parts separating. Examine the housing bores for

Caution! Always follow the manufacturer's procedure for servicing or replacing an oil pump.

FIGURE 11–57 Mark the gear teeth so they can be reassembled with the same indexing.

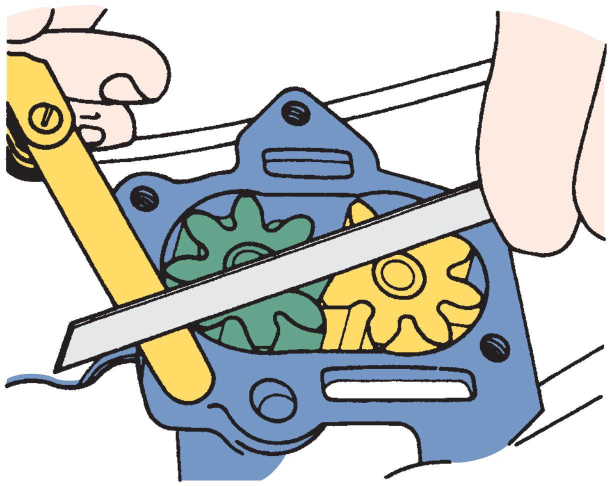


FIGURE 11–58 Use a straightedge and feeler gauge to check the flatness of the pump's sealing surface.

similar signs of wear. If any part of the housing is scored or noticeably worn, replace the pump assembly.

Check the mating surface for the pump cover for wear. If the cover is excessively worn, scored, or scratched, replace the pump. Use a feeler gauge and straightedge to check its flatness **(Figure 11–58)**. There are specifications for the amount of acceptable warpage. If the cover is excessively warped, replace the pump.

With gear-type pumps, reinstall the gears into the pump body. Use a feeler gauge to check the clearance between the outer gear and pump body **(Figure 11–59)**. If the housing-to-gear clearance exceeds specifications, replace the oil pump.

Use a micrometer to measure the diameter and thickness of the rotors **(Figure 11–60)**. If these dimensions are less than the specified amount, the rotors or the pump must be replaced.

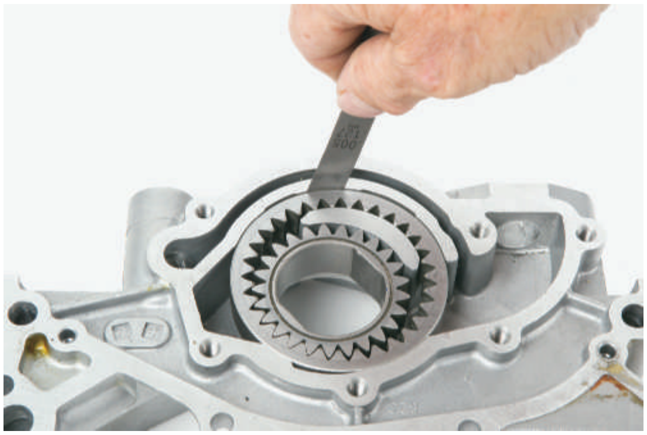


FIGURE 11–59 Check the clearance between the outside diameter of the outer gear and the pump body.

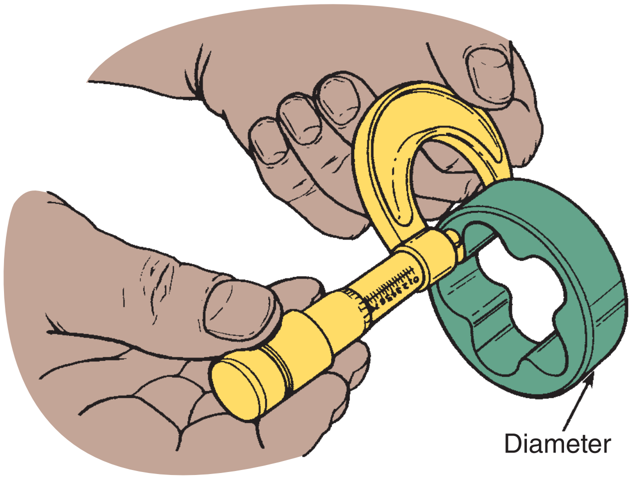


FIGURE 11–60 Measuring the outer rotor with an outside micrometer.

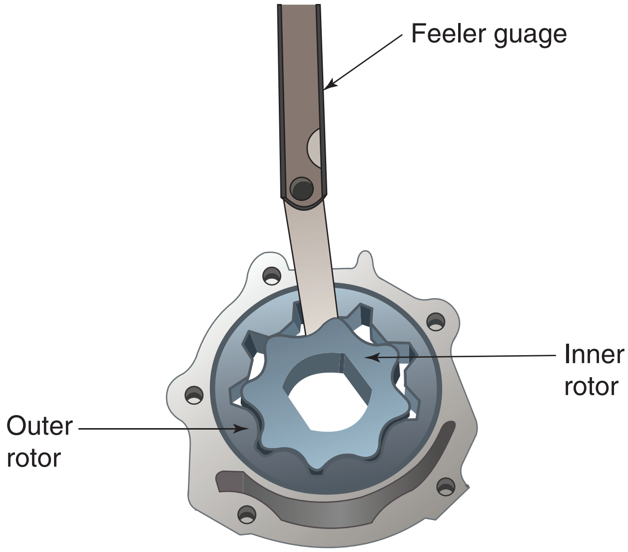


FIGURE 11–61 Measuring clearance between the inner and outer rotor lobes.

With rotor pumps, reinstall the rotors into the pump body. Use a feeler gauge to check the clearance between the outer rotor and pump body. If the housing-to-rotor clearance exceeds specifications, replace the oil pump.

Position the inner and outer rotor lobes so that they face each other. Measure the clearance between them with a feeler gauge **(Figure 11–61)**. A clearance of more than 0.010 inch (0.2540 mm) is unacceptable and the pump should be replaced. The timing case and gear thrust plate might also be worn. Excessive clearance can limit pump efficiency. Replace them as necessary.

Install the cover and tighten the bolts to specifications. The gasket used to seal the end housing is designed to provide the proper clearance between the gears and the end plate. Do not substitute another gasket or make a gasket to replace the original one. If a precut gasket was not originally used, seal the end housing with a thin bead of anaerobic sealing material. Turn the input shaft or gear by hand. It should rotate easily. If it does not, replace the pump.

Remove the old oil seal from the oil pump. Install a new seal into the pump housing. Make sure all mating surfaces of the pump are clean, undamaged, and dry.

If the pump uses a hexagonal drive shaft, inspect the pump drive and shaft to make sure that the corners are not rounded. Check the drive shaft-to-housing clearance by measuring the OD of the shaft and the ID of the drive.

Pickup Unit The pickup screen is normally replaced when an engine is rebuilt. It is important that the pickup is positioned properly. This will avoid oil pan interference and ensure that the pickup is always submerged in oil. When installing the pickup tube, be sure to use new gaskets and seals. Air leaks on the suction side of the oil pump can cause the pressure relief valve to hammer back and forth. Over time, this will cause the valve to fail. Air leaks can also cause oil aeration, foaming, marginal lubrication, and premature engine wear. Air leakage often comes from cracked seams in the pickup tube **(Figure 11–62)**.

Installing the Oil Pump

The pump should be primed before assembly. The preferred way is to submerge the pump in clean engine oil. Make sure the inlet port is fully in the oil.

FIGURE 11-62 Air leaks on the suction side of the oil pump can cause the pressure relief valve to fail, oil aeration, foaming, marginal lubrication, and premature engine wear.

Then turn the pump until you see oil flow from the outlet of the pump.

Crankshaft-Driven Pump

The installation of a typical crankshaft-driven oil pump is as follows:

1. Install a new oil seal into the pump.
2. Apply liquid gasket evenly to the pump's mating surfaces on the block.
3. Do not allow the gasket material to dry.
4. Coat the lip of the oil seal and the O-rings with oil.
5. Align the inner rotor with the crankshaft.
6. Install and tighten the oil pump.
7. Clean all excess grease on the snout of the crankshaft.
8. Install the oil pickup.

Cam-Driven Pumps

The installation of a typical camshaft-driven oil pump is as follows:

1. Apply a suitable sealant to the pump and block.
2. Make sure that the drive gears are properly meshed and the drive shaft is seated in the pump.
3. Install the pump to its full depth and rotate it back and forth slightly to ensure proper positioning and alignment.
4. Once installed, tighten the bolts or screws. The pump must be held in a fully seated position while installing the bolts or screws.
5. Install the oil pump inlet tube and screen assembly.

Distributor-Driven Pump When installing an older-style, distributor-driven oil pump, position the drive shaft into the distributor socket. The stop on the shaft should touch the roof of the crankcase when the shaft is fully seated. With the stop in position, insert the drive shaft into the oil pump. Install the pump and shaft as an assembly. Make sure that the drive shaft is seated in the pump drive. Then tighten the oil pump, attaching screws to specifications. Install the pump inlet tube and screen assembly.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2010	**Make:** Honda	**Model:** CR-V	**Mileage:** 59,919	**RO:** 17201
Concern:	Customer states oil light comes and oil level is low after about 900 miles since oil change.			
Given this concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				
Cause:	Performed oil consumption test and found oil is burning at an excessive rate. Engine is subject to service bulletin regarding incorrect piston ring alignment causing excessive oil consumption.			
Correction:	Remove pistons and replace piston rings.			

KEY TERMS

Babbitt
Backlash
Chamfered
Core plug
Deck
Dome
Flexplate
Flywheel
Forge
Full-round bearing
Glaze
Hypereutectic
Long block
Piston pin
Piston rings
Plastigage
Ring lands
Short block
Split bearing
Taper
Total indicator reading (TIR)
Wrist pin

SUMMARY

- The basic short block assembly consists of the cylinder block, crankshaft, crankshaft bearings, connecting rods, pistons and rings, and oil gallery and core plugs. On OHV engines the camshaft and its bearings are also included.
- The cylinder block houses the areas where combustion occurs.
- A properly reconditioned cylinder must be of the correct diameter, have no taper or runout, and have a surface finish such that the piston rings can seal.
- Glaze is the thin residue that forms on cylinder walls due to a combination of heat, engine oil, and piston movement.
- Core plugs and oil gallery plugs are normally removed and replaced as part of cylinder block reconditioning. The three basic core plugs are the disc or dished type, cup type, and expansion type.
- The camshaft is driven by the crankshaft at half its speed.
- Most premature cam wear develops within the first few minutes of operation.
- The crankshaft turns on a film of oil trapped between the bearing surface and the journal surface. The journals must be smooth and highly polished. The flywheel adds to an engine's smooth running by applying a constant moving force to carry the crankshaft from one firing stroke to the next. The flywheel surface may be used as part of the clutch.
- Crankshaft checks include saddle alignment, straightness, clearance, and end play.
- Bearings carry the critical loads created by crankshaft movement. Most bearings used today are insert bearings.
- Maintaining a specific oil clearance is critical to proper bearing operation. Bearings are available in a variety of undersizes.
- Aluminum pistons are light, yet strong enough to withstand combustion pressure.
- Piston rings are used to fill the gap between the piston and cylinder wall. Most of today's vehicle engines are fitted with two compression rings and one oil control ring.
- When installing a piston and connecting rod assembly, various markings can be used to make sure the installation is correct. Always check the service information for exact locations.
- Connecting rod side clearance determines the amount of oil throw-off from the bearings and is measured with a feeler gauge.
- The camshaft is supported in the cylinder block by friction-type bearings, or bushings, which are typically pressed into the camshaft bore in the block or head. Camshaft bearings are normally replaced during engine rebuilding.
- During most engine rebuilds, a new timing assembly is installed. When installing the timing gears, make sure they are aligned to specifications.
- A new or rebuilt oil pump is normally installed when an engine is rebuilt.
- The oil pump should be primed before engine assembly.

REVIEW QUESTIONS

Short Answer

1. Describe how to inspect an oil pump.
2. What is cylinder taper?
3. Describe how to measure main bearing oil clearance.
4. Where does maximum cylinder bore wear occur and why?

5. List three types of compression rings.
6. What is the purpose of a thrust main bearing?
7. How should the oil pump be primed when installing it into the engine?

Multiple Choice

1. Most pistons used today are made of ___.
   a. cast iron
   b. aluminum
   c. ceramic
   d. none of the above
2. Cam bearings in OHV engines are typically which type?
   a. Split insert
   b. Full-round
   c. Thrust
   d. None of the above
3. Which of the following is not of concern when checking a piston?
   a. Diameter
   b. Surface finish
   c. Groove wear
   d. Pin boss wobble
4. Each half of a split bearing is made slightly larger than an exact half. What is this called?
   a. Spread
   b. Crush
   c. Both a and b
   d. Neither a nor b
5. The connecting rod journal is also called the ___.
   a. balancer shaft
   b. vibration damper
   c. Plastigage
   d. crankpin
6. Which of the following are not typically found in the block of a modern engine?
   a. Pistons
   c. Valves
   b. Crankshaft
   d. Oil pump
7. All of the following are functions of the flywheel, *except* it ___ .
   a. provides a mounting place for the clutch assembly
   b. smooths out cylinder firing pulsations
   c. has marks used to set the valve timing
   d. meshes with the starter drive gear
8. Which type of oil ring is slotted so that excess oil can pass through it?
   a. Cast iron
   b. Segmented
   c. Both a and b
   d. Neither a nor b

ASE-STYLE REVIEW QUESTIONS

1. When removing the balance shaft assembly: Technician A inspects the bearings for unusual wear or damage. Technician B smoothens a damaged camshaft or balance shaft journal by lightly sanding it. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. After installing cam bearings: Technician A checks that the oil holes in the bearings are properly aligned with those in the block by squirting oil into the holes. Technician B checks for proper alignment by inserting a wire through the holes. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. Technician A says that a cylinder wall with too smooth a surface will prevent the piston rings from seating properly. Technician B says that a cylinder wall should have a crosshatch honing pattern. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. Technician A installs a cup-type core plug with its flanged edge outward. Technician B installs a dish-type core plug with the dished side facing inward. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

5. Technician A uses a micrometer to measure the connecting rod journal for taper. Technician B uses a micrometer to measure the connecting rod journal for out-of-roundness. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. Technician A says that piston ring end gaps should be the same for each ring on a piston. Technician B says that piston ring end gaps should be aligned before installing the piston into its bore. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. Technician A checks crankshaft oil clearance with a feeler gauge. Technician B uses a dial indicator to check crankshaft oil clearance. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. When removing the piston and rod assemblies from a cylinder block: Technician A positions the throw of the crankshaft at the top of its stroke and removes the connecting rod nuts and cap. Technician B covers the rod bolts with protectors and pushes the piston and rod assembly out with the wooden hammer handle or wooden drift and supports the piston as it comes out of the cylinder. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. Technician A says that crankshaft counterweights offset the weight of the connecting rods and pistons. Technician B says that crankshaft counterweights are used to dampen crankshaft torsional vibrations. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. Technician A uses a feeler gauge and straightedge to determine the pump cover flatness. Technician B uses an outside micrometer to measure the diameter and thickness of the outer rotor. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER 12

UPPER END THEORY AND SERVICE

OBJECTIVES

- Describe the purpose of an engine's cylinder head, valves, and related valve parts.
- Know why there are special service procedures for aluminum and OHC heads.
- Describe the types of combustion chamber shapes.
- Describe the different ways manufacturers vary valve timing.
- Do a complete inspection on valve train parts.
- Describe the purpose, operation, and location of the camshaft.
- Inspect the camshaft and timing components.
- Be able to reassemble a cylinder head.

Camshafts

A camshaft has a cam lobe for each exhaust and intake valve. The height of the lobe is proportional to the amount the valve will open. In all engines, the camshaft converts rotary motion, that of the spinning camshaft lobes, into the linear or reciprocating motion of the valves. In OHC engines, the camshaft fits in a bore in the cylinder head. Many camshafts are cast iron or steel; others are forged steel units. To reduce weight and add strength, the camshaft in many late-model engines is a steel tube with lobes welded to it.

On OHV engines, as the cam lobe rotates, it pushes up on the lifter, which moves the pushrod and one end of the rocker arm up **(Figure 12–1)**. Since a rocker arm is a lever, as that end goes up, the other end moves down. This pushes down on the valve to open it. As the cam continues to rotate, the valve spring closes the valve while maintaining contact between the valve and the rocker arm, thereby keeping the pushrod and the lifter in contact with the rotating cam.

OHC engines may have separate camshafts for the intake and exhaust valves. As these camshafts

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2002	**Make:** Honda	**Model:** Accord	**Mileage:** 119,559	**RO:** 17887
Concern:	Engine cranks but does not start. Customer was driving when engine died.			

Given this concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.

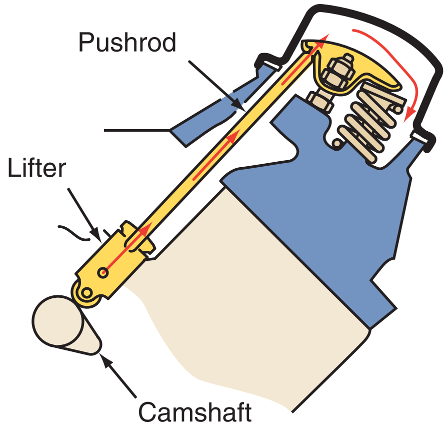


FIGURE 12–1 A basic operation for a camshaft and valve movement.

rotate, the lobes directly open the valves or open them indirectly with cam followers, rocker arms, or bucket-type tappets. The closing of the valves is still the responsibility of the valve springs. Service to the camshaft(s) in an OHC engine is usually part of the procedures for reconditioning the engine's cylinder head.

A camshaft is driven by the crankshaft at half its speed. The size of the camshaft drive gear or sprocket is twice as large as the crankshaft sprocket. During one full rotation of the camshaft, the intake and exhaust valves open and close once. To synchronize the opening and closing of the valves with the position and movement of the pistons, the camshaft is timed to the crankshaft.

In **Figure 12–2** valve action is shown in relation to crankshaft rotation. The intake valve starts to open at 21 degrees BTDC and remains open until it has traveled 51 degrees past BDC. The number of degrees between the valve's opening and closing is called intake valve duration time, which in this example is 252 degrees (21 BTDC + 180 (TDC to BDC) + 51 past BDC = 252). The exhaust stroke begins at 57 degrees before BDC and continues until 15 degrees ATDC. The total exhaust valve duration is 252 degrees. The specifications for the camshaft used in the figure show the duration of the intake valve to be the same as the exhaust. This is typical; however, some camshafts are designed with different durations for the intake and exhaust valves. Different engine designs require different valve opening and closing times. Therefore, each engine design has a unique camshaft.

The actual design of the cams and lobes varies with the type of lifter or follower used in the engine. There are four distinct types of lifters: solid nonroller, hydraulic nonroller, solid roller, and hydraulic roller. Camshafts designed for solid and hydraulic nonroller cams are often called "flat-tappet" cams. A camshaft must be matched with the type of lifter for which it was designed.

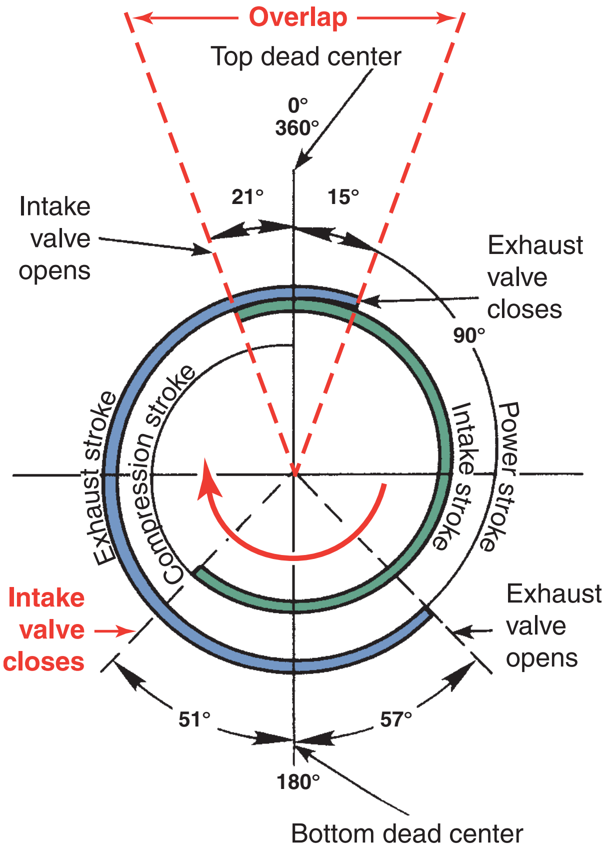


FIGURE 12–2 Typical valve timing diagram.

Camshaft Terminology

Many different terms are used to define the specifications of a camshaft. The actual shape of a cam lobe is called the cam profile. The profile determines the duration and lift provided by the camshaft.

Camshaft **duration** is how long the cam holds the valves open and is expressed in crankshaft degrees. The width of the lobe determines the cam's duration. Lift is the distance the lobe moves the lifter or follower to open the valve. The valve is fully open only when the lifter is at the top of the lobe. Camshaft lift does not express how far the valve is open. Rocker arms increase the actual amount of valve opening.

Both valves are open slightly at the end of the exhaust stroke and the beginning of the intake stroke; this is called valve **overlap**. A camshaft with a long overlap helps empty the cylinders at high engine speeds for improved efficiency. However, since both valves are open for a longer period, low-rpm cylinder pressure tends to drop. Because the

Performance TIP *Installing a camshaft with a different profile is a popular way to increase the performance of an engine. Choosing the right cam for an engine can be tricky. There are many things that must be considered, such as performance goals, type of transmissions, the weight of the vehicle, and other modifications made to the engine. Most camshaft suppliers offer guidelines for choosing the right cam. Basically, opening the valves more and keeping them open longer allows more air and fuel into the engine but allows more mixture to escape through the exhaust. Longer duration camshafts improve high engine speed performance but weaken low-speed power. Lower duration improves low-speed torque, but it limits high-speed power.*

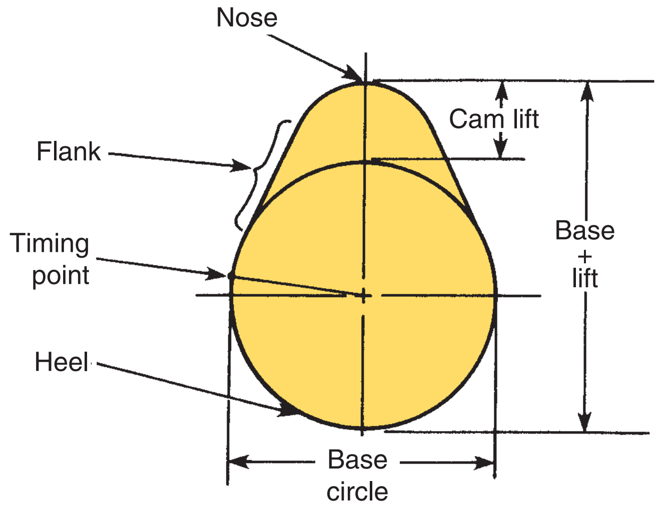


FIGURE 12–3 The basic terminology used to describe the lobe of a camshaft.

amount of overlap has an effect on cylinder pressure, it affects overall engine efficiency and exhaust emissions. Valve overlap also helps to get the intake mixture moving into the cylinder. As the exhaust gases move out of the cylinder, a low pressure is present in the cylinder. This low pressure causes atmospheric pressure to push the intake charge into the cylinder. Less overlap provides for more pressure in the cylinder at low speeds, resulting in more torque at lower speeds.

Lobe Terminology Other terms are used to describe a camshaft's profile **(Figure 12–3)**:

- *Base Circle*—The base circle is the cam without its lobe. It is also the part of the cam where valve adjustments are made.
- *Nose*—The nose is the highest portion of the cam lobe measured from the base circle. This point provides for the maximum amount of lift.
- *Ramp (Flank)*—The ramps are the sides of a cam lobe that lie between the nose and base circle. The ramp on one side is for valve opening and the other for valve closing. How quickly a valve will open and close depends on the steepness of the ramp.

Timing Mechanisms

The camshaft and crankshaft must always remain in the same relative position to each other. The alignment is initially set by matching marks on the gears for both shafts; these are called timing marks. Below are the common configurations for driving the camshaft.

Belt Drive Sprockets on the crankshaft and the camshaft are linked by a continuous neoprene belt. The belt has square-shaped internal teeth that mesh with teeth on the sprockets. The timing belt is reinforced with nylon or fiberglass to give it strength and prevent stretching.

Chain Drive Sprockets on the camshaft and the crankshaft are linked by a continuous chain. Nearly all OHV engines use a chain drive system. Chain drives are also used on many OHC engines, especially DOHCs. Often multiple chains are used and arranged in an elaborate fashion. Most chain drives have a chain tensioner to maintain proper tightness and different silencing pads to reduce chain noise.

Gear Drive A gear on the crankshaft meshes directly with a gear on the camshaft. The crankshaft gear is usually iron or steel. The camshaft gear is steel on heavy-duty applications, or aluminum or pressed fiber when quiet operation is a major consideration. Gear drives are used in a few OHV applications.

Tensioners There is a tensioner on long chain and belt drives. The tensioner may be spring loaded and/or hydraulically operated. Its purpose is to keep the belt or chain under the correct tension as it wears and stretches.

Variable Valve Timing Previously, variable intake and exhaust timing was only possible with overhead cams. Chrysler became the first manufacturer

to produce a cam-in-block engine with independent control of exhaust camshaft timing. This system was introduced in the 2008 Dodge Viper SRT10's 8.4-liter engine. The **variable valve timing (VVT)** system electronically adjusts valve overlap by changing exhaust valve opening times in response to engine speed and load. The system provides an increase in horsepower and torque. It also reduces fuel consumption and exhaust emissions.

This VVT system uses a special camshaft and phaser. The phaser is attached to the end of the camshaft. Inside the phaser are vanes that move within a fixed cavity inside a sealed hub. The movement of the vanes is controlled by oil pressure. The applied oil pressure is controlled by the powertrain control module (PCM). The PCM transmits a signal to a solenoid to move a valve spool that regulates the flow of oil to the phaser cavity. As the applied oil pressure increases, the vanes move against spring pressure. Each vane can rotate a total of 22.5 degrees inside its chamber.

The camshaft is actually two camshafts: an inner shaft and an outer hollow tube-type shaft. It is a camshaft within a camshaft. The exhaust lobes are attached to the outer shaft and the intakes are pinned to the inner camshaft through slots in the outer tube **(Figure 12–4)**.

The phaser hub is fit with an external gear that is driven, via a chain, by the crankshaft. The vanes are connected to the outer tube and the hub. As the vanes rotate, the position of the exhaust lobes change. The amount the exhaust lobes can move is limited by the size of the oil cavity and the slots in the outer tube.

Valve Lifters

Valve lifters, sometimes called **cam followers** or tappets, follow the shape of the cam lobe. Lifters are either mechanical (solid) or hydraulic. Solid

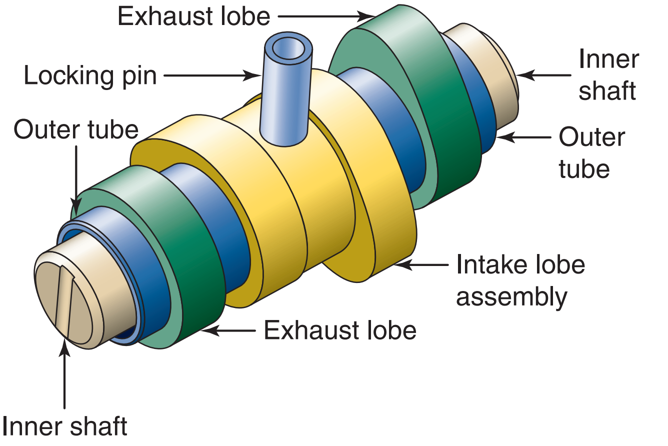


FIGURE 12–4 The basic construction of the camshaft within a camshaft used for variable valve timing on an OHV engine.

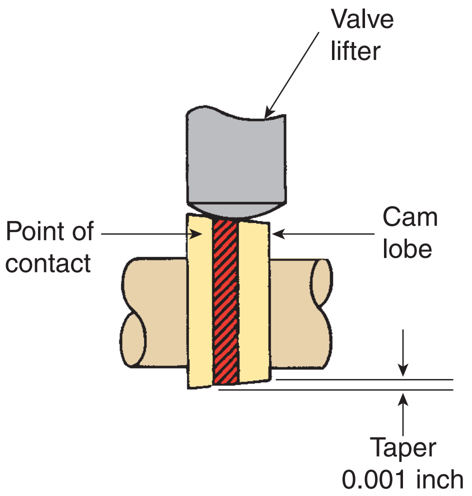


FIGURE 12–5 The camshaft's lobe is tapered to cause the lifters to rotate.

valve lifters provide a rigid connection between the camshaft and the valves. Hydraulic valve lifters provide the same connection but use oil to absorb the shock that results from the movement of the valve train.

Hydraulic lifters are designed to automatically compensate for the effects of engine temperature. Changes in temperature cause valve train components to expand and contract. Hydraulic lifters automatically maintain a direct connection between valve train parts.

Solid lifters require a clearance between the parts of the valve train. This clearance allows for component expansion as the engine gets hot. Periodic adjustment of this clearance must be made. Excessive clearance might cause a clicking noise. This clicking noise is also an indication of the hammering of valve train parts against one another, which results in reduced camshaft and lifter life.

Nonroller lifters rotate in their bore. The contact area between the cam lobe and lifter is one of the highest stressed areas in an engine. Lifter rotation places this stress at different areas at the bottom of the lifter and prevents excessive wear. Cam lobes are ground with a slight taper **(Figure 12–5)**, this causes the lifters to rotate. The speed at which the lifter rotates in its bore depends on the amount of taper. The interface of the lifter and lobe taper also prevents the camshaft from moving to the front or rear while the engine is running.

Roller Lifters In an effort to reduce the friction of the lifter rubbing against the cam lobes—and the resulting power loss—most manufacturers use roller-type lifters. Roller lifters **(Figure 12–6)** have a roller on the camshaft end of the lifter. The roller acts as a wheel and allows the lifter to follow the contour of

FIGURE 12-6 A typical roller lifter.

the cam lobe with little friction. The lifter rolls along the surface of the lobe rather than rub against it. Roller lifters may be solid or hydraulic.

The rollers also allow the lifter to follow aggressive cam lobe designs that provide more lift at a given duration than a flat tappet **(Figure 12–7)**. The lobes on a roller camshaft have steeper ramps and a blunt nose. If the same lobe was used with flat tappets, the edge of the lifter would contact the lobe. This would cause serious damage to the lifter and cam lobe **(Figure 12–8)**.

Roller lifters do not and should not rotate in their bores. Therefore, the lobes on roller camshafts are not tapered. To prevent the lifters from rotating, a pair of lifters may be connected by a bar. The bar prevents the lifters from rotating but allows each lifter to move up and down independently. Some manufacturers do not use a tie-bar; rather, they use special fixtures mounted on the block to prevent lifter rotation.

Since the lobes of the camshaft are not tapered, a roller cam will tend to walk toward the front or rear of the engine block. Cam walk can cause a number

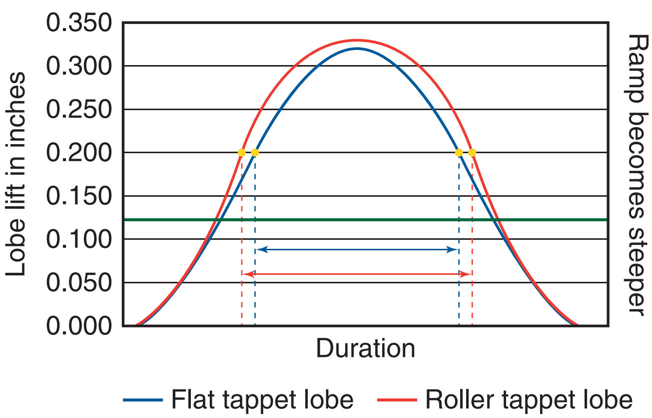


FIGURE 12-7 Roller lifters are able to follow very aggressive cam lobe designs that provide more lift at a given duration than a flat tappet.

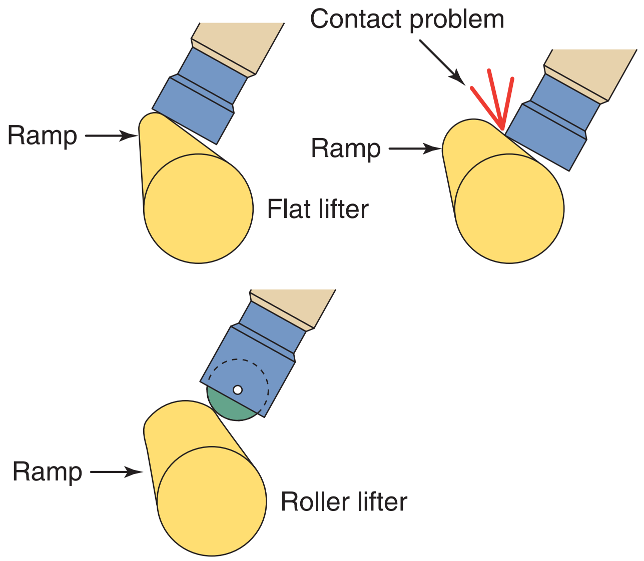


FIGURE 12-8 The lobes on a roller camshaft can hold the valves open longer at higher lifts. If the same lobe was used with flat tappets, the edge of the lifter would contact the lobe.

of problems to the lifters and camshaft. To prevent this problem, thrust washers or cam buttons are fitted at the ends of the camshaft.

Operation of Hydraulic Valve Lifters A hydraulic lifter has a plunger, oil metering valve, pushrod seat, check valve spring, and a plunger return spring housed in a hardened iron body.

When the lifter is resting on the cam's base circle, the valve is closed and the lifter maintains a zero clearance in the valve train. Oil is fed to the lifter through feed holes in its bore. Oil pressure forces the lifter's check valve closed to keep the oil inside the lifter. This forms a rigid connection between the lifter and pushrod. When there is some clearance in the valve train, a spring between the plunger and lifter body pushes the plunger up to eliminate the clearance. As the cam lobe turns and opens a valve, the lifter's oil feed hole moves away from the oil feed in the lifter bore. New oil cannot enter the lifter. The effort to open the valve pushes the lifter's plunger down slightly. This allows a small amount of oil to leak out; this is called **leakdown**. When the lifter returns to the base of the cam, oil can again fill the lifter **(Figure 12–9)**.

If a hydraulic lifter is not able to leak down or does not fill with oil, a noise will be heard from the engine.

Camshaft Bearings

OHC camshafts may be supported by split plain bearings. These split bearings are similar to main and

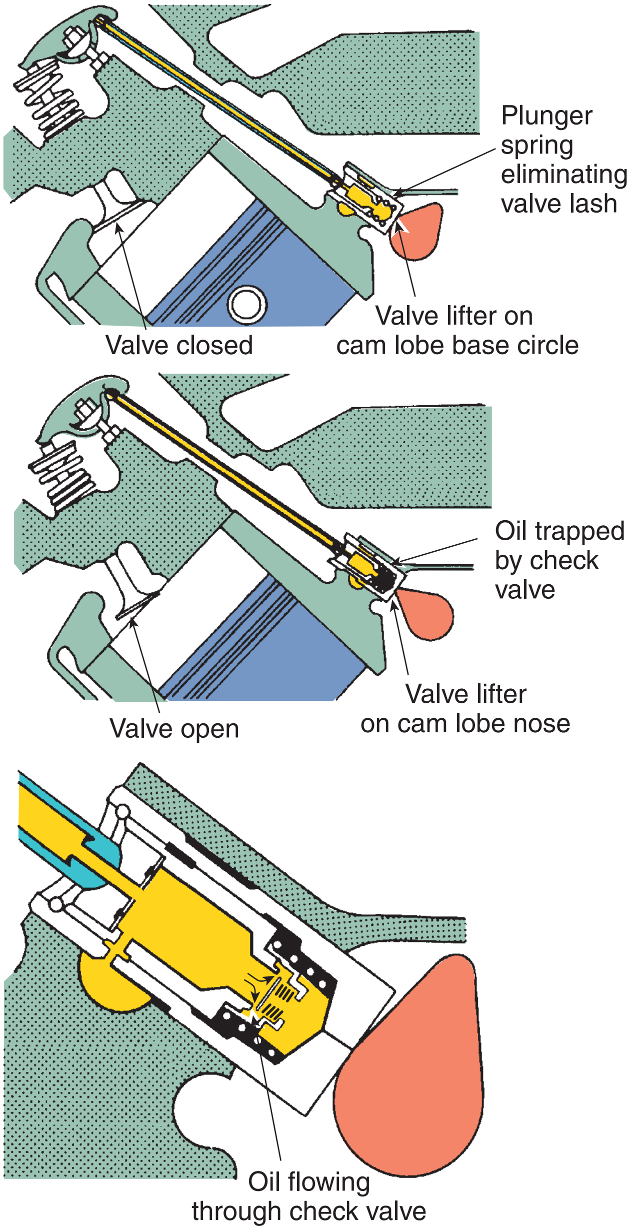


FIGURE 12–9 Hydraulic lifter operation.

connecting rod bearings. The bearings should be inspected for signs of unusual wear that may indicate an oiling or bore alignment problem. Many overhead cams simply ride in the aluminum journals of the cylinder head and no separate bearings are needed.

SHOP TALK

If one cylinder head on a V-type engine is resurfaced, the other one must be cut so that equal amounts of metal are removed from each head.

Cylinder Head

The cylinder head is made of cast iron or aluminum. On OHV engines, the cylinder head contains the valves, valve seats, valve guides, valve springs, rocker arm supports, and a recessed area that makes up the top portion of the combustion chamber. On OHC engines, the cylinder head contains these items, plus the supports for the camshaft and camshaft bearings.

All cylinder heads **(Figure 12–10)** contain passages that match passages in the cylinder block. These passages allow coolant to circulate in the head and oil to drain back into the oil pan. Oil also moves through the head to lube the camshaft and valve train. The coolant flows from passages in the cylinder block through the cylinder head. The coolant then flows back to other parts of the cooling system.

A cylinder head also has tapped holes in the combustion chamber to accept the spark plugs.

The sealing surface of the head must be flat and smooth. To aid in the sealing, a gasket is placed between the head and block. This gasket, called the head gasket, is made of special material that can withstand high temperatures, high pressures, and the expansion of the metals around it. The head also serves as the mounting point for the intake and exhaust manifolds and contains the intake and exhaust ports.

Ports

Intake and exhaust ports are cast into the cylinder head. The size and shape of the ports affect the velocity and volume of the mixture entering and leaving the cylinders.

Normally there is one port for each valve. The intake and exhaust ports may be located on the

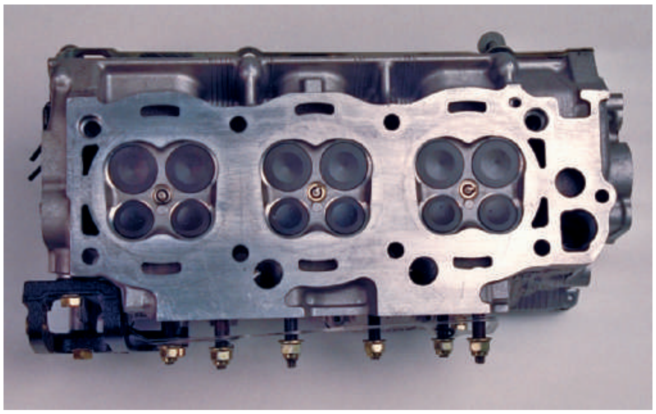


FIGURE 12–10 A typical late-model cylinder head.

same side of the combustion chamber or set on the opposites of the chamber. The ports in this arrangement are called cross-flow ports. The ports for the intake or exhaust valves may be combined on engines with more than two valves per cylinder. These ports are called **Siamese ports**. With Siamese ports, the individual ports around each valve join together to form a larger single port that is connected to a manifold.

Combustion Chamber

The performance of an engine, its fuel efficiency, and its exhaust emissions depend to a large extent on the shape of the combustion chamber. The combustion chamber should be compact to minimize the surface area through which heat is lost to the engine's cooling system. The point of ignition should be at the center of the combustion chamber to minimize the distance from the spark to the furthermost point in the chamber. The shorter the flame path, the more evenly the mixture will burn.

Manufacturers have designed several shapes of combustion chambers. Before looking at the popular combustion chamber designs, two terms should be defined.

1. **Turbulence** is the very rapid movement of gases. Turbulence improves combustion because the air and fuel are mixed better.
2. Quenching is the mixing of gases by pressing them into a thin area, called the quench area.

Wedge Chamber

In the **wedge-type combustion chamber**, the spark plug is located at the wide part of the wedge **(Figure 12–11)**. The spark travels from a large area in the chamber to a smaller one, in the quench area. The mixture in this area is squeezed out at

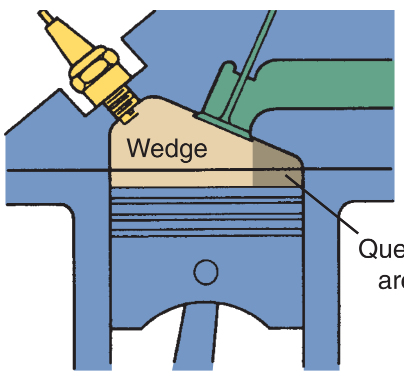


FIGURE 12–11 A typical wedge combustion chamber.

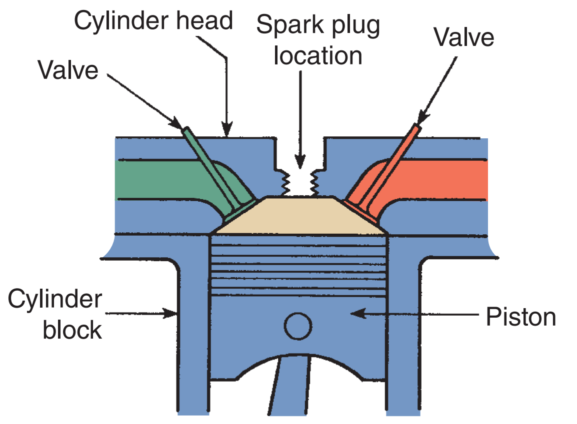


FIGURE 12–12 A typical hemispherical combustion chamber.

high speed as the piston moves up. This causes turbulence, which breaks down the fuel into small particles and helps mix the air and fuel. The turbulence also helps the flame front move evenly throughout the chamber.

Hemispherical Chamber

The **hemispherical combustion chamber** is so named because of its basic shape. Hemi is defined as half, and spherical means circle, and the combustion chamber is shaped like a half circle. This type of cylinder head is also called the hemi-head. The valves are inclined at an angle of 60 to 90 degrees to each other, with the spark plug positioned between them **(Figure 12–12)**.

This design has several advantages. The flame path from the spark plug to the top of the piston is short, resulting in efficient burning. The cross-flow arrangement of the inlet and exhaust ports allows for a relatively free flow of gases in and out of the chamber. The result is that the engine can breathe deeply, meaning that it can draw in a large volume of mixture for the space available and give a high power output. Plus, the mixture is evenly compressed on the compression stroke.

Pentroof Chamber

Many of today's engines have a **pentroof** combustion chamber. This is a modified hemispherical chamber. It is mostly found in engines with four valves per cylinder. The spark plug is located in the center of the chamber and the intake and exhaust valves are on opposite sides of the chamber **(Figure 12–13)**. Pentroof chambers have a squish area around the entire cylinder.

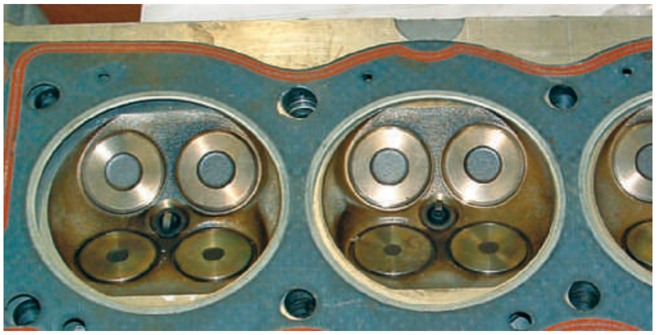


FIGURE 12–13 A cylinder head with pentroof combustion chambers.

Intake and Exhaust Valves

The intake and exhaust valves are also called poppet valves **(Figure 12–14)**. They tend to pop open and close. When they open, intake air flows into the combustion chamber or exhaust gases leave it. When closed, they seal the chamber. The heads of the intake and exhaust valves have different diameters. The intake valve is the larger of the two. An exhaust valve can be smaller because exhaust gases move easier than intake air.

Valve Construction

Most valves are made from hardened steel, steel alloys, or stainless steel. Other metals are often used in high-performance valves. Heat control is an important factor in the design and construction of a valve. The material used to make a valve must be able to withstand high temperatures and be able to dissipate the heat quickly. Most of the heat is dissipated through the contact of the valve face and seat. The heat then moves through the cylinder head to its coolant passages. Heat is also transferred through the valve stem to the valve guide and again to the cylinder head **(Figure 12–15)**.

Intake and exhaust valves are typically made with different materials. Intake valves are low-alloy steels, or heat- and corrosion-resistant high-alloy steels. Intake valves run cooler than exhaust valves. Therefore, intake valves need less heat resistance. However, because the air-fuel mixture tends to wash away the lubrication on the valve stems, the stems may have a coating, such as chrome, or are made from an alloy that offers a good degree of scuff resistance. Intake valves also need less corrosion protection because they are not exposed to the hot exhaust gases.

The alloy used in a typical exhaust valve is chromium with small amounts of nickel, manganese, silicon, and/or nitrogen. Heat resistance is critical for exhaust valves because they face temperatures of 1,500 °F to 4,000 °F (816 °C to 2,204 °C). Resistance to heat and corrosion are especially important for exhaust valves used in turbo- or supercharged engines.

A valve can be made as a single piece or two pieces. Two-piece valves allow the use of different metals for the valve head and the stem. The pieces are spun welded together. These valves typically have a stainless steel head and a high-carbon steel stem. The stems are often chrome plated so that the weld is not visible. One-piece valves run

FIGURE 12–14 A poppet valve.

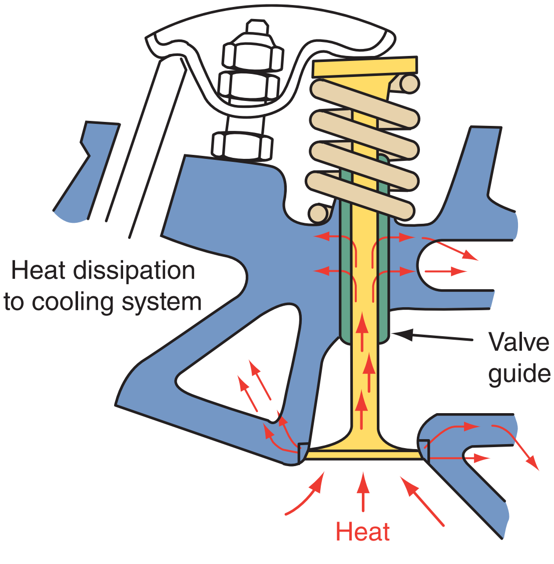


FIGURE 12–15 Valves cool by transferring heat to the liquid passages in the cylinder head.

cooler because the weld of a two-piece valve inhibits the flow of heat up the stem.

Today's engines require higher quality valves that contain more nickel to withstand the heat. The alloys used to make valves depend on the intended use and the design of the engine. Intake valves with high nickel are used in turbocharged engines. Newer engines tend to have smaller and lighter valves than what was used in the past. The lighter weight decreases the amount of power lost moving the valves.

Many late-model valves have a black nitride coating to resist scuffing. Some performance valves may have their stems treated with a dry film lubricant to reduce friction and wear.

Stainless Steel Valves Valves made with stainless steel are quite common. **Stainless steel** is an iron-carbon alloy with a minimum of 10.5 percent chromium content. Stainless steel does not stain, corrode, or rust as easily as ordinary steel. Different types of stainless steel are used to make valves. Austenitic stainless steels contain a maximum of 0.15 percent carbon, a minimum of 16 percent chromium, and nickel and/or manganese to give it strength and improve its heat resistance. Stainless steel is nonmagnetic.

Inconel® Valves Inconel® has a nickel base with 15 percent to 16 percent chromium and 2.4 percent to 3.0 percent titanium. This alloy is used for exhaust valves because it has very good high-temperature strength and good oxidation and corrosion resistance. Inconel® is difficult to machine; therefore, Inconel® valves are replaced when they are damaged.

Stellite Valves Another alloy used in high-temperature applications is stellite. **Stellite** is a cobalt-based alloy with a high chromium content. Stellite is a hard material that is welded to valve faces and stems. It may also be used on the stem tip. It comes in various grades depending on the mix of ingredients that are used in the alloy. This alloy has high resistance to wear, corrosion, erosion, abrasion, and galling.

Sodium Filled Some exhaust valves have a hollow stem. The hollow section of the stem is partially filled with sodium **(Figure 12–16)**. Sodium is a silver-white alkaline metallic substance that transfers heat much better than steel. At operating temperatures, the sodium becomes a liquid. When the valve opens, the sodium splashes down toward the head and absorbs heat. Then as the valve moves up, the sodium moves away from the head and up the stem. The heat absorbed by the sodium is then transferred to the guide where it moves to the coolant passages in the head.

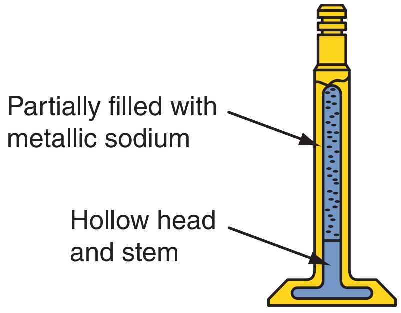


FIGURE 12–16 Some exhaust valves are partially filled with sodium to help cooling.

Warning! Never machine or cut open a sodium-filled valve. Sodium will burn violently when it comes in contact with water.

Titanium Valves Some high-performance engines have titanium valves. These valves dissipate heat well, are durable, and are very light. A titanium valve weighs less than half of a comparable steel valve. Titanium valves are often coated with moly or another friction-reducing material to reduce wear on the valve stems.

Ceramic Valves Ceramic valves are being tested for future use. Ceramic materials weigh less than half of what a comparable size steel valve weighs and can withstand extreme temperatures without weakening or becoming deformed. Ceramic coatings may be applied to the combustion side of the valve head to control heat buildup.

Valve Terminology

Valves **(Figure 12–17)** have a round head with a tapered face used to seal the intake or exhaust port. This seal is made by the **valve face** contacting the valve seat. The angle of the taper depends on the design and manufacturer of the engine. The distance between the valve face and the head of the valve is called the **margin**.

Valve Stems The **valve stem** guides the valve during its up-and-down movement and serves to connect the valve to its spring through its valve spring retainers and keepers. The keepers are fit into a machined slot at the top of the stem, called the valve keeper groove. The stem moves within a **valve guide** that is either machined into (integral type) or pressed into the head (insert type).

Little oil passes through the clearance between the stem and valve guide. Therefore, the surfaces of

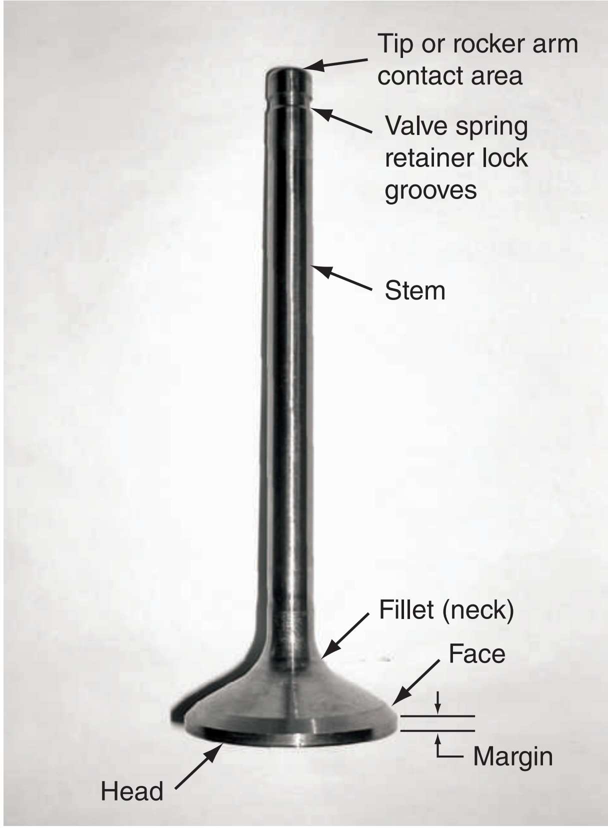


FIGURE 12–17 The parts of a typical valve.

the guide and the stem are designed to minimize friction. The tips of the stem are hardened or stellited to resist damage from the constant hammering they face as the stems are pushed open.

Valve Seats The valve seat **(Figure 12–18)** is the area of the cylinder head contacted by the valve's face. The seat may be machined in the head (integral type) or pressed into the head (insert type). Insert seats are always used with aluminum cylinder heads. They are also used to replace damaged integral seats.

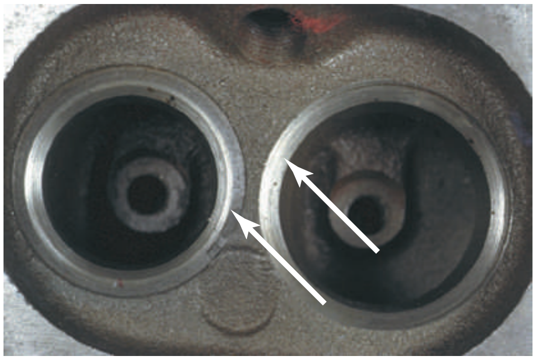


FIGURE 12–18 Valve seats.

Valve seats provide a sealing area for the valves. They also absorb the valve's heat and transfer it to the cylinder head. Seats must be hard enough to withstand the constant closing of the valve. Due to corrosive products found in exhaust gas, seats must be highly resistant to corrosion. When the head is made of cast iron, it has integral seats because cast iron meets those requirements.

Many late-model engines with aluminum heads have sintered powder metal (tungsten carbide) seats. Powder metal seats are harder and more durable than cast-iron seats.

Valve Guides

Valve guides support the valves and prevent them from moving in any direction other than up and down. The inside diameter of a guide is machined to provide a very small clearance with the valve stem. This clearance is important for the following reasons:

- It keeps oil from being drawn into the combustion chamber during the intake stroke, and it keeps oil from leaking into the exhaust port when the pressure in the exhaust port is lower than the pressure in the crankcase.
- It keeps exhaust gases from leaking into the crankcase past the exhaust valve stems during the exhaust stroke.
- It keeps the valve face in perfect alignment with the valve seat.

Valve guides can be cast integrally with the head, or they can be removable **(Figure 12–19)**. Removable or insert guides are press-fit into the head. Aluminum heads are fitted with insert guides. Guides are made from materials that provide low friction and can transfer heat well. Cast-iron guides are mixed or coated with phosphorus and/or chrome. Bronze alloys are also used. These may contain some aluminum, silicon, nickel, and/or zinc.

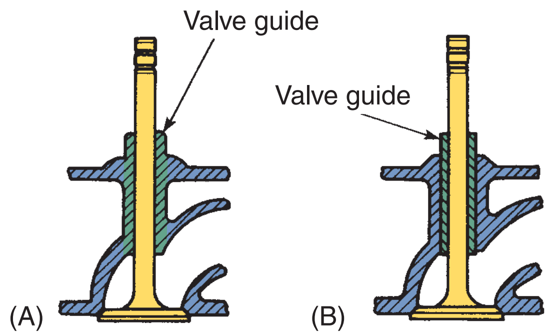


FIGURE 12–19 (A) Integral and (B) removable valve guides.

Valve Spring Retainers and Oil Seals The valve assembly is fit in the head with a spring, retainer, and seal. The oil seal is placed over the top of the valve stem and prevents oil from running down the valve stem and into the combustion chamber. The valve spring, which keeps the valve in a normally closed position, is held in place by the retainer. The retainer locks onto the valve stem with two wedge-shaped parts that are called **valve keepers**. **Figure 12–20** shows the components that make up a valve spring assembly.

Valve Rotators Some engines are equipped with retainers that cause the exhaust valves to rotate. These rotators prevent carbon from building up between the valve face and seat. Carbon buildup can hold the valve partially open, causing it to burn.

Valve Springs A valve spring closes the valve and maintains valve train contact during valve opening and closing. Some engines have one spring per valve. Others use two or three springs. Often the second or third spring is a flat spring called a damper spring, designed to control vibrations. To **dampen** spring vibrations and increase total spring pressure, some engines have a reverse wound secondary spring inside the main spring.

Low spring pressure may allow the valve to float during high-speed operation. Too much pressure will cause premature valve train or camshaft lobe wear and can also lead to valve breakage.

Other Valve-Related Parts

Other parts are associated with the valves.

Rocker Arms Rocker arms change the direction of the cam's lifting force. As the lifter and pushrod move upward, the rocker arm pivots at its center point. This causes a change in direction on the valve side and pushes the valve down. Rocker arms also allow the valve to open farther than the actual lift of the cam lobe. The difference in length from the valve end of the rocker arm and the center of the pivot point (shaft or stud) compared to the pushrod or cam end of the rocker arm is expressed as a ratio. Usually, rocker arm ratios range from1:1 to 1:1.75. A ratio larger than 1:1 results in the valve opening farther than the actual lift of the cam lobe.

GO TO Chapter 3 for an explanation of rocker arm ratios.

The camshaft in some OHC engines rides directly on the rocker arm. One end of the rocker arm fits over a cam follower or lifter and the other end is over the valve stem **(Figure 12–21)**.Often OHC cylinder heads have a complex arrangement of rocker arms **(Figure 12–22)**. Other OHC engines have no rocker arms and the camshaft rides directly on top of the valves.

Rocker arms are made of stamped steel, cast aluminum, or cast iron. Cast rocker arms are attached to a rocker arm shaft mounted to the head by brackets **(Figure 12–23)**. Cast-iron rockers are used in large, low-speed engines. Aluminum rockers typically pivot on needle bearings and are used on high-performance applications. Some engines have a stamped steel rocker arm for each valve. The rocker arm is mounted

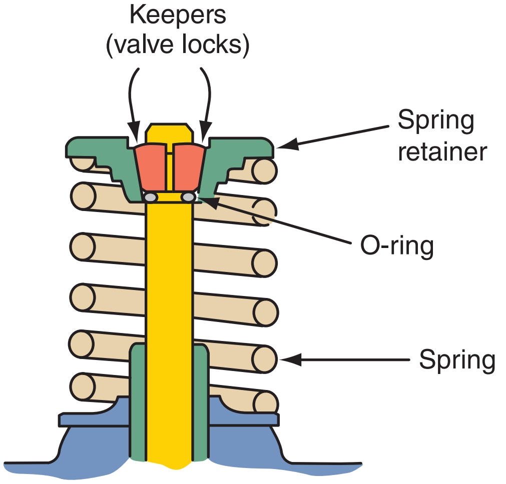


FIGURE 12–20 Valve assembly with spring, retainer, seals, and keepers.

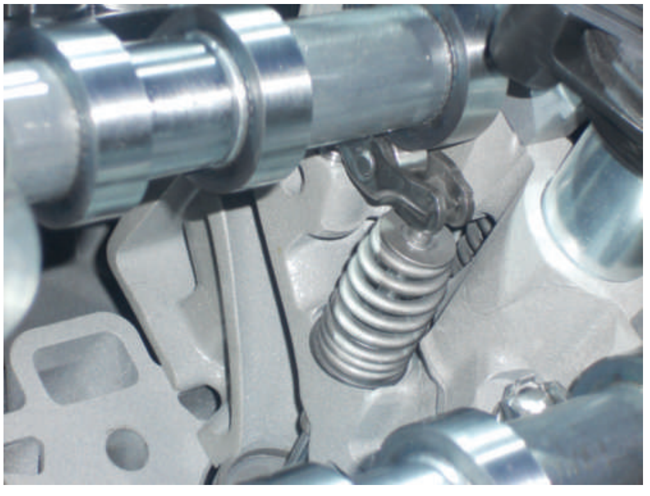


FIGURE 12–21 The camshaft in this setup rides on a rocker arm that has a hydraulic lash adjuster.

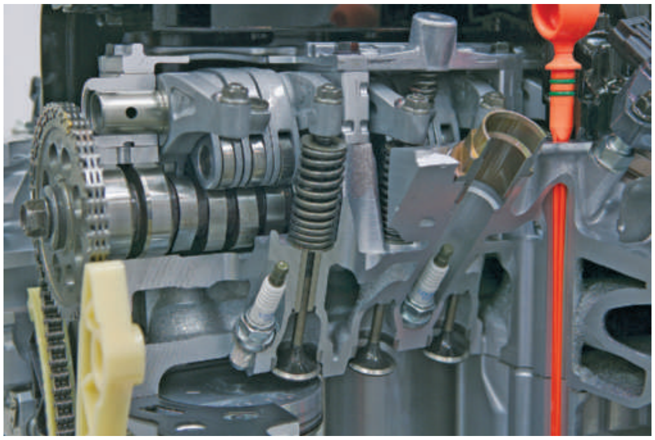


FIGURE 12–22 This arrangement has three different cam lobes for each intake valve.

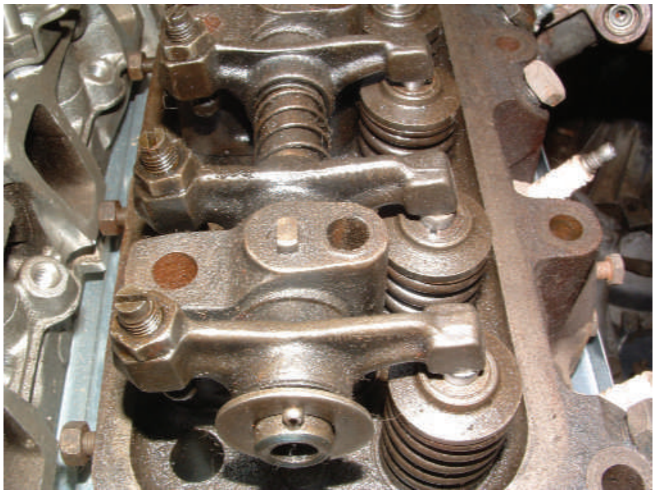


FIGURE 12–23 Rocker arm shaft assemblies.

to a stud that is either pressed or threaded into the cylinder head and must be replaced if worn, bent, broken, or loose.

Pushrods In an OHV engine, a pushrod is the connecting link between the rocker arm and the valve lifter. They transmit the rotation of the camshaft to the valves. The pushrods may have a hole in the center to allow oil to pass from the lifter to the rocker arm assembly **(Figure 12–24)**. Some engines use pushrod guide plates to limit the side movement of the pushrods.

Cam Followers Found on some OHC engines, cam followers are cups that provide a surface for the cam lobes to move the valves. Some followers have a hydraulic unit that fits under the cup to maintain proper valve clearance. Others require periodic adjustment. Most use metal shims between the cup and cam lobe **(Figure 12–25)**. To adjust valve clearance, a shim with a different thickness is inserted.

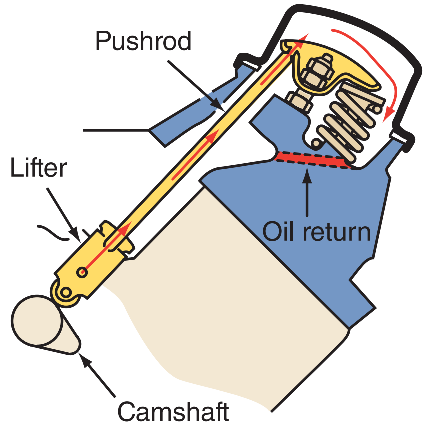


FIGURE 12–24 Most pushrods have a hole through the center to allow oil flow from the hydraulic lifter to the rocker arm assembly.

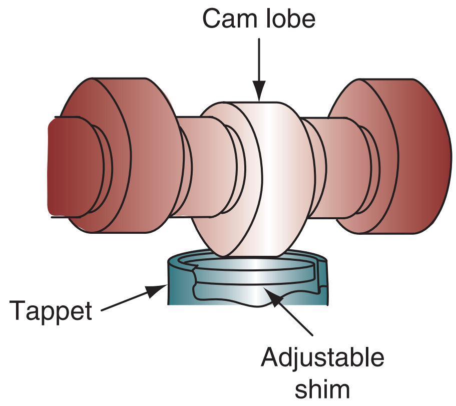


FIGURE 12–25 Some camshafts ride on a tappet that contains a removable shim, which is used to adjust valve clearance.

Camshaft Bearings The camshaft is part of the cylinder head assembly in all OHC-type engines. The unit that holds the camshaft(s) may be a separate unit bolted to the cylinder head or the camshaft's bore is machined into the upper part of the head. Typically, the cylinder heads are machined to accept one or two camshafts and have caps to secure the camshaft **(Figure 12–26)**.

Multivalve Engines

Most newer engines use multivalve arrangements. The basic reason for using more than one intake and/or exhaust valve is simple—better efficiency. To improve efficiency, the flow in and out of the combustion chamber must be improved. In the past, this was attempted by making the valves larger and by changing valve timing. Larger valves allowed more air in and more exhaust out, but the bigger valves are heavy and require stronger springs to close them.

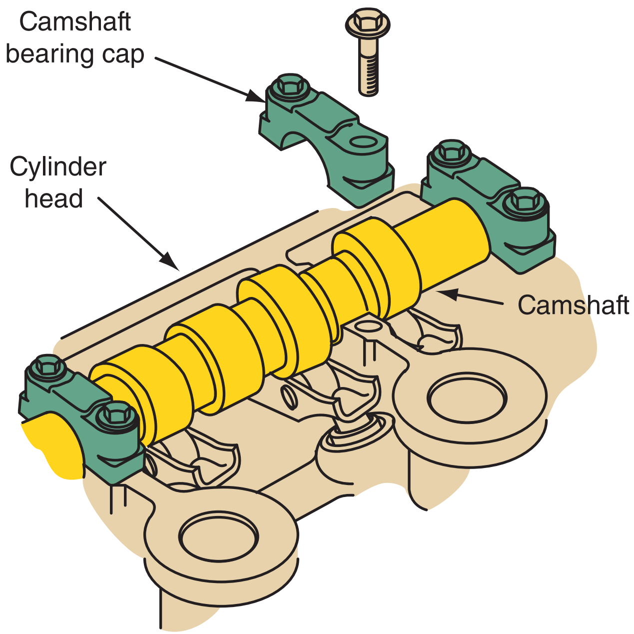


FIGURE 12–26 Many OHC cylinder heads are machined to accept one or two camshafts above the valves and have bearing caps to secure the camshaft.

The stronger springs hold the valves closed tighter and more engine power is required to open them. Also, when an engine is running at low speeds, the air moving past a large valve has a low velocity. This decreases the available engine torque at low speeds.

Although two small valves weigh as much or more than one valve, each valve weighs less and, therefore, the spring tension on each is less. This means less power is required to open them. Also, the velocity of the air in and out at low engine speeds is quicker than it would be with large valves.

Today, multivalve engines can have three **(Figure 12–27)**, four **(Figure 12–28)**, or five valves per cylinder **(Figure 12–29)**. The most common arrangement is four valves per cylinder with two intake and two exhaust valves.

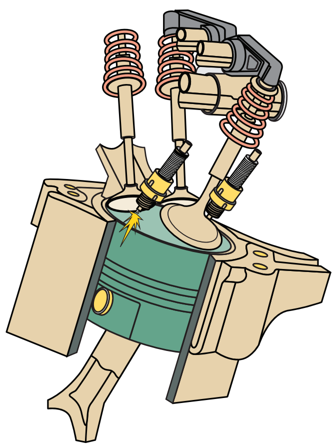


FIGURE 12–27 An engine with two spark plugs, two intake valves, and one exhaust valve for each cylinder.

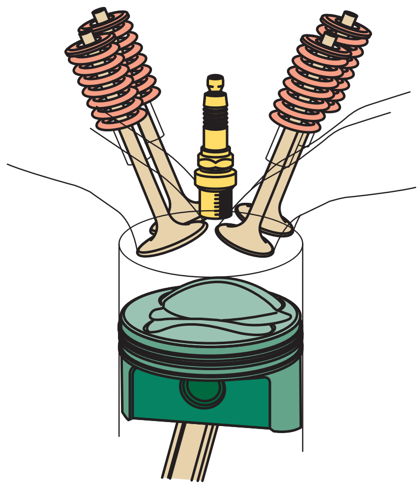


FIGURE 12–28 Typical layout for a cylinder with four valves.

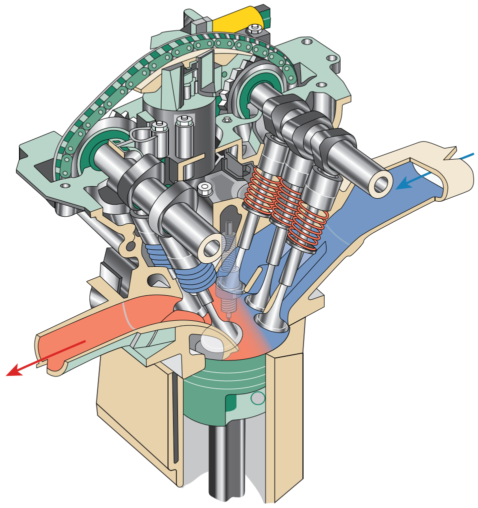


FIGURE 12–29 This five-valve per cylinder arrangement has three intake valves and two exhaust valves.

Using additional intake and exhaust valves results in a more complete combustion, which reduces the chances of misfire and detonation. It also results in better fuel efficiency, cleaner exhaust, and increased power output.

Variable Valve Timing Systems

Changing valve timing in response to driving conditions improves driveability and lowers fuel consumption and emission levels. There are many different variable valve timing (VVT) systems used on today's engines. Many systems only vary the timing of the

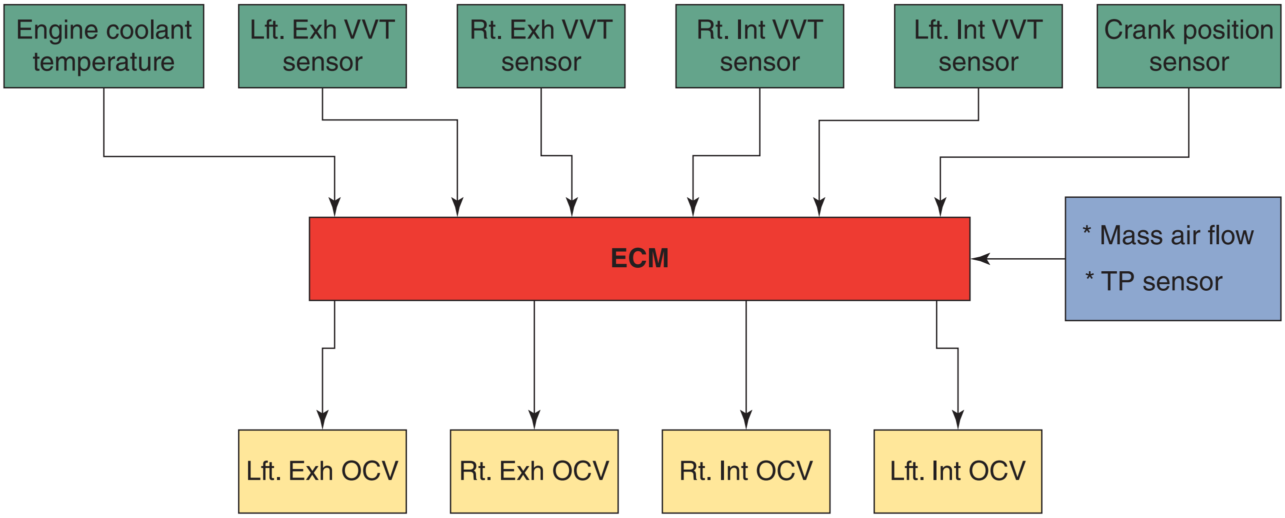


FIGURE 12-30 The information flow for a typical VVT system.

intake or exhaust valves, some vary the timing of both valves, others vary the lift and timing of the intake or exhaust valves, and a few vary the timing and lift of both valves. An ECM advances or retards valve timing based on operating conditions, such as engine speed and load **(Figure 12–30)**.

VVT systems are either staged or continuously variable designs. Most staged systems allow two different valve timing and lift settings. Continuously variable systems alter valve timing whenever operating conditions change. Continuously variable systems change the phasing or timing of a valve's duration **(Figure 12–31)**. These systems provide a wider torque curve, reduction in fuel consumption, improved power at high speeds, and a reduction in hydrocarbon and NO_x emissions. On some engines, VVT has eliminated the need for an exhaust gas recirculation (EGR) valve.

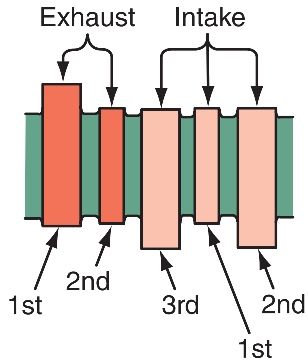
Staged Valve Timing

Most staged valve timing systems switch between two or more different camshaft profiles based on operating conditions. An example of this is Honda's VTEC system used on multivalve engines. The camshaft has three lobes for each pair of intake valves. The third lobe is shaped for more valve lift and different open and close times **(Figure 12–32)**. There is a rocker arm over each of the three lobes. At low engine speeds, only the second lobe's rocker arms move the valves. At high speed, a solenoid valve sends pressurized oil through the rocker shaft to a piston in the outer rocker arms **(Figure 12–33)**. This pushes the piston partly into the center rocker arm, locking the three rocker arms together. The valves now open according to the shape of the third lobe. When the solenoid valve closes, a spring pushes the pistons back into the outer rockers, and the engine runs with normal valve timing.

Late-model Honda i-VTEC engines switch between low-speed and high-speed lobes, similar to older

Advancing	Retarding
Begins Intake Event Sooner	Delays Intake Event
Lengthens Valve Overlap	Shortens Valve Overlap
Builds More Low-End Torque	Builds More High-rpm Power
Decreases Piston-to-Intake Valve Clearance	Increases Piston-to-Intake Valve Clearance

FIGURE 12-31 The effects of changing intake valve timing.



LOBE	INTAKE	EXHAUST
1st	1.1692 in. (29.700 mm)	1.1771 in. (29.900 mm)
2nd	1.4003 in. (35.568 mm)	1.4054 in. (35.699 mm)
3rd	1.4196 in. (36.060 mm)	

FIGURE 12-32 The size of the cam lobes for one cylinder for Honda's three-stage VTEC system.

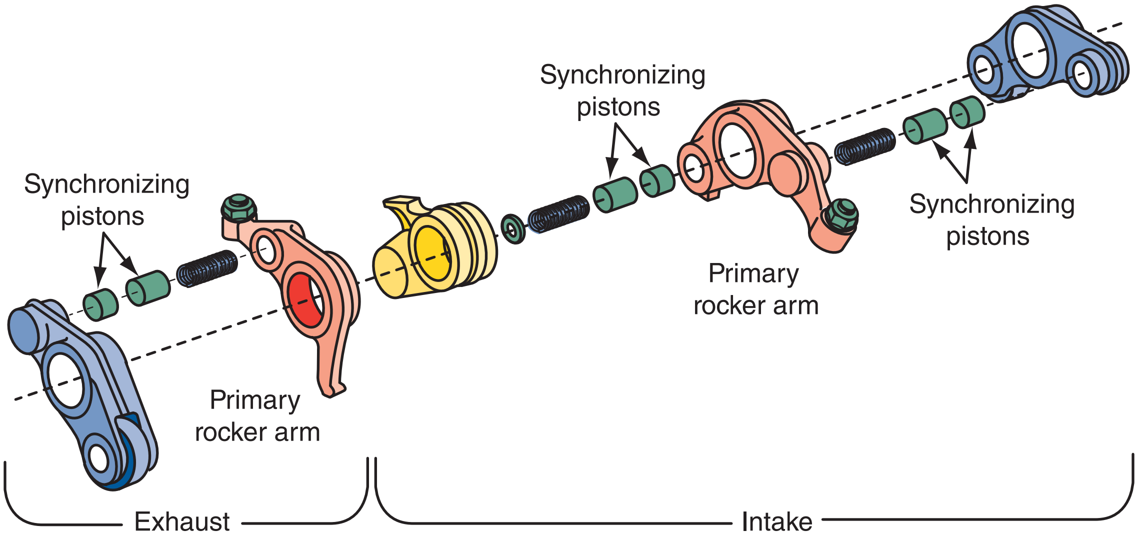


FIGURE 12-33 The synchronizing pin is controlled by oil pressure and locks the rocker arms together.

VTEC engines, but also change intake valve timing to reduce pumping losses at low engine speed. Under light loads, cruising, and low engine rpm, the electronic throttle control system completely opens the throttle plates to increase airflow into the engine. The i-VTEC system switches to the low-speed cam lobes and rocker arms. The cam lobe profile retards intake valve opening, allowing some of the air-fuel mixture to be pumped out of the cylinder and back into the intake manifold, as in an Atkinson cycle engine. This reduces engine output and increases fuel economy. Under high loads and rpm, the system switches to the high-speed lobes which increases valve lift.

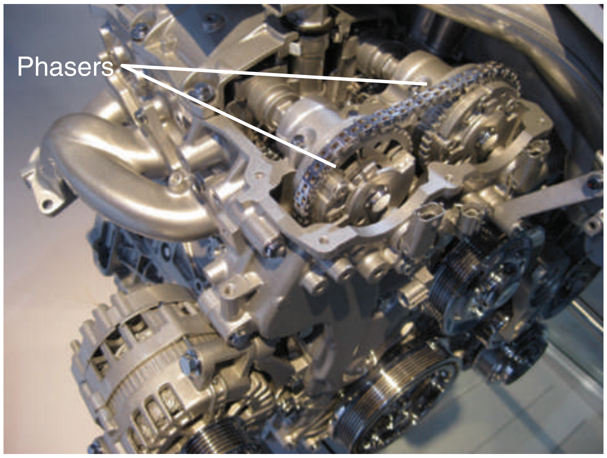


FIGURE 12-34 The phaser assemblies on a late-model engine.

Continuously Variable Timing

To provide continuously variable valve timing, camshafts are fitted with a **phaser.** The phaser is mounted where a timing pulley, sprocket, or gear would be **(Figure 12–34)**. The phaser allows camshaft-to-crankshaft timing to change while the engine is running. Phasers can be electronically or hydraulically controlled. In a hydraulically controlled system, oil flow is controlled by the ECM. Electronic systems rely on stepper motors **(Figure 12–35)**.

Phasers are either based on a helical gear set or vanes enclosed in a housing. A helical phaser has an outer gear driven by the timing belt, an inner gear attached to the camshaft, and a piston placed between the outer gear and inner gear. As the hydraulically controlled piston moves, the helical splines on the piston and inner gear force the camshaft to change its position in relationship to the timing gear.

FIGURE 12-35 Electric camshaft phasers that rely on stepper motors.

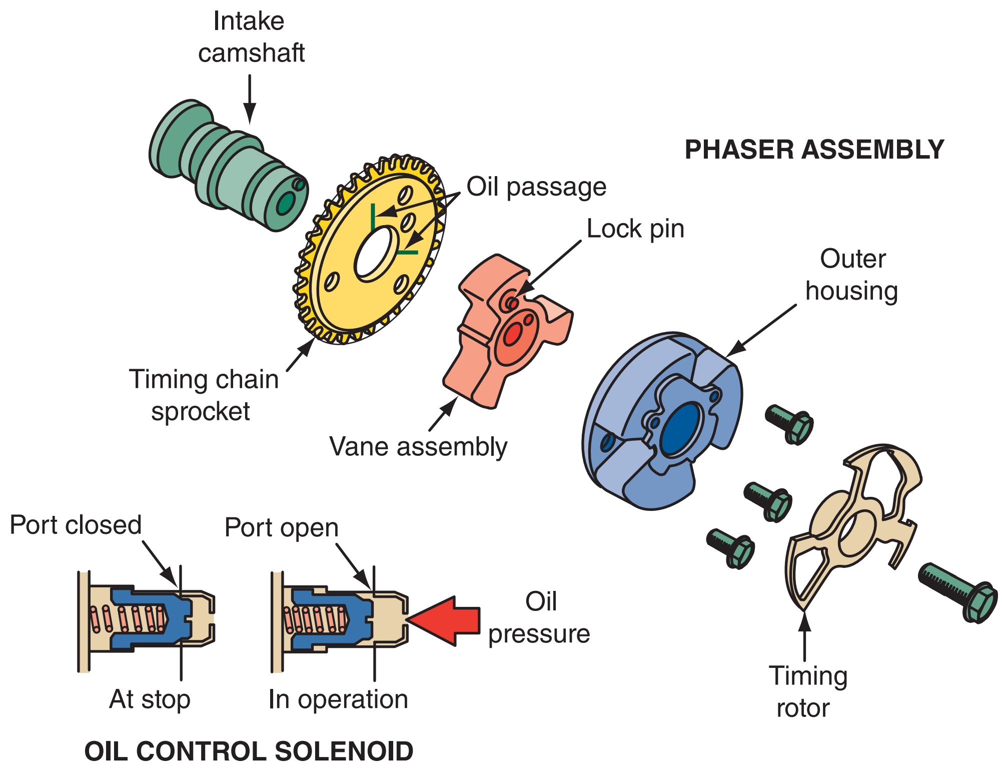


FIGURE 12–36 An exploded view of a phaser.

A vane-type phaser assembly is a sealed unit with a hub and an internal vane assembly **(Figure 12–36)**. Around the hub is the timing gear connected by a chain or belt to the crankshaft. The vane assembly is attached to the camshaft. The vane assembly moves to change the phasing of the camshaft. At the base of the hub are oil ports. Oil from control solenoids enters and exits through these ports. When the ECM determines a need to change valve timing, oil is sent to the correct port. The pressurized oil then pushes on the vanes and causes a change in valve timing.

On a few SOHC engines, the phaser alters the timing, in equal amounts, of both the intake and exhaust camshafts. When more low-speed torque is required, the ECM orders earlier valve opening and closing. When more high-speed power is needed, the cam timing is retarded. By altering the timing of both the intake and exhaust valves, valve overlap is also changed.

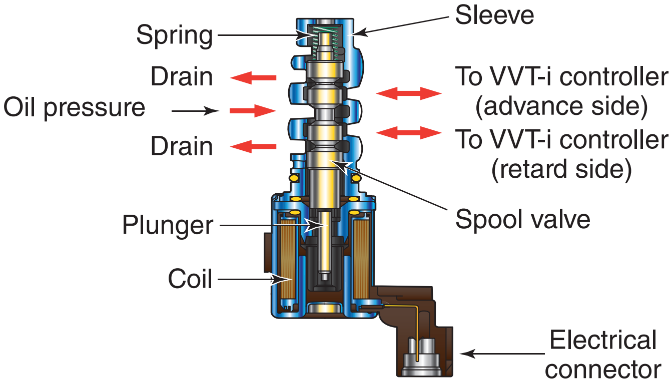


FIGURE 12–37 The spool valve in the camshaft timing oil control valve is duty cycled by the PCM. This allows oil pressure to be applied to the advance or retard side of the phaser.

Toyota's VVT-i System The engine in Toyota hybrids, like other hybrids, operates on the Atkinson cycle. However, it also runs with a conventional four-stroke cycle. The switching between the two cycles is done by valve control. Toyota's VVT-i system is reprogrammed to allow the intake valve to close later for the Atkinson cycle. The Atkinson cycle effectively reduces the displacement of the engine and is in operation when there is low engine load.

The VVT-i system is controlled by the ECM. The ECM adjusts valve timing according to engine speed, intake air volume, throttle position, and water temperature. In response to these inputs, the ECM sends commands to the camshaft timing oil control valve (OCV). The OCV **(Figure 12–37)** directs oil pressure to the advance or retard side of the VVT-i phaser. The position of the OCV spool valve is determined by a varying magnetic field strength, due to varying duty cycles. This magnetic field opposes a constant spring pressure in the valve. The various valve timing settings are shown in **Figure 12–38.**

The VVT-i system relies on crankshaft position sensors and camshaft position sensors to monitor

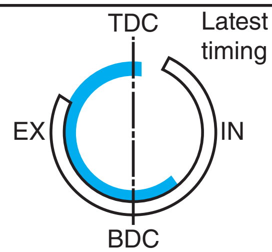
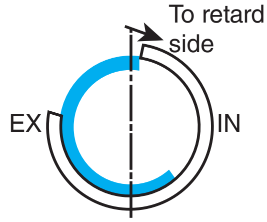
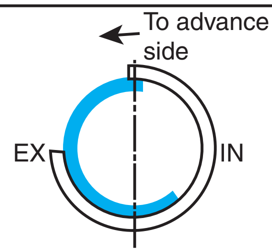
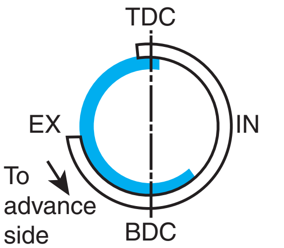
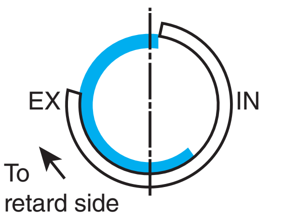
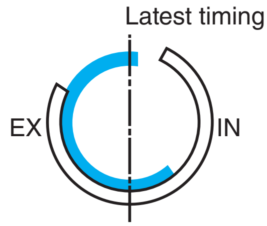
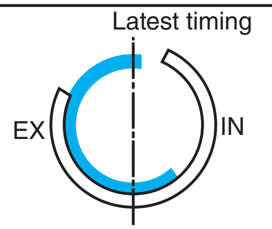
Operation state	Range	Valve timing	Objective	Effect
During idling	1		Eliminating overlap to reduce blow back to the intake side	Stabilized idling rpm better fuel economy
At light load	2		Decreasing overlap to eliminate blow back to the intake side	Ensured engine stability
At medium load	3		Increasing overlap to increase internal EGR for pumping loss elimination	Better fuel economy improved emission control
In low- to medium-speed range with heavy load	4		Advancing the intake valve close timing for volumetric efficiency improvement	Improved torque in low-to-medium speed range
In high-speed range with heavy load	5		Retarding the intake valve close timing for volumetric efficiency improvement	Improved output
At low temperatures	—		Eliminating overlap to prevent blow back to the intake side for reduction of fuel increase at low temperatures, and stabilizing the idling rpm for decreasing fast idle rotation	Stabilized fast idle rpm better fuel economy
Upon starting/ stopping the engine	—		Eliminating overlap to eliminate blow back to the intake side	Improved startability

FIGURE 12–38 The action of Toyota's VVT-i to provide for the Atkinson cycle.

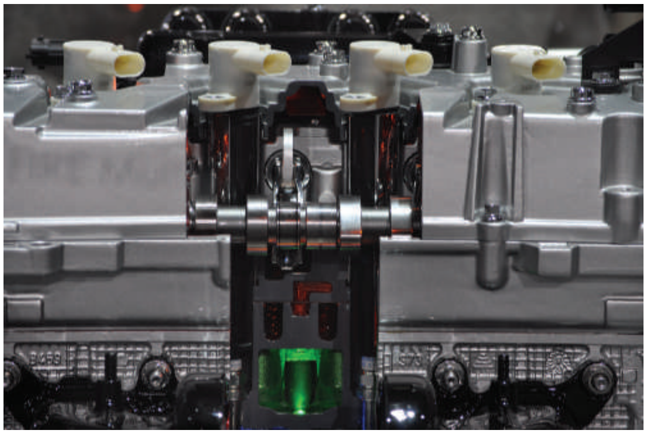


FIGURE 12–39 An outside look at the valve train for Fiat's MultiAir system.

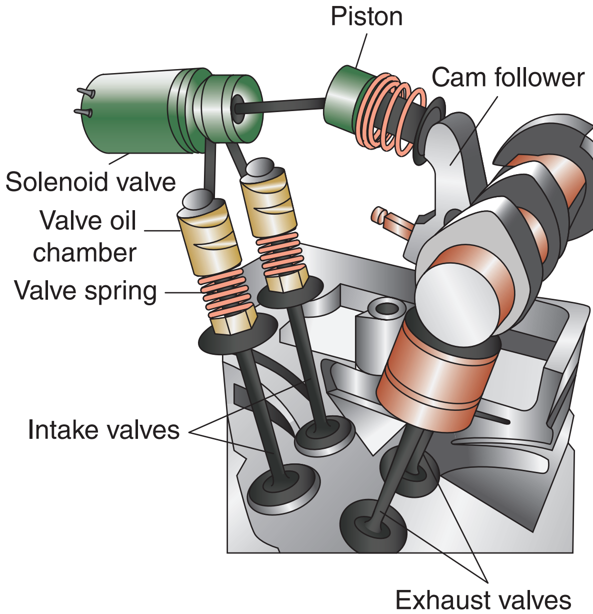


FIGURE 12–40 The primary parts of a Fiat MultiAir system.

camshaft position. Systems that control intake and exhaust valve timing are called dual VVT-i systems. This system allows for varying amounts of valve overlap.

Fiat's MultiAir System Fiat's MultiAir (or UniAir) system is a variable valve lift and duration control system for gasoline or diesel engines. It is a system that relies on mechanical, hydraulic, and electronic technologies **(Figure 12–39)**.

The system controls individual intake valves through the interaction of a roller cam follower, hydraulic piston, hydraulic chamber, an electronically controlled solenoid valve, and a hydraulic valve actuator. As a result, the system allows for variable timing and lift for the intake valves. The camshaft directly operates the exhaust valves.

The system takes direct control of the air that passes through the intake valves. It does not rely on a throttle plate to regulate intake air; therefore "**pumping losses**" are minimized, which accounts for many of the gains from the system. Pumping losses result from the work the pistons must do in order to move air in and out of the cylinders. In an engine with throttle plates, pumping losses affect overall engine performance at all times except when the throttle plates are wide open. All other times, the throttle plates restrict the air flowing to the intake valve and reduce volumetric efficiency. On its intake stroke, a piston must use extra energy to draw air into the cylinder when the throttle plate is partially closed. The amount of lost energy depends on engine speed. It is very low when the engine is at a low rpm, but increases until the throttle plates are more than half open.

The intake valves are controlled by the action of the hydraulic solenoid valve **(Figure 12–40)**, which is controlled by an ECM. When the solenoid valve is closed, trapped oil in the hydraulic chamber provides a solid link between the cam follower and the intake valve. Therefore the intake valves operate according to the profile of the camshaft lobes. The camshaft is designed to maximize power at high engine speeds, by providing high lifts and long opening times.

When the solenoid valve is open, the hydraulic connection between the chamber and the intake valves is lost. Therefore the intake valves do not follow the camshaft lobes and the pressure of the valve spring closes the valve. This action controls when and how much the intake valve will open. For example, to close the valve early, the solenoid is closed at the beginning of the intake stroke and then opens partway through the intake stroke. The early closing of the intake valve provides low speed torque.

The system reacts in an opposite way during engine start-up and low engine speeds. During these times, the solenoid valve is open at the beginning of the intake stroke, and then closes partway through the stroke. This action reduces emissions by increasing the speed of the incoming air.

The length of time the solenoid valve is closed not only controls the valve's duration but it also controls the lift of the valve. Short solenoid closing times result in low lift. Long solenoid closing times result in high valve lift.

Valvetronic System Most BMW engines have infinitely variable intake valve control (Valvetronic). This system is used to regulate the flow of air into the cylinders by controlling valve lift. Therefore, the engine has no need for a throttle plate.

Courtesy of BMW of North America, LLC

FIGURE 12–41 The secondary eccentric shaft and stepper motor assembly for the Valvetronic system.

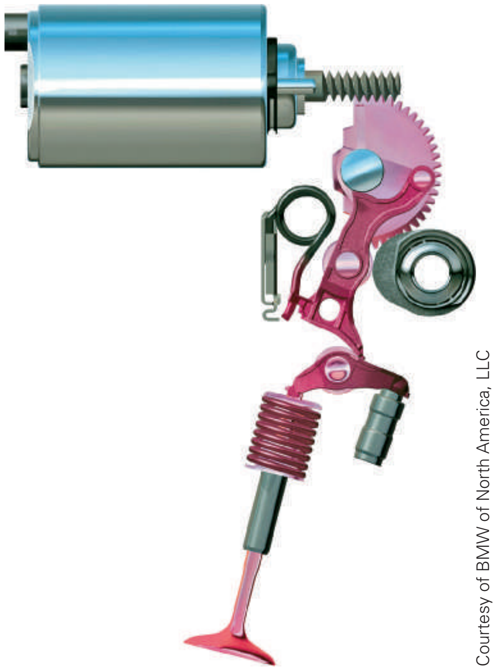
The system uses a conventional camshaft with a secondary eccentric shaft and a series of levers and roller followers that are activated by a stepper motor **(Figure 12–41)**. A computer changes the phase of the eccentric cam to change the action of the valves. The cylinder heads have an extra set of rocker arms, called intermediate arms, positioned between the valve stem and the camshaft. These arms are able to pivot on a central point, which is an electronically actuated camshaft. Therefore the system can vary the lift of the valves without relying on the profile of the conventional camshaft.

At high engine speeds the system provides maximum lift, opening the ports for maximum flow to guarantee rapid filling of the cylinder **(Figure 12–42)**. At low engine speeds, the system reverts to minimal valve lift **(Figure 12–43)**. This reduces the amount of air entering the cylinder. The action of the valves becomes the engine's throttle plates.

The system is coordinated with the independent Double VANOS (**va**riable **No**ckenwellen**s**teuerung) system that continuously varies the timing of the intake and exhaust camshafts. VANOS is a hydraulic and mechanical camshaft control device. It uses engine speed and accelerator pedal position to determine to ideal valve timing for the conditions.

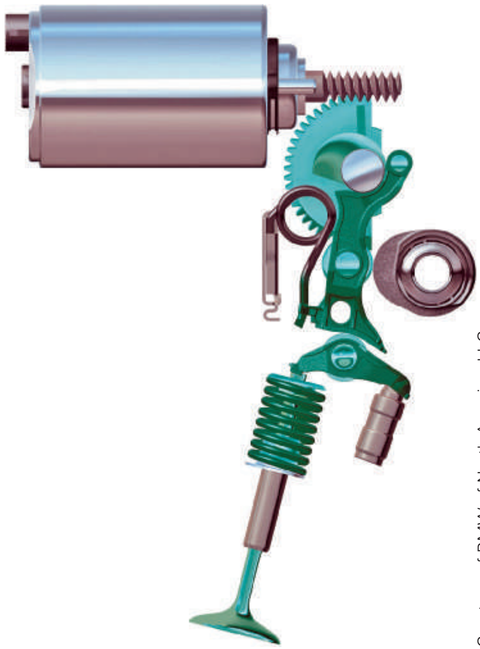
Other VVT Systems

A unique setup for controlling intake and exhaust valve timing and lift relies on a conventional camshaft, which is ground for high performance, with hydraulic lifters fitted with ultra-high-speed valves to



Courtesy of BMW of North America, LLC

FIGURE 12–42 The position of the eccentric shaft to provide maximum lift in a Valvetronic system.



Courtesy of BMW of North America, LLC

FIGURE 12–43 The position of the eccentric shaft to provide minimum lift in a Valvetronic system.

bleed off the fluid. The ECM changes the pressure in the lifter to delay valve openings, change valve duration, or prevent valves from opening. A solenoid is used to control the flow of oil into a piston in each lifter that effectively determines the tappet's height.

Another design uses pressurized oil to allow a four-valve-per-cylinder engine to operate as a three-valve engine at low speeds. At high speeds the engine

uses the four valves. Below 2,500 rpm, each intake valve follows a separate camshaft lobe. The primary valve opens and closes normally, while the secondary intake opens just enough to keep the engine running smoothly. As the engine reaches 2,500 rpm, the ECM allows pressurized oil to move small pins that lock each pair of rocker arms together, causing both intake valves to follow the normal cam lobe. When the engine slows down, the pressurized oil is bled off and the pin releases, separating the two rocker arms.

Cylinder Deactivation

Cylinder deactivation works by keeping the intake and exhaust valves closed in a group of the engine's cylinders. This decreases the working displacement of the engine and provides an increase in fuel economy and reduced emissions. The systems are designed to make the deactivation and activation of the cylinders unnoticeable to the driver. This is accomplished by controlling the fuel injectors, ignition timing, throttle opening, and valve timing. The exact system used for cylinder deactivation varies with the engine design and the manufacturer.

OHC engines typically have a pair of rocker arms at each valve. One of the rocker arms rides on the camshaft lobe and the other works the valve. When the two rocker arms are locked together, the valve moves according to the rotation of the camshaft. To disable a cylinder, the rocker arms are unlocked. The rocker arm on the cam lobe continues to work but does not transfer its movement to the other. The locking device is simply a pin that moves in response to oil pressure. A solenoid, controlled by the ECM, directs oil pressure to the pin.

Honda Honda's variable cylinder management (VCM) system is based on the i-VTEC variable valve control system, which is a staged valve timing system. The system is primarily used on Honda's hybrid to increase the regenerative braking capabilities of the vehicle and to minimize fuel consumption. The system is called the cylinder idling system and increases the amount of energy captured during deceleration. The system also allows normal and high-output valve timing, plus cylinder idling at all or some cylinders.

Basically the system has five rocker arms per cylinder **(Figure 12–44)**. A hydraulically controlled pin connects and disconnects the rocker arms. When there is no connection between the cam-riding rockers and the valve rocker, the cylinder is idling or deactivated. There are three separate oil passages leading to the pin. As the pressure moves through a passage, it moves the pin. The PCM controls a spool valve that directs the pressurized oil to the appropriate passage. It also controls solenoids that control the amount of pressure. With the valves closed, the pistons in those cylinders move quite freely. This, in turn, reduces the amount of engine braking or resistance that takes place during deceleration.

In a typical Honda hybrid system, when the brake pedal is released and the accelerator depressed, the vehicle moves by both electric and engine power. At this time the engine is running in the economy mode with the valves opening by the low lift camshaft profile. When the driver is maintaining a very low cruising speed, the engine shuts off and the electric motor powers the car by itself. During this time, the engine's rocker arms are not opening the valves. During acceleration from a low speed, the engine runs in the economy mode. During heavy acceleration, the engine runs in its high-output mode and the electric motor assists the engine. During deceleration, the motor begins to work as a generator and the engine's valves close and remain closed. This allows for maximum regenerative braking and reduces fuel consumption. When full engine power is needed, the system quickly gets the three idling cylinders back into action. While the cylinders are idling, the VCM system controls the ignition timing

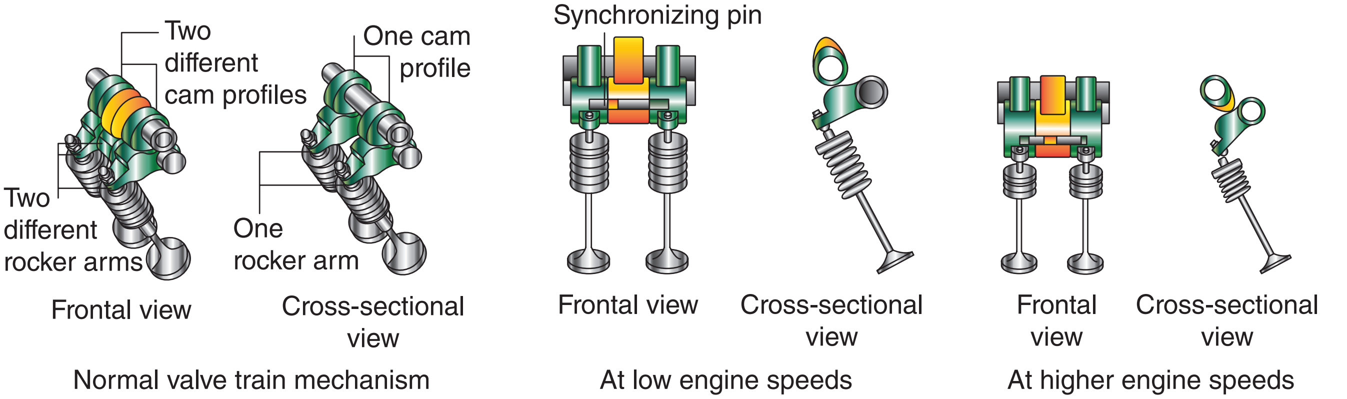


FIGURE 12–44 The activity of the rocker arms in Honda's VTEC system.

and cycles the torque converter lock-up clutch to suppress any torque-induced jolting caused by the switch from six- to three-cylinder operation.

The rocker arms and lifters in Honda's VCM require special inspection procedures. When inspecting them, keep all parts in order so that they can be installed in their original location. Measure the outside diameter of each rocker shaft at the location of the first rocker arm. Then measure the inside diameter of the rocker arm. The difference between the two is the clearance. This clearance should be compared to specifications. Repeat this procedure for each rocker arm and shaft. If the clearance is beyond specifications, replace the shaft and all over-tolerance rocker arms. If one rocker arm needs replacement, all of the rocker arms on that shaft should be replaced.

Next, inspect the synchronizing pistons in the rocker arms. Slide them into the rocker arms; they should move smoothly. If they do not or are damaged, the rocker arm assembly should be replaced. The rocker arm oil control solenoid has a filter. This should be checked and replaced if it is clogged.

Other Cylinder Deactivation Systems OHV engines can also use oil pressure to deactivate the cylinders. High pressure is sent to the lifters to collapse them. The lifters then follow the cam lobes but do not move the pushrods and rocker arms. Chrysler's multidisplacement system (MDS), found in some engines, has an oil circuit controlled by solenoids and unique hydraulic roller lifters. When conditions dictate that the vehicle does not need all cylinders, the ECM energizes the solenoids. Oil pressure is sent to the lifters. The pressure pushes on a small pin in the lifters **(Figure 12–45)**. As the pin moves, the piston inside the lifter is disconnected from the lifter body.

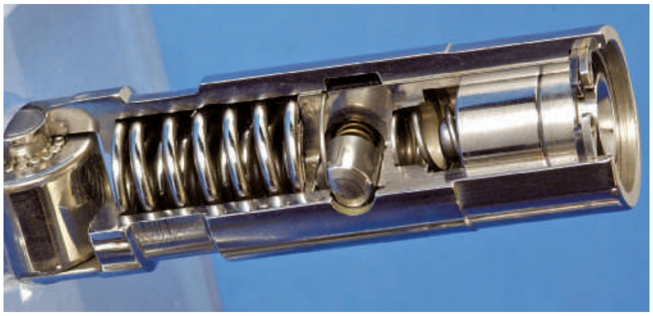

Courtesy of Chrysler LLC.

FIGURE 12–45 The lifter used in Chrysler's multidisplacement system. When the pin in the center is moved, the piston inside the lifter is disconnected from the lifter body.

The lifter body continues to move with the cam lobe but no motion is passed on to the rocker arms.

General Motors' displacement on demand (DoD) system, now called active fuel management (AFM), uses two-stage switching lifters. The lifters have an inner and outer body connected by a spring-loaded pin. High oil pressure, sent by solenoids, collapses the spring and the two lifter bodies disconnect **(Figure 12–46)**.

Cylinder Head Disassembly

On some engines, the rocker arms must be removed before the head is disassembled. If the camshaft rides directly above the rocker arms, use the appropriate spring compressor and depress the valve enough to pull the rocker arm out **(Figure 12–47)**. Some have the rocker arms mounted on a separate

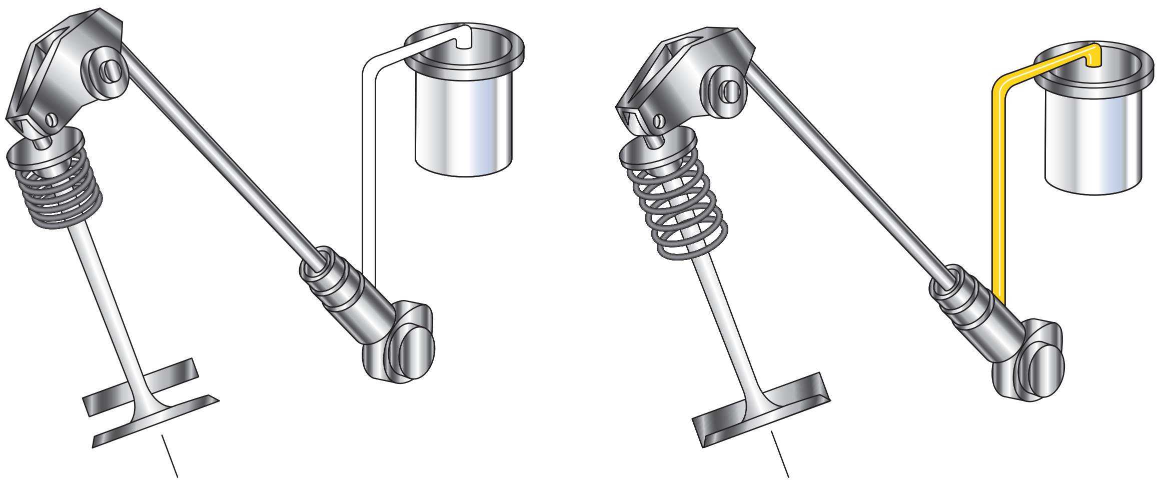


FIGURE 12–46 The action of the lifters in GM's displacement on demand (DoD) system.

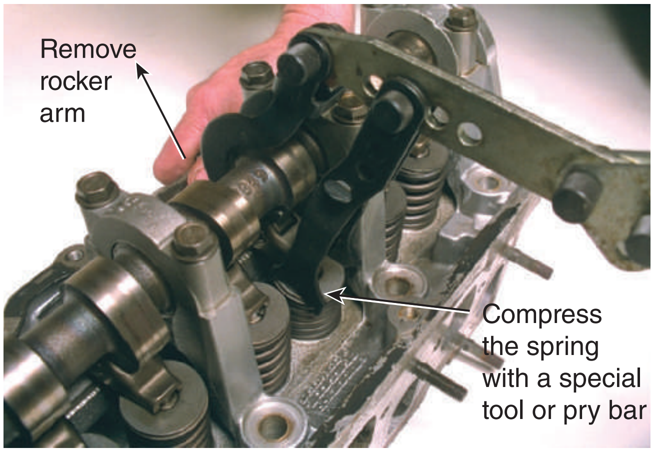


FIGURE 12–47 On some OHC heads, the valve springs must be slightly compressed to remove the rocker arms.

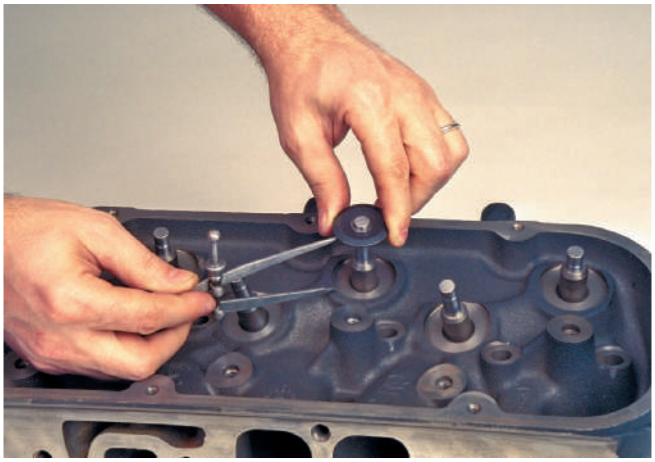


FIGURE 12–49 Measure valve spring height before disassembling the cylinder head.

shaft. The ends of the rocker arms do not directly contact the valves; rather a bridge rocker arm is used. The bridge rocker arm assembly is also mounted on a shaft. To remove these rocker arms, both shafts are unbolted **(Figure 12–48)**.

On all OHC engines, the camshaft must be removed before the cylinder head can be disassembled. Follow the specified order for loosening the camshaft bearing caps. Keep the caps in the order they were on the head. Also, take a picture or draw a diagram of the arrangement of the cam follower assemblies and mark each part. This will ensure that each part is returned to the same position.

Measure the installed spring height for each valve **(Figure 12–49)**. This measurement will be needed during reassembly. To remove the valves, use a valve spring compressor. First, select a socket that fits over the valve tip and onto the retainer. Tap the socket with a plastic mallet to loosen the keepers. Adjust the jaws of the compressor so that they fit securely over the spring retainers. Compress the valve springs just enough to remove the keepers **(Figure 12–50)**.

Next, remove the valve oil seals and valves. Keep the assemblies together according to the cylinder they were in. If a valve cannot pass through its guide, its tip might be mushroomed or peened over. Do not force the valve through the guide. It could score or crack the valve guide or head. Raise the stem and file off the ridge until the stem slides through the guide easily **(Figure 12–51)**.

Inspection of Head

Cylinder heads should be carefully inspected after they are cleaned. Any severe damage to the sealing and valve areas indicates that the head should be repaired or replaced. Also, use the appropriate

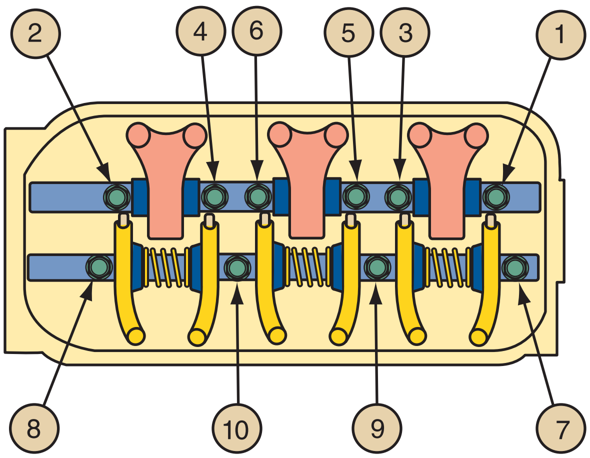


FIGURE 12–48 Rocker arm assemblies should always be removed by following the prescribed order for loosening the mounting bolts.

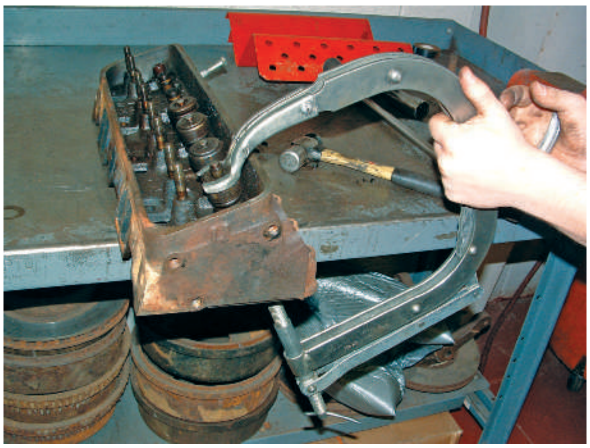


FIGURE 12–50 With a spring compressor, compress the springs just enough to remove the keepers.

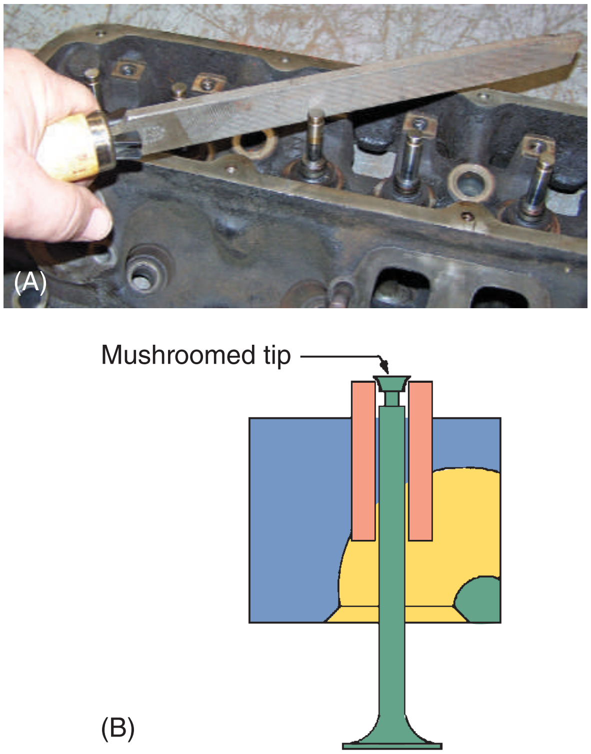


FIGURE 12–51 A mushroomed valve tip should be (A) filed before removing the valve from (B) its guide.

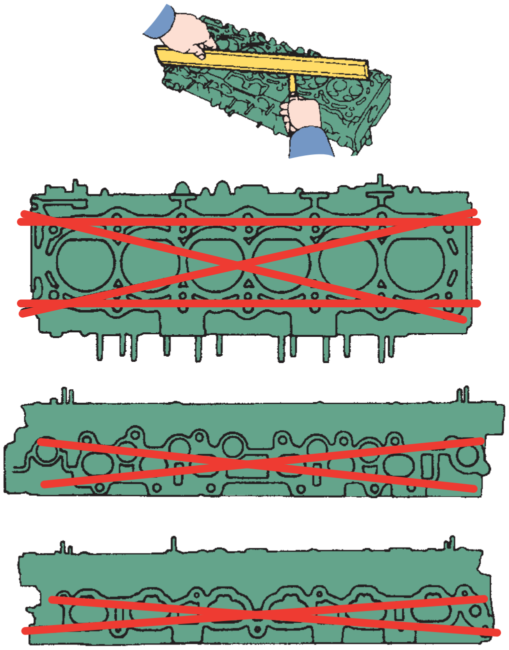


FIGURE 12–52 Checking a cylinder head for warpage.

method for detecting cracks. Check the heads for dents, scratches, and corrosion around water passages.

As engines undergo heating and cooling cycles over their life span, certain parts tend to warp. This is especially true of cylinder heads. By using a precision straightedge and feeler gauge, the amount of warpage can be measured. The surface should be checked both across the head as well as lengthwise **(Figure 12–52)**. In general, maximum allowable deformation is 0.004 inch (0.1016 mm). Check the manufacturer's recommendations for the maximum allowable warpage for the engine. Many manufacturers recommend head replacement if the warpage exceeds allowable limits. Also check the flatness of the intake and exhaust manifold mounting surfaces.

Aluminum Cylinder Heads

> **Warning!** Aluminum cylinder head bolts should never be loosened or tightened when the metal is hot. Doing so may cause the cylinder head to warp due to torque changes.

Aluminum heads experience fair amounts of thermal expansion, which can lead to cracking. Cast iron heads can also crack, especially if the engine has overheated. The most crack-prone areas are the areas around the valve seats **(Figure 12–53)**. High-combustion temperatures and the constant pounding of the valve against its seat can cause cracks between the intake and exhaust seats or just under the exhaust seat.

Aluminum heads should be checked for dents, scratches, and corrosion around water passages. Also, they should be checked for warpage. Warpage in an aluminum cylinder head usually results from overheating. On aluminum heads, the

FIGURE 12–53 Heads are prone to cracking, especially if the engine has overheated.

maximum allowable warpage is less than it is for cast-iron heads.

Before machining the head to make it flat, compare the cylinder head thickness to the specifications to make sure material can be safely removed from it. Some manufacturers do not recommend any machining; rather they require head replacement.

Valves

Each valve face should be checked for evidence of burning **(Figure 12–54)**. Also check the entire valve for signs of wear or distortion **(Figure 12–55)**. Replace any valves that are badly burned, worn, or bent. Discard any valve that is badly burned, cracked, pitted, or shows signs of excessive wear. Examine the facings on the stem. If the plating is flaking or chipped, the valve should be replaced.

Examine the backside of the intake valves. A black oily buildup on the neck and stem area indicates that oil is entering the cylinder through the intake valve **(Figure 12–56)** or valve guide seats. Measure the margin on the valve. Valves that cannot be refaced without leaving at least a 1/32-inch (0.79 mm) valve margin should not be reused. Reusable valves are cleaned by soaking them in solvent, which will soften the carbon deposits. The deposits are then removed with a wire buffing wheel. Once the deposits are removed, the valve can be resurfaced.

FIGURE 12–54 Severely burnt valves.

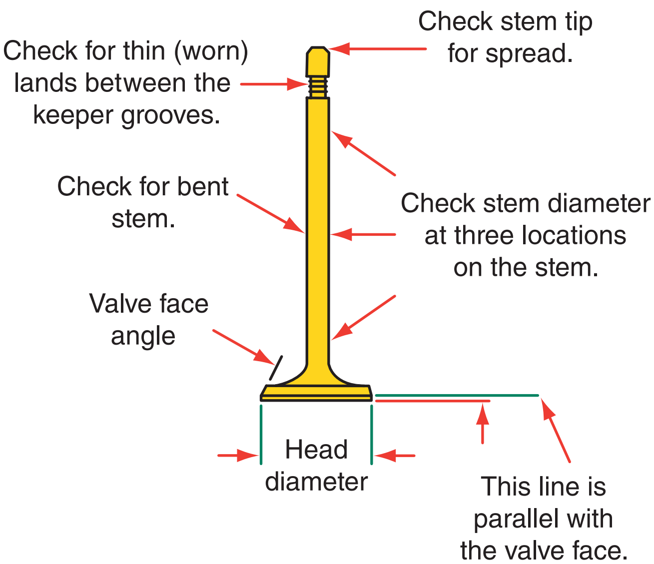


FIGURE 12–55 Parts of a valve that should be checked during your inspection.

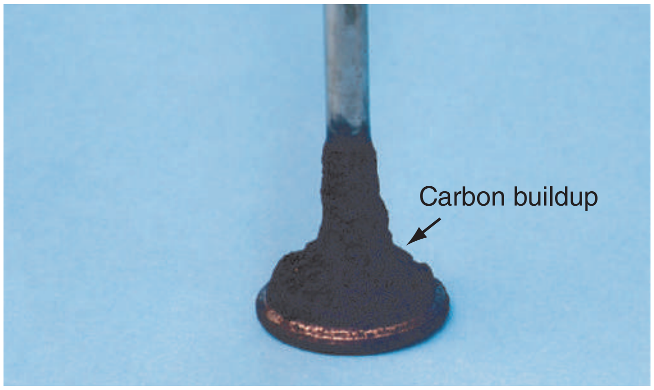


FIGURE 12–56 An oily soot or heavy carbon buildup on the back of the valves indicates bad valve seals.

When replacing a valve, make sure the new one is an exact replacement for the original. This includes the stem diameter, stem height, head diameter, and the material used to make the valve. Replacement valves should be made from the same or a better alloy than the original valve. A good starting point to identifying the metal is to see if it is magnetic or not. Stainless steel is nonmagnetic, while carbon steel is magnetic.

Valve Seats

Valve seats should be checked for damage, cracks, burning, and deterioration. Also, check insert seats for looseness in their bores. This is done by prying on the inside of the seat. With moderate pressure there should be no movement. If any damage is found on the seat, a new insert seat can be installed. If an integral seat is damaged, the area around it will need to be cut out and an insert seat installed. If the seat appears to have sunk too deeply in its bore, it needs to be replaced.

A seat should also be replaced if its valve was broken or bent. This may be caused by the seat not being concentric with the guide, which causes the valve stem to flex every time the valve closes.

Retainers and Keepers

A worn retainer will allow the spring to move away from the centerline of the valve. This affects valve operation because spring tension on the valve will not be evenly distributed. Each retainer should be

carefully inspected for cracks. The inside shape of most retainers is a cone that matches the outside shape of the keepers. There must be a good fit to secure the keepers in their grooves on the valve stem. If the retainers and keepers show damage or wear, they should be replaced.

The valve stem grooves should match the inside shape of the keepers. Some valves have multiple keeper grooves. Others have only one. All of the valve stem grooves should be inspected for damage and fit by inserting a keeper in them.

Valve Rotators

When valves are refaced or replaced, rotators should be replaced because they cannot be accurately inspected. Whether or not they rotate by hand is no indication of how they function. Uneven wear patterns on the valve stem tip are an indication that the rotators are not working properly.

Valve Springs

The valve spring assemblies **(Figure 12–57)**, including the damper springs, should be checked for signs of cracks, breaks, and damage. The high stresses and temperatures imposed on valve springs during operation cause them to weaken and sometimes break. Rust pits will also cause valve spring breakage. To determine if the spring can be reused, perform an open/close spring pressure test, a freestanding height test, and a spring squareness test.

> **Performance TIP**
>
> *When making a change to increase engine performance, especially when making a cam change, do not forget to install stiffer valve springs. Higher-tension springs will help keep the lifters in contact with the cam lobes and overcome the increased momentum of the valves and the valve train during high engine speeds. Excessive spring tension is not good. It can put too much stress on the cam lobes, lifters, rocker arms, and so on, and cause them to wear prematurely. Always follow the recommendations of the camshaft manufacturer when replacing valve springs.*

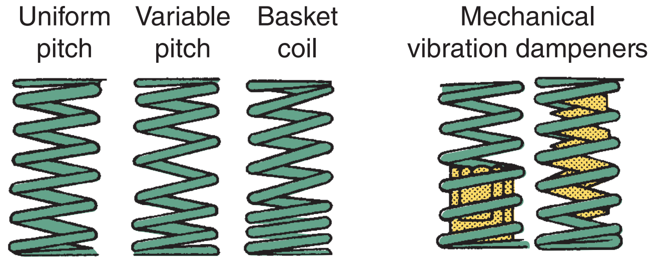


FIGURE 12–57 Common valve spring designs.

Inspection of the Valve Train

When inspecting the valve train, each part should be carefully checked. Use the following guidelines when inspecting the components.

Timing Belts

Most often, the belt is replaced when the engine or head is rebuilt. Belt failure is commonly due to insufficient tensioning, extended service life, abusive operation, or worn tensioners. Most manufacturers recommend timing belt replacement every 60,000 miles. Loose timing belts will jump across the teeth of the timing sprockets, causing shearing of the belt teeth. Check for cord separation and cracks on all surfaces **(Figure 12–58)** of the belt. Also check for evidence of exposure to oil or water. Both can cause deterioration of the belt. If the belts are contaminated or damaged, they should be replaced.

On many engines, severe engine damage can result from a broken timing belt. When a timing belt breaks, the camshaft no longer turns, but the

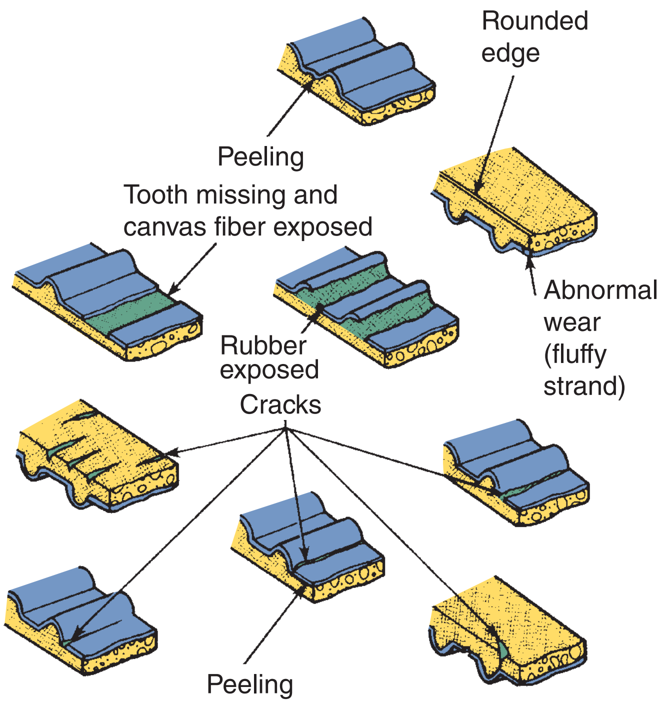


FIGURE 12–58 Various forms of timing belt wear.

crankshaft continues to rotate. When the camshaft stops, the valves stay where they were when the belt broke. This means some of the valves are open. As the pistons continue to move, they can strike the open valves. This results in bent or broken valves and/or damaged piston domes.

Timing Chains

Late-model engines may have many drive chains. Those with one chain use it to drive the camshaft(s) by the crankshaft. The engine shown in **(Figure 12–59)** has a long chain to drive the camshafts and a short chain to drive the balance shaft. Some engines have an additional chain that aligns the intake camshaft with the exhaust camshaft. V-type engines may have a separate chain from the crankshaft to the camshafts of each cylinder bank, then additional chains to connect the intake and exhaust camshafts on each bank **(Figure 12–60)**.

Each drive chain should be inspected and replaced if it is damaged. The length of the chain should also be checked. Some manufacturers recommend measuring the entire length of the chain and comparing that to specifications. The chains on other engines should be measured in sections while they are being stretched. To do this, pull the chain with the specified tension. Then measure the length of the specified number of chain links **(Figure 12–61)**. This measurement is taken at three random sections of the chain. The average length is then compared to specifications. The chain should be replaced if it is not within specifications.

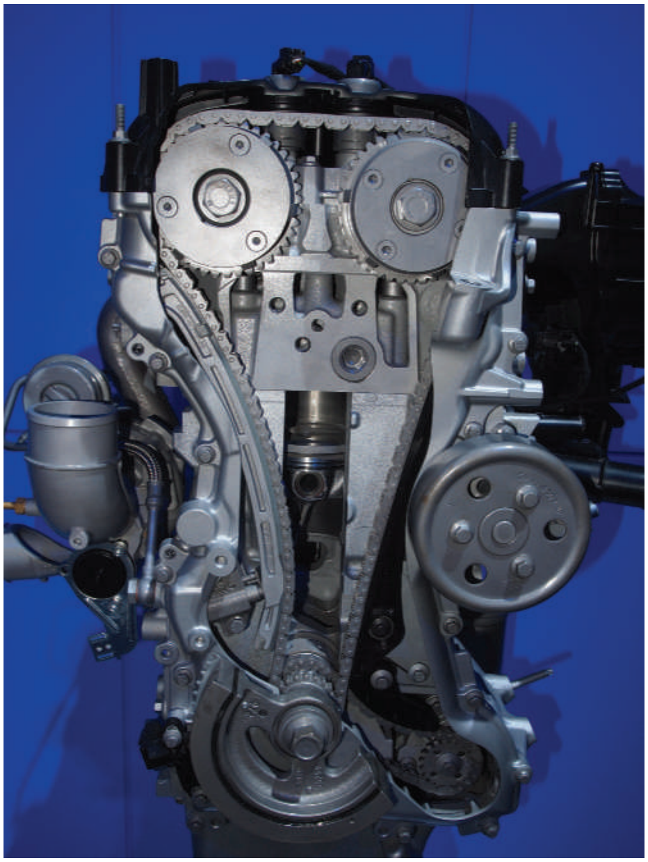


FIGURE 12-59 An engine with two separate drive chains.

FIGURE 12-60 This engine has three separate timing chains.

Belt Idler Pulley

All idler pulleys should be rotated by hand. They are okay if they move smoothly. The pulley should also be checked for signs of lubricant leakage. Check around the seal. If leakage is evident, the idler should be replaced.

Tensioners

The tensioners of belt and chain drive systems should be checked. There are many types of tensioners; refer to the service information for the

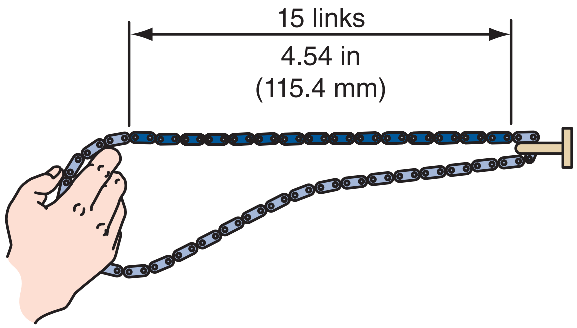


FIGURE 12-61 The timing chain on some engines should be measured in sections while it is being stretched.

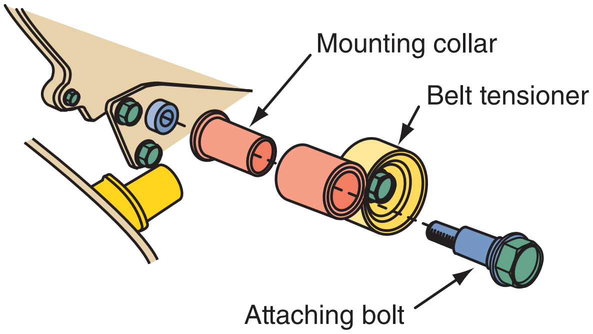


FIGURE 12–62 A timing belt tensioner assembly.

correct inspection procedure. Check the surface of the tensioner's pulley. It should be smooth and have no buildup of grease or oil **(Figure 12–62)**. Most belt tensioners should also be checked for signs of lubricant leakage. Check around the seal. If any damage or leakage is evident, the tensioner should be replaced.

The action of a belt tensioner should be checked. Make sure the spring is free to move the tensioner pulley. If the tensioner spring is defective, replace the tensioner. On plunger-type tensioners, hold the tensioner with both hands and push the pushrod strongly against a flat surface. The pushrod should not move. If it does, replace the tensioner. Measure the distance the pushrod extends from the housing. Compare that distance to specifications. If this measurement is not within specifications, replace the tensioner.

Chain drive systems can have a variety of tensioners, dampers and guides **(Figure 12–63)**. These should be checked for wear. In most cases, their width is measured and compared to specifications. If they are worn, they should be replaced. Again, there are different types of chain tensioners, each with a unique inspection procedure. The plunger in ratchet-type tensioners should be able to be moved smoothly out by hand but not able to be pushed in by hand.

Gears and Sprockets

All timing gears and sprockets should be carefully inspected. A gear with cracks, spalling, or excessive wear on the tooth surface is an indication of improper backlash. All damaged or worn gears should be replaced. The oil pump, camshaft timing, crankshaft timing, and balance shaft gears and sprockets on some engines are measured with the drive chain wrapped around the individual gears. The diameter of the gear with the chain around it is measured with a vernier caliper. The caliper's jaws must contact the chain's rollers while doing this. If the diameter is less

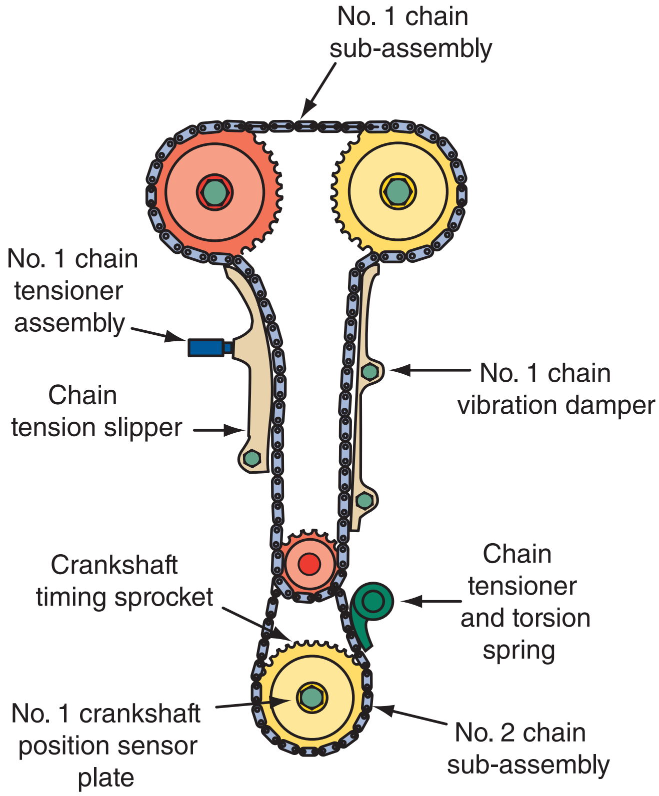


FIGURE 12–63 Timing chain components.

than specifications, the chain and gear or sprocket should be replaced.

Cam Phasers

Camshaft phasers can be checked while it is attached to the camshaft. Clamp the camshaft in a soft-jawed vise. Attempt to rotate the timing gear on the phaser. If it moves, the phaser must be replaced. Next, cover all of the oil ports on the phaser with electrical tape except the advance port **(Figure 12–64)**. Using an air nozzle with a rubber tip, apply the specified air pressure to the exposed port **(Figure 12–65)**. The timing gear should move counterclockwise. When the air is released, the

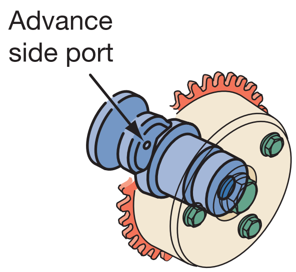


FIGURE 12–64 Location of the advance port on a camshaft phaser.

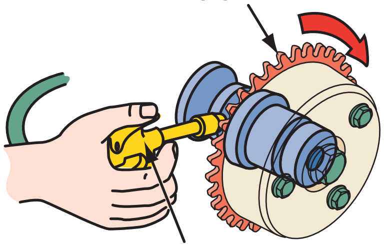


FIGURE 12-65 The action of the phaser is checked by applying air to the port and observing the timing gear.

timing gear should move clockwise. This check should be conducted several times and the timing gear should move smoothly. This process is then repeated at the retard port. In this case all ports, except the retard port, are sealed.

Cam Followers and Lash Adjusters

Overhead cam follower arm and lash adjuster assemblies should be carefully checked for broken or severely damaged parts. If pads are used to adjust the valve lash, the cups and the shim pads should also be carefully checked. A soft shim will not hold the valve at its correct lash; therefore, the hardness of each shim should be checked. You can do this by placing a shim on the base circle of the camshaft and, with your hand, press down on the shim. You should feel no give.

Rocker Arms

Inspect the rocker arms for wear, especially at points that contact the valve stem and pushrod. Make sure the oil feed bore in each rocker arm is clear and not plugged with dirt. The fit between a rocker arm and its shaft is checked by measuring the outside diameter of the shaft and comparing it to the inside diameter of the rocker arm. Excessive clearance requires replacement of the rocker arm or the rocker shaft, or both. Another wear point that should be checked is the pivot area of the rocker arm. Also check for loose mounting studs and nuts or bolts. Replacement press-in studs are available in standard sizes and oversizes. The standard size is used to replace damaged or worn studs and the oversizes are used for loose studs.

Excessive wear on the valve pad occurs when the rocker arm repeatedly strikes the valve tip in a hammer-like fashion. This is caused by excessive valve lash due to improperly adjusted valves or bad hydraulic lifters. Worn rocker arm valve pads can also be caused by poor lubrication. Although a cast rocker arm can be resurfaced, a stamped nonadjustable rocker arm that is worn must be replaced.

Pushrods

During inspection, some pushrods may have a groove worn in the area where they pass through the cylinder head, and some may have tip wear. All damaged pushrods should be replaced. Hollow pushrods should be thoroughly cleaned so that there are no blockages in the bore. Also, the ends of the pushrods should be checked for nicks, grooves, roughness, or signs of excessive wear.

Check the straightness of each of the pushrods. Pushrods can be checked while they are in the engine by rotating them with the valve closed. With the pushrods out of the engine, roll them over a flat surface. If a pushrod is not straight, it will appear to hop as it is rolled. The most accurate way to check them is with a dial indicator.

Camshaft and Bearings

The camshafts in most OHC engines are secured to the cylinder head by bearing caps. Some ride on split bearings, whereas others ride on a machined surface in the cylinder head. The bearings or bearing surface should be carefully inspected for signs of unusual wear. If the engine is equipped with camshaft bearings, they are normally replaced during engine rebuilding. If the camshaft bore is damaged, the cylinder head is normally replaced.

Inspection of Camshaft and Related Parts

After the camshaft has been cleaned, check each lobe **(Figure 12–66)** for scoring, scuffing, fractured surface, pitting, and signs of abnormal wear; also check for plugged oil passages.

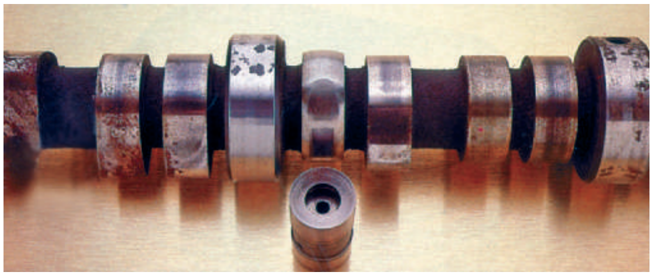


FIGURE 12-66 A worn lifter and camshaft.

Measure the lobe height with a micrometer. Measure from the heel to the nose and then again 90 degrees from that measurement. Record the measurement for each intake and exhaust lobe. Check the measurements to specifications. Any variation indicates wear.

Measure each camshaft journal at several places to see if it is worn. If a journal is 0.001 inch (0.0254 mm) or more below specifications, it should be replaced.

The camshaft should also be checked for straightness with a dial indicator. Place the camshaft on V-blocks. Position the dial indicator on the center bearing journal and slowly rotate the camshaft. If the dial indicator shows excessive runout, the camshaft is not straight and must be replaced, along with new lifters, and/or followers.

Servicing Cylinder Heads

Service to the cylinder head may involve many different procedures. These vary with the metal used to make the head and the design of the engine. Always refer to the appropriate service information before starting any work on the head.

Crack Repair

Common locations of cracks in a cylinder head include: between the spark plug bore and the valve seat, between the valve seats, around the valve guides, and in the exhaust ports. In most cases, a cracked head should be replaced. However, some cracks can be effectively repaired. Crack repair is normally done by specialty shops.

The cause of the cracking needs to be identified and corrected. No matter what caused the crack, the crack needs to be repaired if the head is reused. Crack repair is done by the cold process of pinning or the hot process of welding.

Resurfacing Cylinder Heads

There are three reasons for resurfacing the deck surface of a cylinder head:

1. To make the surface flat so that the gasket seals properly.
2. To raise the compression ratio.
3. To square the deck to the main bores.

A cylinder head can be resurfaced with a belt surfacer, milling machine, broaching machine, or a surface grinder **(Figure 12–67)**. They set up and operate similarly to milling machines.

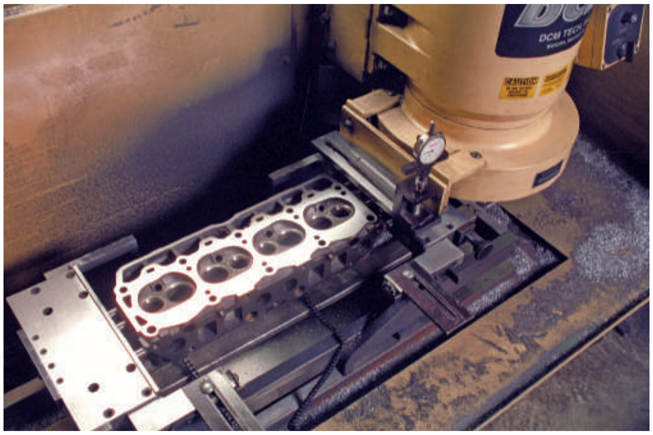


FIGURE 12–67 A surface grinder.

The refinished surface should not be too smooth. For proper head gasket seating, the finish should have shallow scratches and small projections that allow for gasket support and sealing of voids.

Warning! **Before operating any surfacing machine, be familiar with and follow all the cautions and warnings given in the machine's operation manual. Also, when operating these machines, wear safety glasses, goggles, or a face shield.**

Stock Removal Guidelines

The amount of stock removed from the head surface must be limited. Excessive surfacing can lead to problems in the following areas.

Compression Ratio After resurfacing a cylinder head, the combustion chamber will be smaller. This will raise the compression ratio. How much depends on how much metal was removed and the type of chamber.

To make sure the compression ratio has not increased too much, the volume of each combustion chamber should be measured. The measured volume should be compared to the specifications. A thicker head gasket can be used to decrease the compression ratio, if necessary.

If the chamber volumes are unequal, individual chambers can be matched by grinding the valve seats to sink the valves and by grinding and polishing metal from the combustion chamber surface.

Valve Timing On many OHC engines, it is necessary to restore the distance between the camshaft and crankshaft gears after the head has been resurfaced. Special shims are used to raise the cylinder head. If 0.030 inch (0.7620 mm) was removed from the head surface, the camshaft must be moved up 0.030 inch (0.7620 mm). If this is not done, valve timing will be altered.

Piston/Valve Interference When the block or head is surfaced, the piston-to-valve clearance becomes less. To prevent the valves from making contact with the piston, a minimum of 0.070 inch piston-to-valve clearance is recommended.

Misalignment Removing metal from the head or block also causes valve tips, rocker arms, and push-rods to be positioned closer to the camshaft. This causes a change in rocker arm geometry and can cause hydraulic lifters to bottom out.

Also, on V-type engines, the mountings for the manifolds will be lower. This can present a sealing problem. Also, the ports might be mismatched and manifold bolts might not line up. In order to return the intake manifold to its original alignment, metal on the sealing surfaces of the manifold must be removed.

Guide Wear

The amount a valve guide is worn can be measured with a ball (small-bore) gauge and micrometer. Insert and expand the ball gauge at the top of the guide, then measure the ball gauge with an outside micrometer. Repeat this process with the ball gauge in the middle and the bottom of the guide **(Figure 12–68)**. Any difference in reading indicates taper or wear inside the guide. Compare the measured diameter to the specifications to determine how much the guide is worn.

A dial indicator can also be used. The accuracy of this check is dependent on the amount the valve is open during the check. Attach the dial indicator to the cylinder head and position it so that the plunger is on the edge of the valve head and at a right angle to the valve stem **(Figure 12–69)**. Move the valve toward the indicator and set the dial indicator to zero. Now move the valve away from the indicator. Observe the reading on the dial. The reading is the total movement of the valve and is indicative of the guide's wear. Compare the reading to specifications.

If the clearance is too great, oil can be drawn past the guides. Although oil consumption is more of a problem with sloppy or worn intake guides, oil can also be pulled down the exhaust guides by the suction created in the exhaust port. The outflow of hot exhaust creates a venturi effect as it exits the exhaust port, creating enough vacuum to draw oil down a worn guide **(Figure 12–70)**.

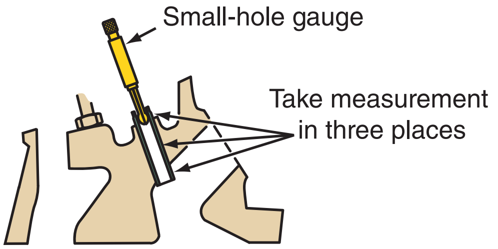


FIGURE 12–68 Valve guide wear can be measured with a small-hole gauge and a micrometer.

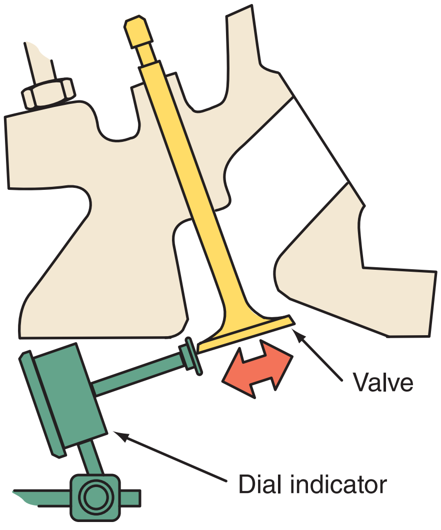


FIGURE 12–69 Checking for valve guide wear with a dial indicator.

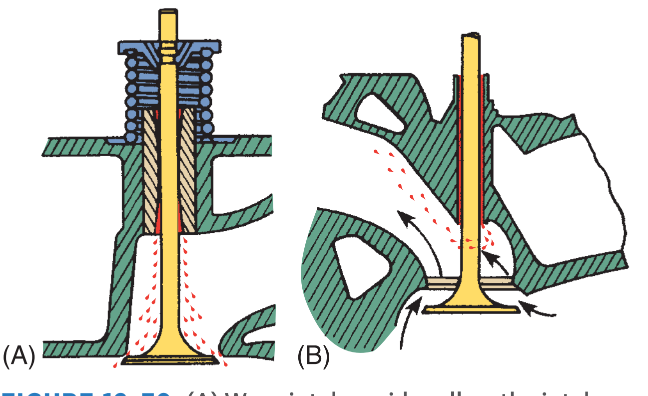


FIGURE 12–70 (A) Worn intake guides allow the intake vacuum to suck oil down the guide, and (B) worn exhaust guides can do the same.

Knurling

Knurling is one of the fastest ways to restore the inside diameter (ID) of a worn valve guide. The process raises the surface of the guide ID by plowing tiny furrows through the surface of the metal. As the knurling tool cuts into the guide, metal is raised or pushed up on either side of the indentation. This decreases the ID of the guide. One of the main advantages of knurling is that it does not change the centerline of the valve stem.

Reaming and Oversized Valves

Reaming increases the guide ID to fit an oversize valve stem or restores the guide to its original diameter after installing inserts or knurling. When reaming, limit the amount of metal removed per pass. Always reface the valve seat after the valve guide has been reamed and use a suitable scraper to break the sharp corner at the top and bottom of the ID of the valve guide.

The use of oversized valve stems is generally considered to be superior to knurling. Yet, like knurling, it is relatively quick and easy. The only tool required is a reamer. Its use is limited to heads in which the guides are not worn beyond the limits of available oversize valves.

Thin-Wall Guide Liners

Thin-wall guide liners **(Figure 12–71)** are often inserted into guides to restore them. They provide the benefits of a bronze guide surface. They can be used in integral and replaceable guides. It is faster, easier, and cheaper than installing new guides and maintains guide centering with respect to the seats.

The original guides are bored to the required diameter for the liner. A phosphor-bronze or silicon-aluminum-bronze liner is then pressed into the bore. A tight fit is necessary for proper heat transfer and to prevent the liner from working loose. It is important to note that some liners are not precut to the length of the original guide. When this is the case, the liner should be cleanly cut or milled to the correct length before installing it. After installation, guide-to-valve stem clearance should be checked and corrected by reaming or knurling.

Guides that cannot be repaired must be replaced. This may require a machine shop to cut out the old guides and install new ones.

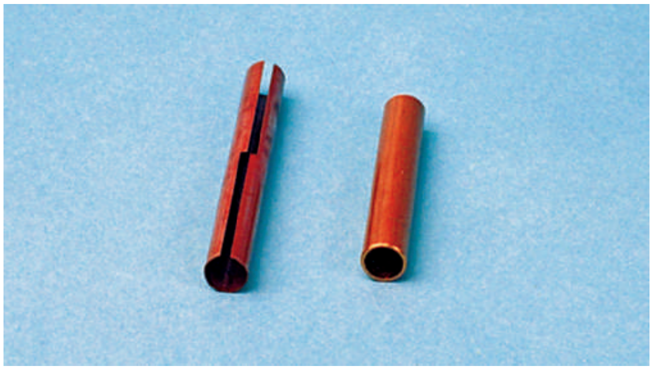


FIGURE 12–71 A thin-wall valve guide liner.

Valve Stem Seals

Valve stem seals are used to control the amount of oil that flows between the valve stem and the guide. Insufficient lubrication will allow the stems and guides to scuff and wear. Too much oil causes a buildup of heavy deposits on the intake valve and hard deposits on the exhaust valve stem. Worn valve stem seals can increase oil consumption by as much as 70 percent.

There are basically three types of seals. **Positive seals** fit tightly around the top of the guide and scrape oil off the valve stem as it moves up and down. Deflector, splash, or umbrella-type seals ride up and down on the valve stems to deflect oil away from the guides. O-ring seals are used to prevent oil from moving into the guide when the valve is open.

If replacing valve stem seals on an engine still installed in the vehicle, remove the valve cover(s) and spark plugs. To keep the valves from dropping down into the guides, compressed air is used to pressurize the cylinder. Remove the Schrader valve from a compression tester adaptor hose. Install the adaptor hose into the spark plug hole. Rotate the engine so that the piston is at TDC and the valves are closed. Connect a shop air hose to the adaptor hose. The shop air will keep pressure in the cylinder and keep the valve tight against the valve seat. Remove the valve spring and replace the seal.

Installing Positive Valve Seals

To install a positive valve seal **(Figure 12–72)**, place the plastic sleeve from the seal kit over the end of the valve stem to protect the seal as it slides over the keeper grooves. Lightly lubricate the sleeve. Carefully place the seal over the valve stem and push the seal down until it touches the top of the valve guide. Remove the plastic sleeve and use the installation tool to finish pushing the seal over the guide until the seal is flush with the top of the guide.

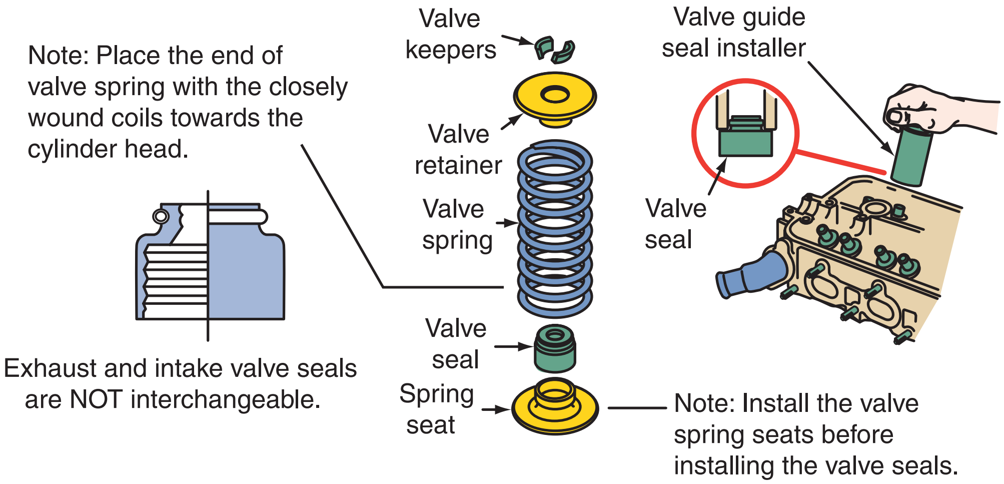


FIGURE 12–72 Installation of a positive oil seal onto a valve guide.

Installing Umbrella-Type Valve Seals

An umbrella-type seal is installed on the valve stem before the spring is installed. It is pushed down on the valve stem until it touches the valve guide boss **(Figure 12–73)**.

Installing O-Rings

When installing O-rings, use engine oil to lightly lubricate the O-ring. Then install it in the lower groove of the lock section of the valve stem **(Figure 12–74)**. Make sure the O-ring is not twisted.

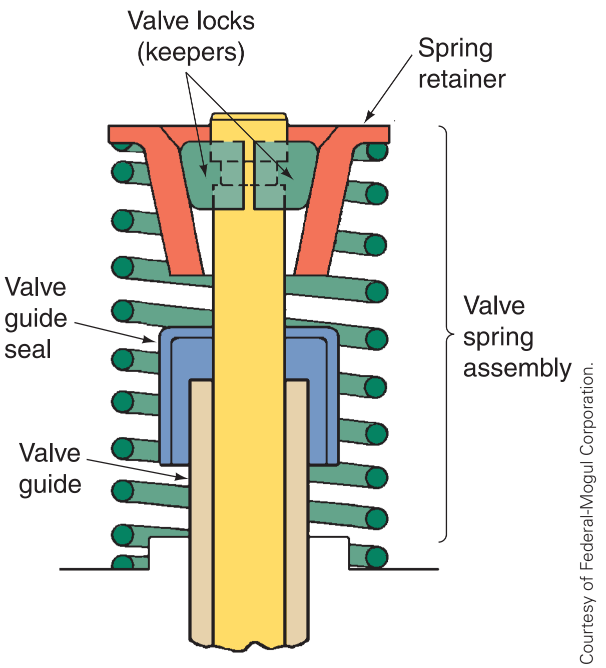


FIGURE 12–73 Valve assembly with an umbrella-type oil seal.

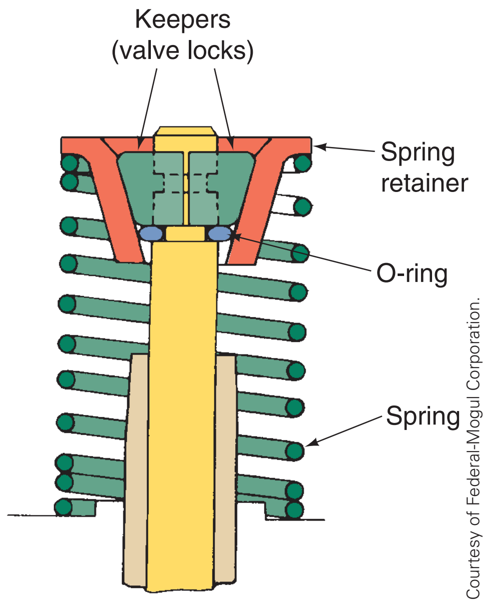


FIGURE 12–74 Valve assembly with an O-ring valve seal.

Assembling the Cylinder Head

Before a cylinder head is reassembled and installed, two measurements must be checked: the installed stem height and the installed spring height.

Installed stem height is the distance between the spring seat and stem tip. A number of tools can be used to obtain an accurate stem height reading, including a depth micrometer, vernier caliper, and telescoping gauge.

USING SERVICE INFORMATION

Stem height specifications are often unavailable in the service information. As a guide for assembly, record the stem heights for all valves during disassembly.

Installed spring height is measured from the spring seat to the underside of the retainer when it is assembled with keepers. This measurement can be made with a set of dividers or scales, telescoping gauge, or spring height gauge.

Adjustments to valve spring height can be made with valve spring inserts, also known as spring shims. These shims come only in three standard thicknesses—0.060, 0.030, and 0.015 inch (1.52, 0.7620, and 0.3810 mm). Using combinations of different shims allows compensation for variations in spring height. If more than one shim is required, place the thickest one next to the spring. If one side of the shim is serrated or dimpled, place that side onto the spring seat.

With the valve inserted into its guide, position the valve spring inserts, valve spring, and retainer over the valve stem. The end of the spring that is wound the tightest should always be placed toward the head of the valve. Using a valve spring compressor, compress the spring just enough to install the valve keepers into their grooves. Release the spring compressor and tap the valve stem with a rubber mallet to seat the keepers.

OHC Engines

After the valves are installed and the cylinder head is assembled, the camshaft can be installed in the cylinder head. Some engines have a separate camshaft housing that bolts to the cylinder head. This should be installed with the proper seals and gaskets.

SHOP TALK

Valve keepers should be replaced in pairs. If a new keeper is mated with a used one, the spring retainer may cock and break off the valve tip or allow the assembly to come apart.

Caution! **If the keepers are not fully seated, the spring assembly could fly apart and cause personal injury. Therefore, it is a good practice to assemble the valves with the retainers facing a wall and to wear eye protection.**

On OHC engines, if the engine uses full-round insert bearings, press them into the bores in the cylinder head. After each bearing is fully seated in its bore, double-check the alignment of the bearing's oil hole with the oil hole in the head.

Most late-model OHC engines use split bearings and bearing caps or have a separate housing for the camshaft. On these engines, the bores in the aluminum casting should be cleaned and/or align bored if needed. Working with these bearings is like working with crankshaft main bearings. This includes checking bearing clearances with Plastigage **(Figure 12–75)**.

Prior to installation, wipe off each cam bearing with a lint-free cloth, then thoroughly coat the camshaft lobes and bearing journals with the lube recommended by the manufacturer. Install the timing gear onto the camshaft, making sure it is properly aligned. Tighten the bolt to specifications. Once the camshaft shaft and gear are aligned with the timing marks, the bearing caps are installed and tightened in a specified order and torque. Then the other camshaft is installed by setting it into the bearing journals. After the timing marks are aligned on both shafts, the bearing caps for the second camshaft are tightened. Once tightened, the shaft should be able to rotate smoothly. When both camshafts are in place, the chain tensioner is installed.

Install new O-rings and gaskets, as required, when installing the camshaft. Some camshafts for OHV engines have an end thrust plate or shims to limit shaft end play. After the camshaft is in place, check the end play and change the thickness of the shims as needed.

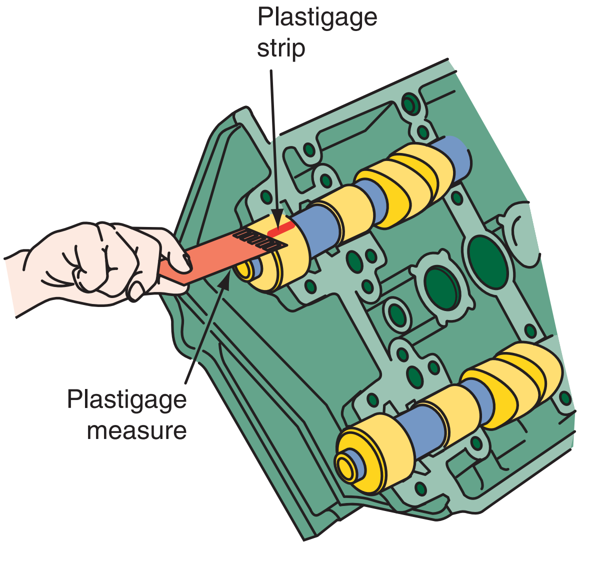


FIGURE 12–75 OHC camshaft bearing clearances can be checked with Plastigage.

Gather the rocker arms, lash adjusters, pushrods, lifters, and other parts that transfer the motion of the camshaft to the valve stem. Coat all of these parts with clean engine oil. These parts should be installed according to the service information. Some are installed before the camshaft; others are installed after.

Normally the rocker arm assemblies are installed by turning the cam until the lobe for that valve faces away from a valve stem. The rocker arms can be slipped into position by depressing the valve spring slightly. Make sure the rocker arm mounting bolts are properly tightened. Follow the same procedure for all of the valves.

Mount all manifolds and other parts that were on the head when it was removed from the block. Use new gaskets or the correct sealant where necessary. Adjust the valve lash (clearance) and mount the head onto the block.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2002	**Make:** Honda	**Model:** Accord	**Mileage:** 119,559	**RO:** 17887
Concern:	Engine cranks but does not start. Customer was driving when engine died.			
Given this concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				
Cause:	Confirmed no start, engine cranking speed faster than normal. Removed timing belt cover, found seized water pump and broken timing belt. Set cam and crank timing and performed cylinder leakage test, found bent valves.			
Correction:	Replaced cylinder head with rebuild head. Replaced water pump, timing belt and related components.			

KEY TERMS

Cam followers
Dampen
Duration
Hemispherical combustion chamber
Knurling
Leakdown
Margin
Overlap
Pentroof
Phaser
Positive seal
Pumping loss
Reaming
Siamese ports
Stainless steel
Stellite
Turbulence
Valve guide
Valve keeper
Valve lifters
Valve stem
Variable valve timing (VVT)
Wedge-type combustion chamber

SUMMARY

- Pushrods are the connecting link between the rocker arm and the valve lifter.
- The rocker arm converts the upward movement of the valve lifter into a downward motion to open the valve.
- Aluminum cylinder heads are used on late-model engines because of their light weight. The thermal expansion characteristics of aluminum can lead to problems such as leaking and cracking.
- Every cylinder of a four-stroke engine contains at least one intake valve and one exhaust valve.
- Multivalve engines feature three, four, or five valves per cylinder, which results in better combustion and reduced misfire and detonation.
- The ways to resurface the deck of a cylinder head include grinding, milling, belt surfacing, and broaching.
- The amount of stock removed from the cylinder head gasket surface must be limited. Excessive surfacing can create problems with the engine's compression ratio, not to mention piston/valve interference and misalignment.
- A cam changes rotary motion into reciprocating motion. The part of the cam that controls the opening of the valves is the cam lobe. The closing of the valves is the responsibility of the valve springs.
- The inside diameter of a worn valve guide can be restored by knurling.
- Reaming increases the guide bore to take an oversize valve stem or restores the guide to its original dimension after knurling or installing inserts.
- Valve stem seals are used to control the amount of oil between the valve stem and guide. Too much oil produces deposits, while insufficient lubrication leads to excessive wear.

- The valve spring closes the valve and maintains valve train contact during the opening and closing of the valve. Three checks can be used to determine if a spring needs to be replaced: free-standing height, spring squareness, and open/close spring pressure.
- Before reassembling a cylinder head, two critical measurements must be made: installed stem height and installed spring height.

REVIEW QUESTIONS

Short Answer

1. Explain staged and continuously variable valve timing systems.
2. How does resurfacing the cylinder head of an OHC engine affect valve timing and what should be done when the head needs resurfacing?
3. Define valve margin.
4. What usually causes warpage in an aluminum cylinder head?
5. What are the two ways pushrods can be checked for straightness?

True or False

1. *True False?* Fiat's MultiAir system relies on mechanical, hydraulic, and electronic technologies.
2. *True False?* Camshaft straightness is checked using V-blocks and a feeler gauge?

Multiple Choice

1. Which of the following is not true of knurling?
   a. It is one of the fastest techniques for restoring the ID dimensions of a worn valve guide.
   b. It reduces the amount of work necessary to reseat the valve.
   c. It is useful for restoring badly worn guides to their original condition.
   d. None of the above.
2. To allow the engine to run on the Atkinson cycle, Toyota's VVT-i system causes the ___.
   a. intake valve to open early
   b. exhaust valve to open late
   c. intake valve to close late
   d. exhaust valve to close early
3. To ensure proper seating of the valve, the valve seat must be ___.
   a. the correct width
   b. in the correct location on the valve face
   c. concentric with the guide
   d. all of the above
4. Many engines with VVT have a phaser mounted to the end of one or more camshafts. Which of the following statements is not true?
   a. A phaser is used to alter valve timing.
   b. Most phasers are controlled by oil pressure.
   c. Phasers are used to change valve lift.
   d. Phasers can be used to change valve overlap.
5. Multiple valve engines tend to be more efficient than two-valve-per-cylinder engines because they ___.
   a. allow for increased port areas
   b. have smaller valves
   c. provide less restriction to the airflow
   d. all of the above
6. Which of the following is *not* a type of valve guide seal?
   a. Positive
   b. Negative
   c. Umbrella
   d. O-ring
7. What type of valve lifter automatically compensates for the effects of engine temperature?
   a. Hydraulic
   b. Solid
   c. Roller
   d. All of the above
8. What device in the valve train changes rotary motion into reciprocating motion?
   a. Eccentric
   b. Cam
   c. Bushing
   d. Mandrel

ASE-STYLE REVIEW QUESTIONS

1. While discussing the reasons for resurfacing a cylinder head: Technician A says it should be resurfaced to make it flat and very smooth so that the head gasket can seal properly during

engine assembly. Technician B says that it can be resurfaced to raise the compression. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

2. While inspecting the timing gears of an engine: Technician A says a gear with cracks, spalling, or excessive wear on the tooth surface indicates improper gear backlash. Technician B says the diameter of many of the engine's timing gears and sprockets should be measured with the drive chain wrapped around the individual gears. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. Technician A says that positive valve stem seals fit tightly around the top of the valve guide. Technician B says that positive stem seals scrape oil off the valve as it moves up and down. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. Technician A says to cylinder heads often crack between the valve seats and around the spark plug holes. Technician B says cracks often appear around the intake ports. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Technician A says an engine may use one or more valve springs per valve. Technician B says additional valve springs are used to control vibration and increase total pressure. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. Technician A says it is not necessary to measure valve stem height unless the valves have been replaced. Technician B says valve stem height can be adjusted with shims. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. While discussing the Valvetronic system: Technician A says the system has no need for a throttle plate. Technician B says the system alters the lift of the intake valves. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. While checking a hydraulic phaser after the camshaft has been removed from the engine: Technician A attempts to rotate the phaser's timing gear by hand and replaces it if it does not move. Technician B applies air pressure to the advance and retard ports and replaces it if the gear does not move. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. While servicing a pair of aluminum cylinder heads: Technician A says if needed, both heads must be machined equally and the same amount of material removed from each. Technician B replaces both heads if the warpage exceeds the specified allowable amount. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While discussing camshafts Technician A says valve lift is based only on the height of the cam lobe. Technician B says valve duration is based on the height of the lobe. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER

13

ENGINE SEALING AND REASSEMBLY

OBJECTIVES

- Explain the purpose of the various gaskets used in an engine.
- Identify the major gasket types and their uses.
- Explain general gasket installation procedures.
- Describe the methods used to seal the timing cover and rear main bearing.
- Reassemble an engine including core plugs, bearings, crankshaft, camshaft, pistons, connecting rods, timing components, cylinder head, valve train components, oil pump, oil pan, and timing covers.
- Reinstall an engine and perform the correct starting and break-in procedures.

Proper sealing of an engine keeps the low-pressure liquids in the cooling system away from the cylinders and lubricating oil. It also keeps the high pressure of combustion in the cylinders. It prevents both internal and external oil leaks and suppresses and muffles noise.

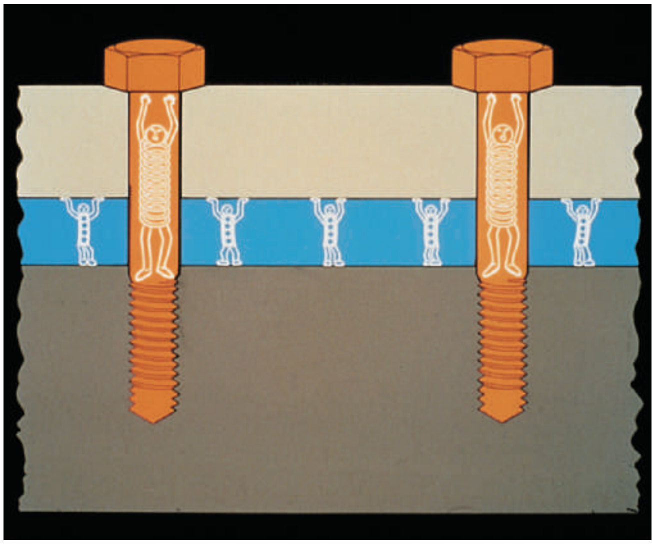
Torque Principles

All metals are elastic. **Elasticity** means a bolt can be stretched and compressed up to a certain point. This elastic, spring-like property is what provides the clamping force when a bolt is threaded into a tapped bore or when a nut is tightened. As the bolt is tightened, it is stretched a few thousandths of an inch. Clamping force or holding power is created due to the bolt's natural tendency to return to its original length **(Figure 13–1)**.

The more a bolt is stretched, the tighter it becomes. However, a bolt can be stretched too far. This is obvious when the grip on the wrench feels "mushy." At this point, the bolt can no longer safely carry the load it was designed to support. The term **yield** represents

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2014	**Make:** Hyundai	**Model:** Sonata	**Mileage:** 48,316	**RO:** 16474
Concern:	Customer states engine is running poorly and lacks power.			
History:	Warranty long block installed at 47,855 miles, RO 15877.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				



Courtesy of Federal-Mogul Corporation.

FIGURE 13–1 Clamping force results from bolt stretch.

the maximum amount of stretch a bolt can experience and still provide clamping pressure.

If a bolt is stretched into yield, it takes a permanent set and never returns to normal **(Figure 13–2)**. The bolt will continue to stretch more each time it is used, just like a piece of taffy that is stretched until it breaks. Appendix B gives standard bolt and nut torque specifications. If the manufacturer's torque specifications are available, follow them.

Nonplated bolts have a rougher surface than plated finishes. Therefore, it takes more torque to produce the same clamping force as on a plated bolt. Most stated torque values are for dry, plated bolts.

Reusing a dry nut will provide a connection with decreasing clamp force each time it is used. Nut threads are designed to collapse slightly to carry the bolt load. Lubricating fasteners provides smoother surfaces and more consistent and evenly loaded connections. They also help reduce thread galling. Lubricate the bolt, never the bore.

FIGURE 13–2 These bolts have been torqued beyond their yield. Note the soda bottle effect.

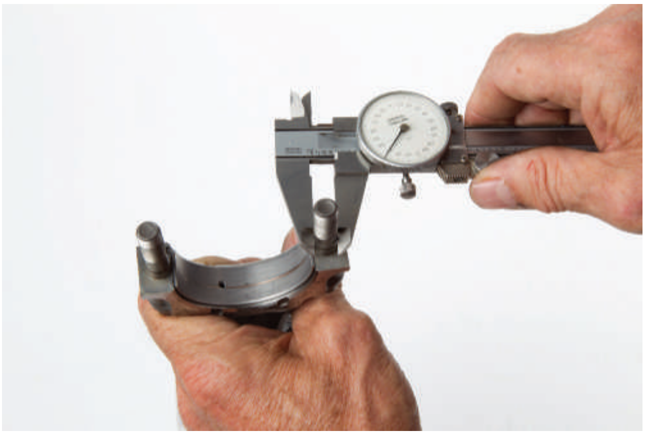


FIGURE 13–3 Bolts can be checked for stretch by measuring the shank and comparing it to specifications.

Otherwise, the bolt may merely be tightening against the oil in the hole.

If a bolt with a reduced shank diameter (for example, a connecting rod bolt) is specified by the OEM, never replace it with a standard, straight shank bolt. The reduced shank is designed to reduce the stress on the threads by transferring it to the shank. A standard bolt under similar conditions would break very quickly at the threads. These bolts can be checked by measuring the diameter of the threads and the shank, and comparing them to specifications **(Figure 13–3)**.

Keep the following points in mind:

1. Visually inspect the bolts.
   - Threads must be clean and undamaged. Discard all bolts that are not acceptable.
   - Run a nut over the bolt's threads by hand. Discard the bolt if any binding occurs.
   - Clean bolt and internal threads with a thread chaser or tap **(Figure 13–4)**.

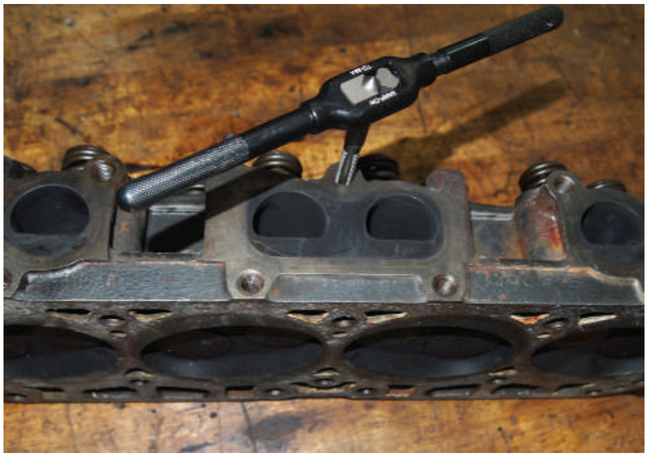


FIGURE 13–4 Cleaning bolt holes with a tap.

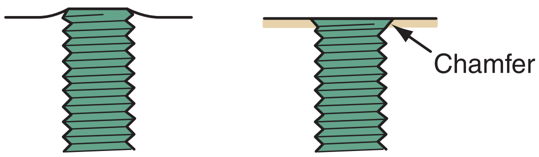


FIGURE 13–5 Bolt hole threads can pull up, leaving a raised edge. Also, if the block has been resurfaced, the threads may run up to the surface. In either case, the hole must be chamfered.

2. Apply a light coat of 10W engine oil to the threads and bottom face of the bolt head. A sealer is required for a bolt that enters a water jacket. This will stop seepage around the bolt threads. Seeping coolant could get in the oil or cause corrosion that might damage parts, resulting in engine failure.
3. Tighten bolts with an accurate torque wrench in the recommended sequence. This is important to prevent warpage of the parts.
4. If bolt heads are not tight against the surface, the bolts should be removed and washers installed.
5. Make sure the bolt is the proper length.

Internal threads often pull up, leaving a raised edge around the bore **(Figure 13–5)**. If a part has been resurfaced, the threads might run up to the surface. The bolt bores should be tapered at the surface by chamfering and the threads cleaned with an appropriate size bottoming tap.

Thread Repair

A common fastening problem is threads stripping inside an engine block, cylinder head, or other structure. This problem is usually caused by overtorquing or by incorrectly threading the bolt into the hole. The threads can be replaced with threaded inserts.

GO TO Chapter 5 for common procedures on thread repair.

SHOP TALK

Impact wrenches should only be used to loosen nuts and bolts. Use other power or hand tools to install them. Final tightening should always be done with a torque wrench.

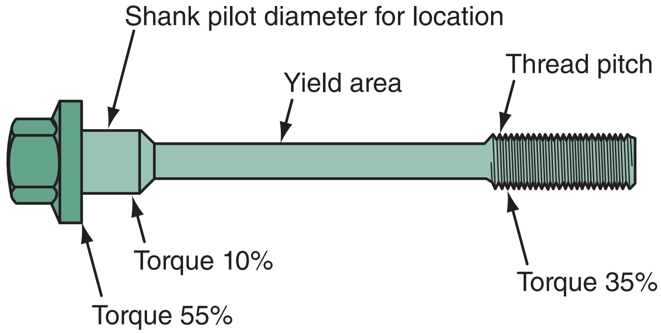


FIGURE 13–6 Torque-to-yield (TTY) bolts are designed with a reduced shank diameter; this is where the intended stretch occurs.

Torque-to-Yield (TTY) Bolts

Some fasteners are intentionally torqued into its yield condition. These fasteners, known as **torque-to-yield (TTY)** bolts, are designed to stretch when properly tightened. When a bolt is stretched to its yield point, it exerts its maximum clamping force. Torque-to-yield (TTY) bolts are not ordinary bolts. The bolt shank is designed to stretch **(Figure 13–6)** and spring back up to its yield point when tightened. Once at the yield point, the bolt becomes permanently stretched and will not return to its original length. Therefore, TTY bolts should not be reused.

Tightening a TTY bolt involves two distinct steps: Tighten the bolt to the specified torque, and then turn the bolt to a specified angle (measured in degrees) to load the bolt beyond its yield point **(Figure 13–7)**. A torque angle gauge is required to do this. This gauge fits between the drive of the torque wrench and the socket **(Figure 13–8)**. Once the specified torque is reached, the angle gauge is set to zero. Then the bolt is turned until the specified angle is read on the gauge.

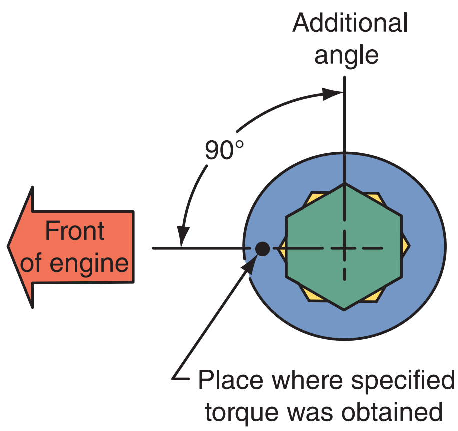


FIGURE 13–7 TTY bolts are tightened to a specified torque and then turned to an additional number of degrees.

FIGURE 13-8 A torque angle gauge.

Gaskets

When parts are bolted together, it is nearly impossible to obtain a positive seal between the parts. **Gaskets** provide that seal and also serve as spacers, wear insulators, and vibration dampers. Gaskets are only used between two stationary parts. Seals are used if one of the parts moves. The material used to make a gasket depends on its application **(Figure 13–9)**.

Cut Gaskets

Gaskets made of paper, fiber, and cork are normally called soft, cut gaskets **(Figure 13–10)**. Each gasket is cut to the desired size and shape from a sheet of material.

Paper/Fiber Gaskets These are made of a fiber-reinforced paper-like material. They do a good job of sealing low-pressure, low-temperature areas. For some applications, paper gaskets may be relatively thick. These gaskets seldom need an additional sealant; however, a thin coating of adhesive may be used to hold the gasket in place while it is installed.

Cork Gaskets Cork gaskets are also used to seal low-pressure areas, however they are not commonly used on today's engines. Cork gaskets are very soft,

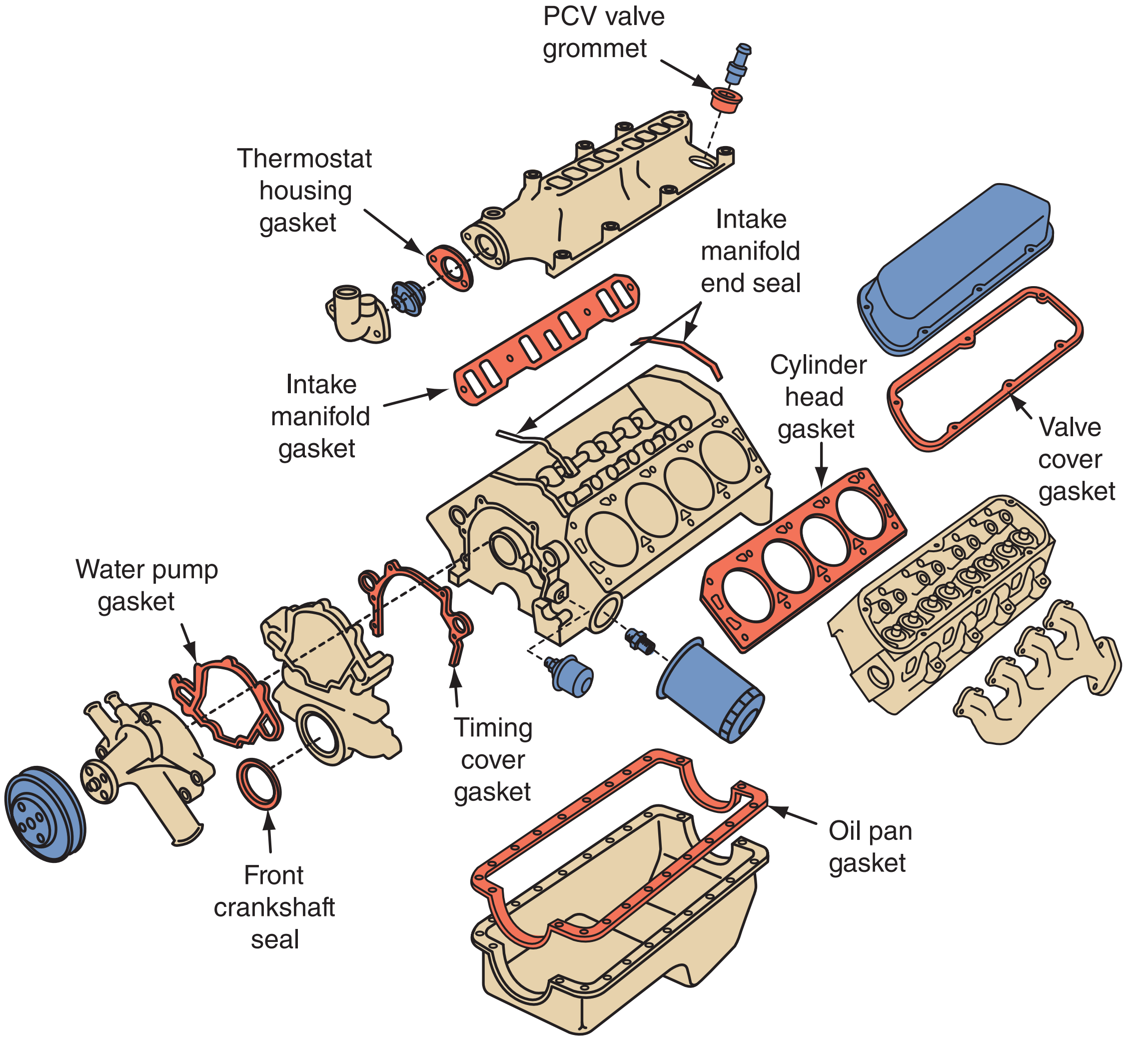


FIGURE 13-9 Typical engine gasket and seal locations.

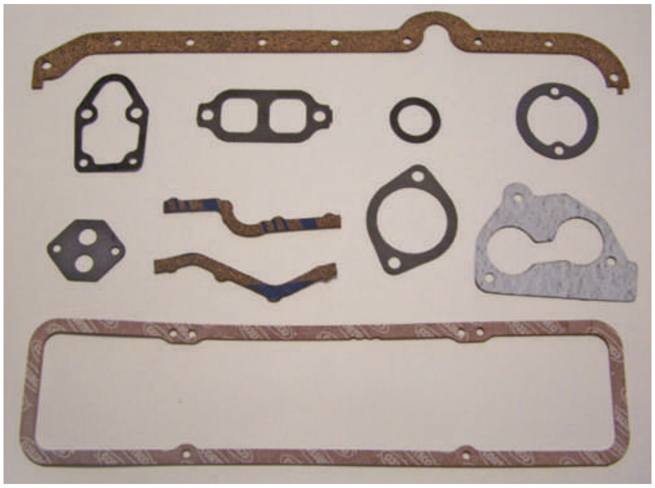


FIGURE 13–10 An assortment of cut gaskets.

FIGURE 13–12 Many newer valve cover and oil pan gaskets have steel inserts that allow for even tightening of the retaining bolts.

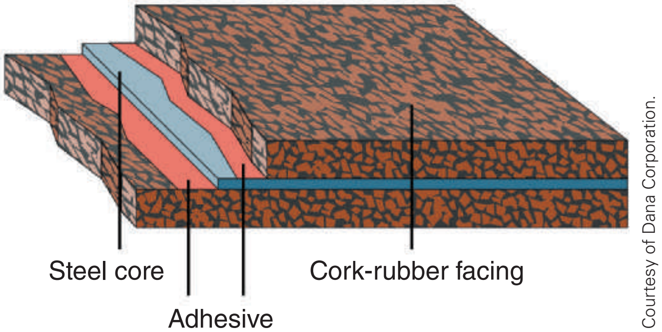


FIGURE 13–11 Composition of a cork/rubber gasket used mainly as valve cover, oil pan, and timing cover gaskets.

Warning! Do not use sealant or adhesive on rubber gaskets; they can prevent the gasket from sealing.

easily distorted, and absorbent and will weep some of the fluid they are sealing. They also tend to become brittle and crack over time. Most manufacturers have replaced cork gaskets with composite gaskets, typically rubberized cork **(Figure 13–11)**.

Molded Rubber Gaskets

Molded rubber gaskets provide excellent sealing and are commonly used on today's engines. These gaskets are made by injecting synthetic rubber (neoprene, nitrile, silicone, or other similar material) into a mold to form one-piece gaskets. Molded gaskets retain their flexibility and are durable. Molded gaskets are often used to seal intake manifolds, some thermostat or water pump housings, valve covers, and oil pans.

Some molded gaskets have a steel insert that adds stiffness and strength to the gasket **(Figure 13–12)**. Also, some gaskets have reinforcements around the bolt holes to limit the amount of crush when the parts are tightened together.

Manufacturers may not use premade gaskets. Rather they use chemical gasketing. Robotic equipment applies a bead of sealant around the sealing area. The result is called a "formed-in-place" gasket.

Hard Gaskets

Hard gaskets are made from steel, stainless steel, copper, or a combination of metals and other materials. Often the metal is enclosed by a compressible and heat-resistant clay/fiber or Teflon® compound **(Figure 13–13)**. Hard gaskets are used for cylinder heads, exhaust manifolds, EGR valves, and some intake manifolds.

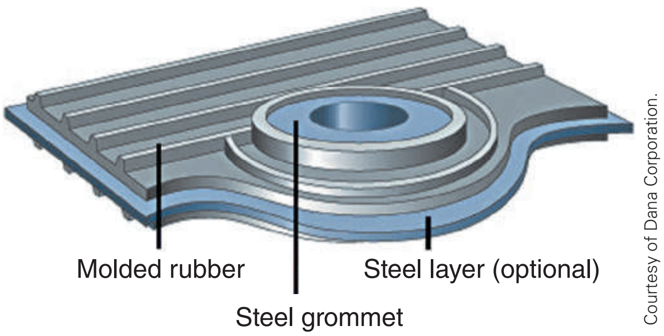


FIGURE 13–13 Composition of a Teflon®-coated perforated steel core gasket used mainly as head and intake manifold gaskets.

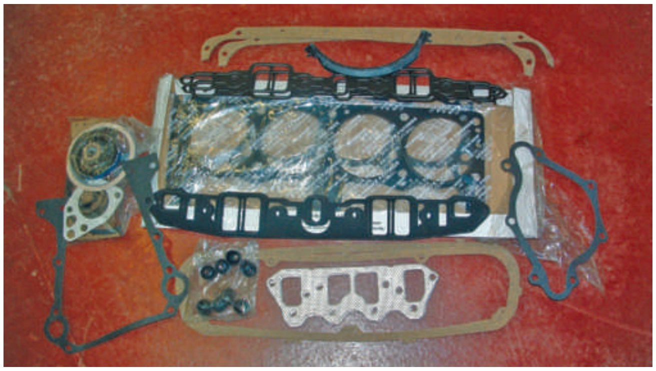


FIGURE 13–14 A full gasket set contains the gaskets and seals required for rebuilding an engine.

Replacement Gaskets

Gaskets can be purchased individually or in sets. Sets are often available for the service performed on the engine. The most common are timing cover, head, manifold, oil pan, and full sets. A full set contains all gaskets and seals required for rebuilding an engine **(Figure 13–14)**. Normally there are more gaskets in a set than are needed. A particular engine may have been available with different equipment and the extra gaskets are for those variations.

General Gasket Installation Procedures

The following instructions will serve as a helpful guide for installing gaskets. Because there are many different gasket materials and designs, it is impossible to list directions for every type of installation. Always follow any special directions provided in the instructions packed with the gasket sets.

SHOP TALK

Before replacing a gasket, check for any TSBs on the engine. There may be a recommended replacement for the OEM gasket. For example, some GM engines built between 1996 and 2002 have experienced premature intake manifold gasket failures. These failures are normally caused by the corrosive effects of organic acid technology (OAT) coolant. The cure is a replacement gasket that is less susceptible to OAT.

USING SERVICE INFORMATION

Always refer to the specific engine and engine part section of the service information for the recommended procedures for using sealants.

SHOP TALK

Some technicians tend to use too much sealant on gaskets. Do not make this mistake. Because sealants have less strength than gasket materials, they create weaker joints. They can also prevent gasket material from doing what it is supposed to do, which is to soak up oil and swell to make a tight seal.

1. Never reuse old gaskets.
2. Make sure you are installing the latest gasket part number. Sometimes gasket designs are revised and improved to correct pattern failures.
3. Handle new gaskets carefully.
4. Cleanliness is essential. New gaskets seal best when used on clean surfaces.
5. Use the right gasket in the right position. Always compare the new gasket to the mating surfaces to make sure it is the right gasket. Check that all bolt holes, dowel holes, coolant, and lubrication passages line up perfectly with the gasket. Some gaskets have directions such as “top,” “front,” or “this side up” stamped on one surface **(Figure 13–15)**. An upside-down or reversed gasket can easily cause a loss of oil pressure, overheating, and engine failure.

FIGURE 13–15 Some gaskets have installation directions stamped on them.

6. Use sealants and adhesives only when the engine or gasket manufacturer recommends their use. Some chemicals will react negatively with the gasket's coating.
7. Always start each bolt into its hole before you begin to tighten any of the bolts. Tightening bolts before all bolts are installed will cause component misalignment and prevent some bolts from threading into their holes.

Specific Engine Gaskets

There is a wide variety of gaskets used on engines, each with its own purpose, and each is designed for that application. The following is a discussion of the most common ones.

Cylinder Head Gaskets

Cylinder head gaskets seal the cylinder head to the block **(Figure 13–16)**. The head gasket has a very demanding job. It must seal the combustion chambers and the coolant and oil passages between the head and the block. The oil and coolant are low-temperature and low-pressure fluids. The gasket must prevent leakage inside and outside the engine. It must be able to do this while sustaining wide temperature ranges and pressures inside each cylinder. When a cold engine is first started, parts near the combustion chamber are very cold. Then, after only a few minutes of running, these same parts might reach 400 °F (204 °C). The inner edges of the head gasket are exposed to combustion temperatures from 2,000 °F to 4,000 °F (1,093 °C to 2,204 °C). On the intake stroke a vacuum or negative pressure is present. After combustion, pressure peaks of approximately 1,000 psi (6,895 kPa) occur. This extreme change from low to high pressure happens in a fraction of a second.

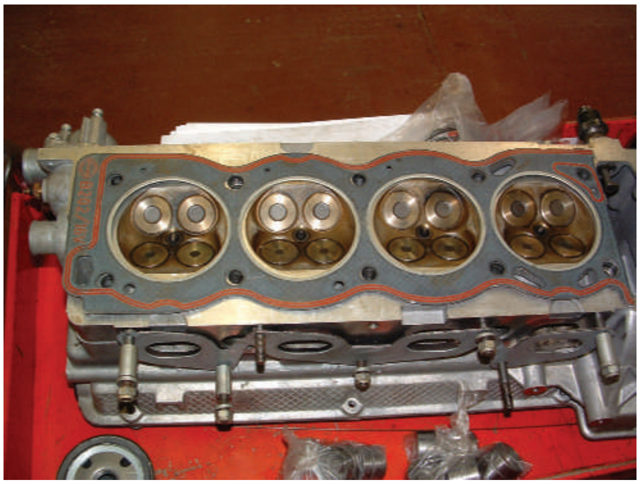


FIGURE 13–16 A head gasket with steel fire rings.

Cylinder head gaskets must simultaneously do the following:

- Seal intake stroke vacuum, combustion pressure, and the heat of combustion.
- Prevent coolant leakage and resist rust, corrosion, and, in many cases, meter coolant flow.
- Seal oil passages through the block and head while resisting chemical action.
- Allow for lateral and vertical head movement as the engine heats and cools.
- Be flexible enough to seal minor surface warpage while being stiff enough to maintain adequate gasket compression.
- Fill small machining marks that could lead to serious gasket leakage and failure.
- Withstand forces produced by engine vibration.

Head gaskets for many late-model cast-iron engines have raised silicone, Viton, or fluoroelastomer sealing beads on their face to increase the clamping pressure around some areas. Most head gaskets have a steel fire ring that surrounds the top of the cylinder. These protect the gasket material used elsewhere. The durability of a head gasket can also be improved by using strong, high-temperature fibers such as aramid and kevlar and by adding reinforcements around oil passages.

Bimetal Engine Requirements Most late-model engines have aluminum cylinder heads and cast-iron blocks. When heated, aluminum expands two to three times more than steel. This creates a back-and-forth scrubbing action on a head gasket as the engine temperature changes **(Figure 13–17)**. This movement can tear a gasket apart if it is not designed to handle it. To reduce the chances of a gasket tearing, graphite or specially coated gaskets are used. **Graphite** is a relatively soft material that can withstand high temperatures, and it is a natural lubricant. Teflon®, molybdenum, and other similar slippery nonstick coatings are used on other gasket designs to prevent the gasket from sticking to either surface. This allows the head to expand and contract without destroying the gasket.

Multilayer Steel (MLS) Many engines have multilayer steel (MLS) head gaskets. These gaskets are comprised of three to seven layers of steel. The outer layers are embossed stainless spring steel

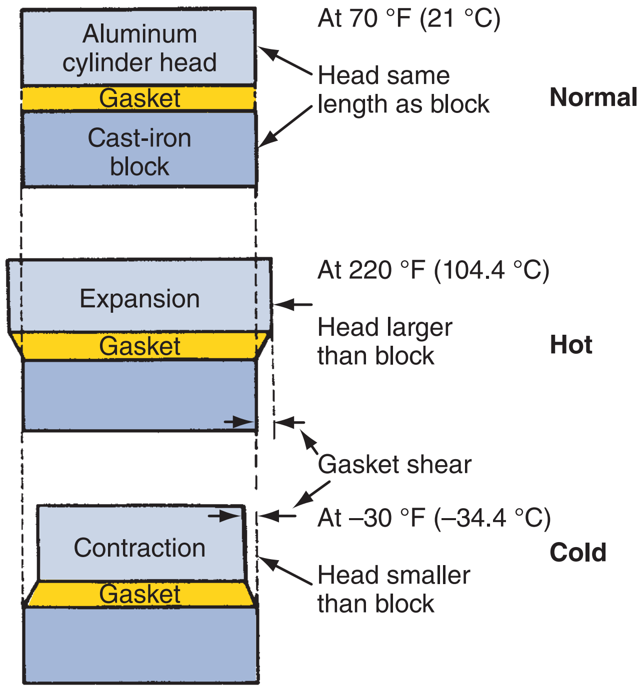


FIGURE 13–17 Thermal growth characteristics of bimetal engines.

FIGURE 13–18 The composition of an MLS head gasket.

Problem	Probable Cause
Preignition/ Detonation	Incorrect ignition timing
	Incorrect air-fuel mixture
	Vacuum leak
	Faulty cooling system
Overheating	Restricted radiator
	Cooling system leak
	Faulty thermostat
	Faulty water pump
	Inoperative cooling fan
	Faulty EGR system
Improper Installation	Wrong surface finish
	Incorrect bolt-tightening sequence
	Use of stretched or damaged bolts
	Improper use of sealant
	Use of incorrect gasket
	Dirty mating surfaces
Hot Spots	Use of incorrect gasket

FIGURE 13–19 Leading causes of cylinder head gasket failure.

coated with a thin layer of an antifriction coating of Teflon®, nitrile rubber, or Viton **(Figure 13–18)**. The inner layers provide the necessary thickness. The use of an MLS gasket reduces the load on the head bolts and allows them to retain their shape after they are tightened in place. They are also very durable but require a smooth finish on the engine block and cylinder head. They are also used with TTY bolts.

Head Gasket Failures When a head gasket has failed, it is important to correct the problem that caused it. **Figure 13–19** shows the common causes of failure and the systems that should be checked.

Some engines have hot spots that cannot be corrected. These engines have exhaust ports that are located next to each other. Heat builds up in these areas and causes the head to swell and crush the head gasket. Gasket manufacturers often incorporate reinforcements in those areas to resist the crushing.

Head Bolts Installation failures are commonly caused by head bolt problems. When installing a cylinder head and bolts:

- Make sure all bolts are clean and have undamaged threads. Replace any bolts that are nicked, deformed, or worn.

SHOP TALK

It is important to find out why a head gasket failed. When inspecting a gasket, measure its thickness at the damaged and undamaged areas. If the damaged area is thinner, the gasket failed due to overheating or a hot spot. If the fire ring around the cylinder bores is cracked or burnt, preignition or detonation caused the gasket to fail.

- Make sure the correct length bolt is installed in the bore. Some engines use longer bolts in some locations.
- Check the length of each bolt and compare the measurements. Longer than normal bolts are stretched and should not be reused.
- Inspect the shank or top of the threaded area of the bolt for evidence of stretching.
- Never reuse TTY bolts.
- When installing an aluminum head, use hardened steel washers under the bolts. Place the washers so their rounded edge faces up.
- Clean the thread bores in the engine block with a bottoming tap.
- Make sure the top of each thread bore is chamfered.
- If the head has been resurfaced, make sure the bolts do not bottom out in their bores. If they do, install hardened steel washers under the bolt to raise them.
- Lubricate the threads and the bottom of the bolt head with engine oil.
- Apply the correct type of thread sealant to all bolts that go into a coolant passage.

Manifold Gaskets

There are three basic types of manifold gaskets—the intake manifold, exhaust manifold, and an intake and exhaust combination. Combination gaskets are often used on inline engines without cross-flow heads. Manifold gaskets are made of a variety of materials, depending on the application. Each type of manifold gasket has its own sealing characteristics and problems **(Figure 13–20)**. Therefore, be sure to follow the manufacturer's instructions when installing them.

FIGURE 13–20 Assorted intake and exhaust manifold gaskets for diverse applications.

FIGURE 13–21 A rubberized cork valve cover gasket.

Before installing a manifold and its gasket, make sure that the mating surfaces on the head and manifold are flat and free of damage. Also, always follow the recommended bolt-tightening sequence and use the exact torque specs.

Valve Cover Gaskets

Valve cover gaskets must make a seal between a steel, aluminum, magnesium, or molded plastic cover and the cylinder head surface. On OHC engines, cam covers are normally made of die-cast aluminum. Some cylinder cover gaskets have spark plug gaskets integrated into the gasket. When installing these, make sure the gasket is perfectly aligned. Valve cover bolts are usually widely spaced so the gasket material is able to seal without being tightly clamped **(Figure 13–21)**. Valve cover gaskets must be able to withstand high temperatures and the caustic action of acids in the oil.

Oil Pan Gaskets

An oil pan gasket seals the joint between the oil pan and the bottom of the block **(Figure 13–22)**. The gasket might also seal the bottom of the timing cover and the lower section of the rear main bearing cap.

Like valve cover gaskets, the oil pan gasket must resist hot, thin engine oil. Oil pans are usually made of stamped steel, cast iron, or cast aluminum. Because of the added weight and splash of crankcase oil, the pan has many retaining bolts closely spaced. As a result, the clamping force on the oil pan gasket is great.

Oil pan gaskets may be made with several types of material. A commonly used material is synthetic rubber, known for its long-term sealing ability. It is tough, durable, and resists hot engine oil. Synthetic rubber gaskets are easy to remove, so the sealing surfaces need less cleanup.

Many late-model engines use a hard gasket with a bead of sealant around the inside dimensions of the gasket **(Figure 13–23)**. The bead increases clamping pressures and provides a positive seal.

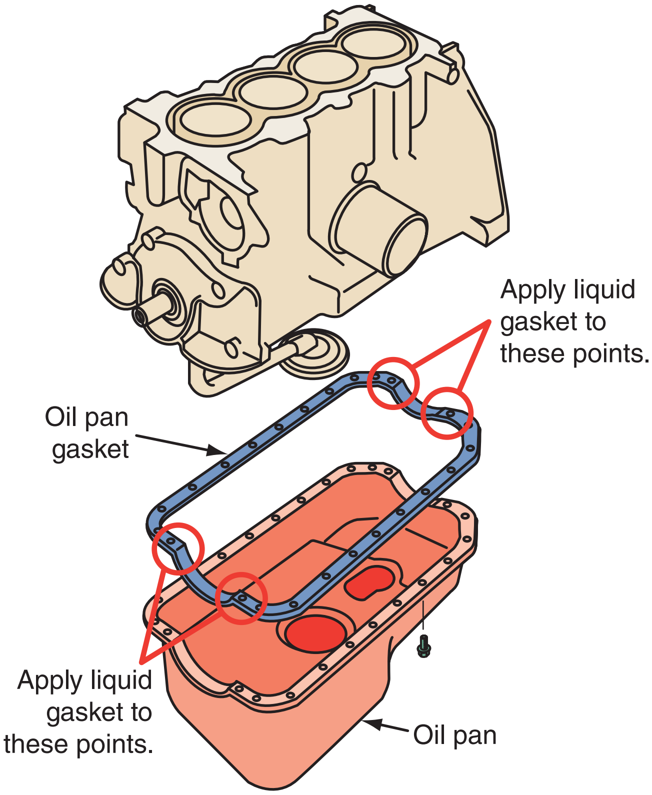


FIGURE 13–22 Oil pan gasket installation; note the points where a liquid gasket is required.

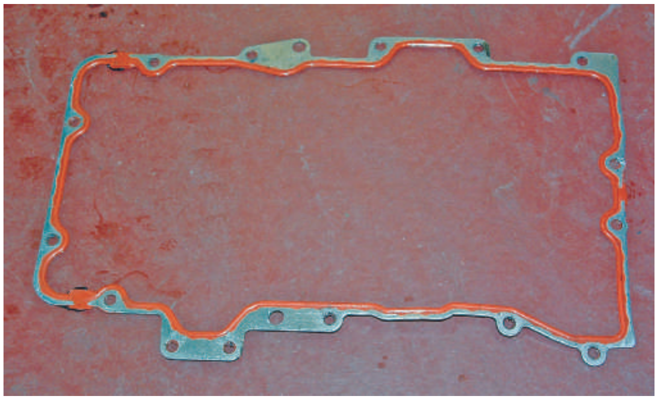


FIGURE 13–23 A hard oil pan gasket with a sealant bead.

The oil pan on some engines is comprised of two parts: the upper unit, which is made of aluminum or magnesium, and the lower unit, which is made of stamped steel. A gasket is used to seal the two units.

Carefully follow the recommendations of the OEM and gasket manufacturer. Before installing a stamped steel oil pan, make sure its flange is flat. Tighten the oil pan bolts according to specifications and in the sequence given in the service manual.

EGR Valve

The exhaust gas recirculation (EGR) valve takes a sample of the exhaust gases and introduces it back into the cylinders. This reduces combustion temperatures and prevents NO_x from forming. The sealing surface of the valve should be carefully inspected. Use a file to remove any minor imperfections that may prevent the valve from sealing. Also make sure that the new gasket is the correct one; some gaskets have specifically sized holes that are used to regulate exhaust flow. Using the wrong gasket could change how the engine performs.

Adhesives, Sealants, and Other Sealing Materials

Many gasket sets include a label with the recommended chemical to use with that gasket set. Some even include sealers when the OEM used a sealer to replace a gasket and a gasket cannot be manufactured for that application. They also include sealers when gasket unions need a sealant to ensure a good seal.

Adhesives

Gasket adhesives form a tough bond when used on clean, dry surfaces. Adhesives do not aid the sealing ability of the gasket. They are meant only to hold gaskets in place during assembly. Use small dabs. Do not assemble components until the adhesive is completely dry **(Figure 13–24)**.

Sealants

Manufacturers sometimes specify the use of sealants to assist a gasket or seal or to form a new gasket.

SHOP TALK

Chemical adhesives and sealants give added holding power and sealing ability where two parts are joined. Sealants usually are added to threads where fluid contact is frequent. Chemical thread retainers are either aerobic (cures in the presence of air) or anaerobic (cures in the absence of air). These chemical products are used in place of lock washers.

FIGURE 13–24 An adhesive is often used to hold a gasket in place during assembly.

These sealants should only be used when specified by the manufacturer. Also make sure to use the specific sealant recommended by the manufacturer.

> **Warning!** Never use a sealant or liquid gasket material on exhaust manifolds.

General-Purpose Sealants General-purpose sealers are liquid and available in a brush type (known as brush tack) or an aerosol type (known as spray tack). General-purpose sealers **(Figure 13–25)** form a tacky, flexible seal when applied in a thin, even coat that aids in gasket sealing by helping to position the gasket during assembly.

> **Warning!** Make sure the sealants you use are catalytic converter and oxygen sensor safe.

Courtesy of Federal-Mogul Corporation.

FIGURE 13–25 Applying gasket sealer with a brush.

FIGURE 13–26 Bolts that pass through a liquid passage should be coated with Teflon® or similar thread sealant.

Thread Sealants Bolts that pass through a liquid passage should be coated with Teflon® thread **(Figure 13–26)** or a brush-on thread sealant. Some head bolts or water pump bolts tighten into a coolant passage and must be sealed or they will leak. These flexible sealants are nonhardening sealers that fill voids, preventing the fluid from running up the threads. They resist the chemical attack of lubricants, synthetic oils, detergents, antifreeze, gasoline, and diesel fuel.

Silicone Sealants Silicone (or formed-in-place FIP) gaskets are a liquid sealant applied directly to mating surfaces and are allowed to cure in place. Many technicians use silicone gasketing to aid the sealing of corners, notches, or dovetails of gaskets **(Figure 13–27)**.

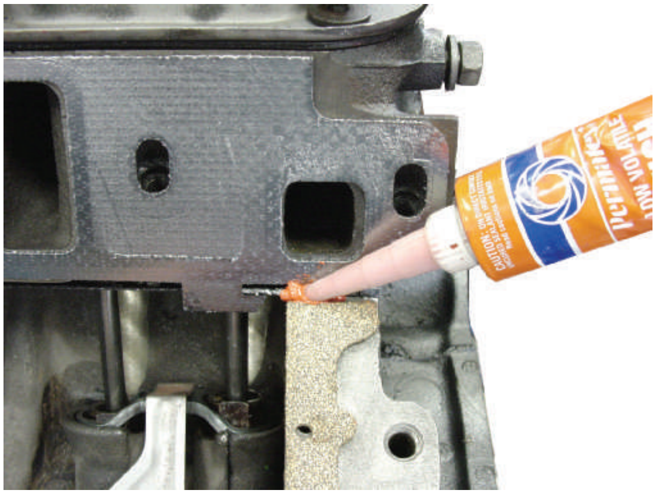


FIGURE 13–27 Applying a bead of RTV gasket material at the point where two gaskets meet.

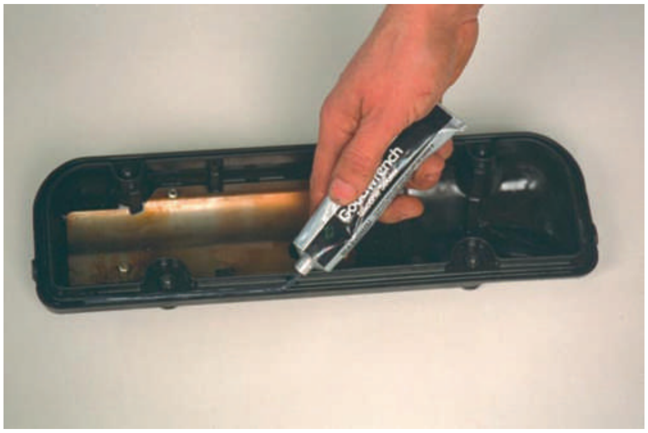


FIGURE 13–28 Applying a bead of RTV gasket material on a valve cover.

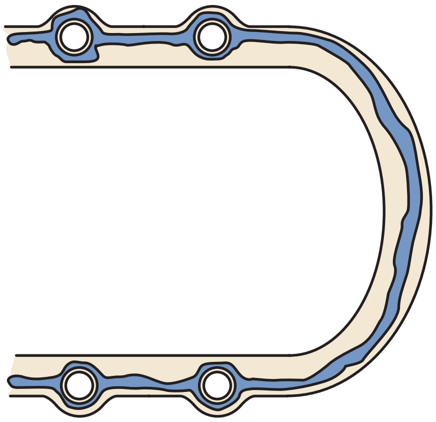


FIGURE 13–29 When applying RTV, make sure the bolt holes are encircled.

Room temperature vulcanizing (RTV) silicone sealing products are the most commonly used FIP gasket products. RTV is an aerobic sealant, which means it cures or hardens in the presence of air. RTV can be used to seal two stationary parts such as water pumps **(Figure 13–28)** and oil pans. It cannot be used as a head or exhaust gasket or in fuel systems. RTV comes in a variety of colors that denote the proper application. Black is for general purpose; blue is for special applications; and red is for high-temperature requirements. Always use the correct type for the application. RTV silicone sealants are impervious to most fluids, are extremely resistant to oil, have great flexibility, and adhere very well to most materials.

Caution! The uncured rubber contained in RTV silicone gasketing irritates the eyes. If any gets in your eyes, immediately flush with clean water or eyewash. If the irritation continues, see a doctor.

Warning! Be careful not to use excessive amounts of RTV. If too much is applied, it can loosen up and get into the oil system where it can block an oil passage and cause severe engine damage.

To use RTV, make sure the mating surfaces are free of dirt, grease, and oil. Apply a continuous ⅛-inch bead on one surface only (preferably the cover side). Encircle all bolt holes **(Figure 13–29)**. Adjust the shape before a skin forms (in about 1 minute), then remove the excess RTV with a dry towel or paper towel. Press the parts together. Do not slide the parts together—this will disturb the bead. Tighten all retaining bolts to the specified torque. Photo Sequence 9 shows the steps in using form-in-place gaskets.

Anaerobic Sealants These materials are used for thread locking as well as gasketing. They are mostly used to hold sleeves, bearings, and locking screw nuts in places subject to much vibration. Anaerobic sealers are intended to be used between the machined surfaces of rigid castings, not on flexible stampings. Use anaerobic sealants only when specified.

Antiseize Compounds

Antiseize compounds prevent dissimilar metals from reacting with one another and seizing. This

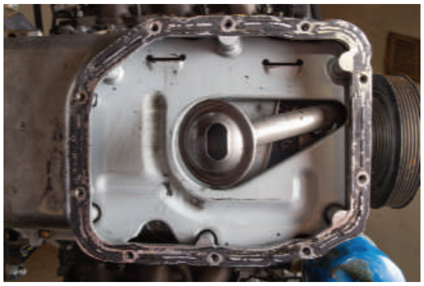
SHOP TALK

Once hardened, an anaerobic bond can withstand high temperatures. Different anaerobic sealants are for specific purposes and not readily interchangeable. For example, thread-locking products range from medium-strength antivibration agents to high strength, weldlike retaining compounds. The inadvertent use of the wrong product could make future disassembly impossible.

PHOTO SEQUENCE 9

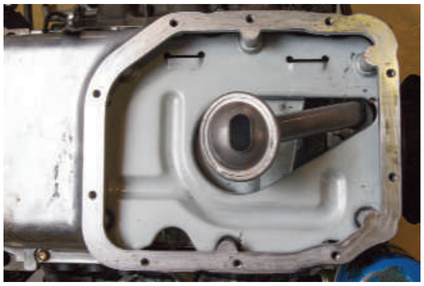
Using Form-In-Place Gasket Maker

P9-1 As a vehicle ages, gaskets and seals harden and often begin to leak. This shows an example of an oil leak at the oil pan.

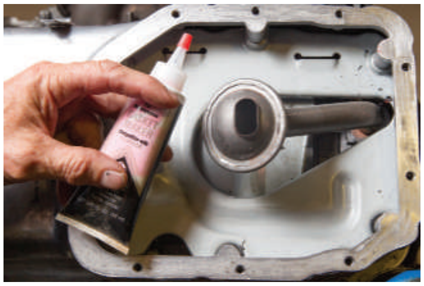


P9-2 Form-in-place gaskets are commonly used in automotive applications such as oil pans, valve covers, and transmission pans. In many cases, the vehicles are assembled from the factory using form-in-place gaskets.

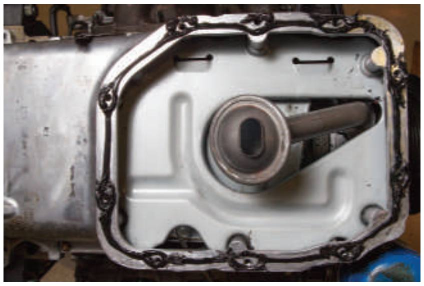
P9-3 Before form-in-place gasket maker can be used, the mating surfaces must be clean and dry. You may need to use a cleaning solvent, aerosol cleaner, and a gasket scraper to remove the old gasket. Be careful not to damage the mating surfaces during cleaning.



P9-4 Make sure both mating surfaces are clean and dry.



P9-5 Next, select the correct type of gasket maker for the applications. It is important that the right type of gasket maker is used to prevent leaks and damage to other components.



P9-6 Apply a continuous ⅛th inch bead of gasket maker around the entire gasket surface and around all bolt holes.

P9-7 Depending on the type of gasket maker being used, you may need to let the bead cure before installing the oil pan. Refer to the directions that came with the product.

P9-8 Install the oil pan and start each bolt before tightening any of the bolts.

P9-9 Locate the torque spec and tighten each bolt to the correct torque. It is important that the bolts be tightened properly to prevent damage to the pan from over-tightening.

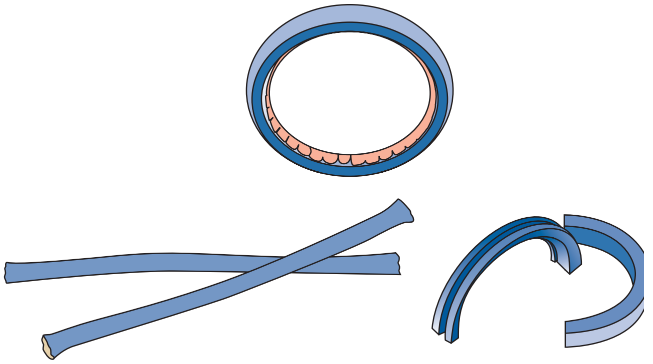


FIGURE 13-30 The three basic oil seal designs.

material is used on many fasteners, especially those used with aluminum parts. Always follow the manufacturer's recommendations when using this compound.

Oil Seals

Seals **(Figure 13–30)** keep oil and other fluids from escaping around a rotating shaft.

Timing Cover Oil Seals

The timing cover seal prevents oil from leaking around the crankshaft. Its installation often requires the use of a special tool **(Figure 13–31)** or a driver. It is important that the seal is positioned squarely in the bore of the cover and the crankshaft is positioned in the center of the seal.

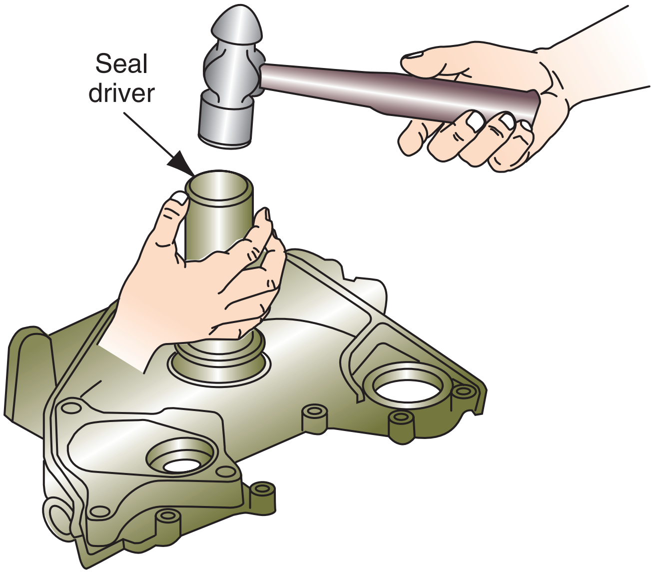


FIGURE 13-31 The installation of the timing cover oil seal requires the use of a special tool or driver.

SHOP TALK

Whenever installing an oil seal, make sure its lip seal is lubricated with a light coating of oil. Also, make sure the lip of the seal is facing the direction that oil is coming against.

Rear Main Bearing Seals

Rear main bearing seals keep oil from leaking around the rear main bearing. Molded synthetic rubber lip-type seals are used on most engines. They do a good job of sealing as long as the surface of the shaft is very smooth. Synthetic rubber seals may be retrofitted to some older engines that have wick seals.

Four types of synthetic rubber are used for rear main bearing seals. **Polyacrylate** may be used because it is tough and abrasion resistant, with moderate temperature resistance. Silicone synthetic rubber has a greater temperature range, but it has less resistance to abrasion and is more fragile than polyacrylate. Silicone seals must be handled carefully during installation to avoid damage. Viton has the abrasion resistance of polyacrylate and the temperature range of silicone, but it is the most expensive of the synthetic types. Synthetic rubber seals may be one piece **(Figure 13–32)** or two pieces **(Figure 13–33)**. PTFE (polytetrafluoroethylene) rubber oil seals now in use have reduced friction, a wider temperature operating range, and better chemical resistance than Viton and polyacrylate seals.

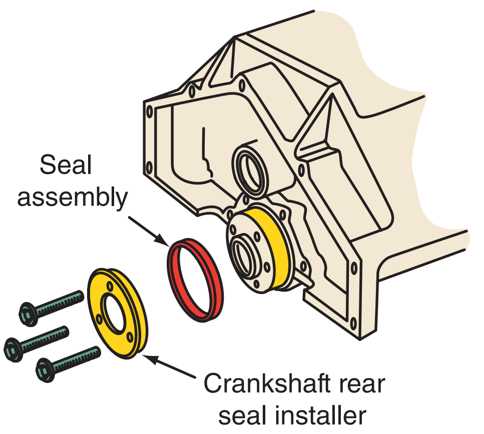


FIGURE 13-32 Installing a one-piece rubber rear crankshaft seal.

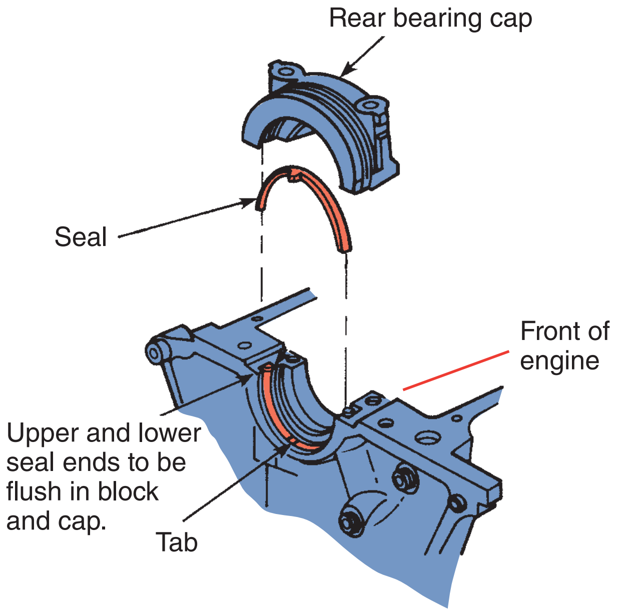


FIGURE 13-33 Typical two-piece rubber rear crankshaft seal.

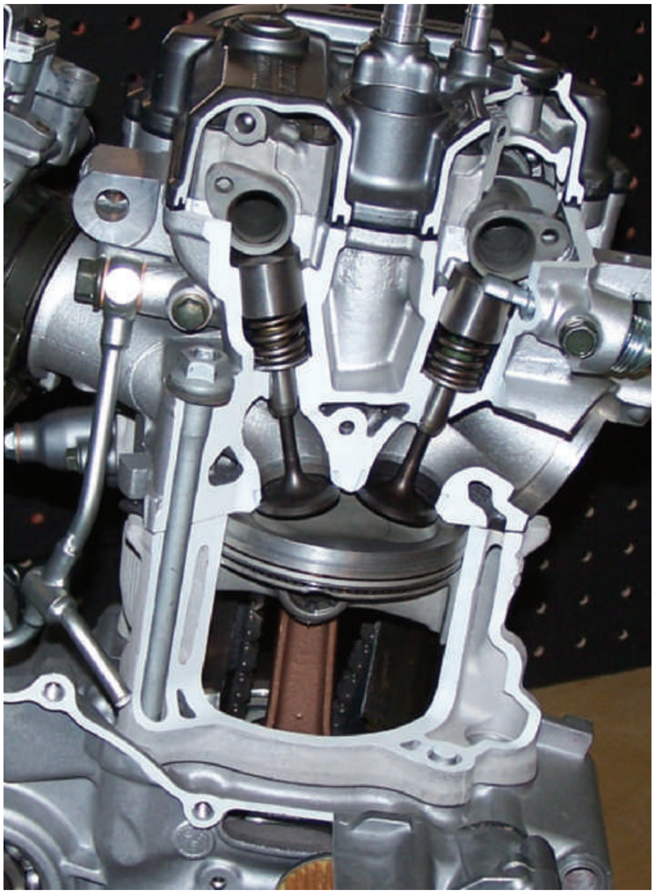


FIGURE 13-34 Head bolts are of different lengths in some engines.

Engine Reassembly

When reassembling an engine, the sequence is essentially the reverse of the teardown sequence given in a previous chapter.

Installing the Cylinder Head and Valve train

Use a wire brush to clean the threads of the head bolts. Then check their condition and length. Many engines use head bolts of different lengths **(Figure 13–34)** and their location is given in the service information. Lightly lubricate the threads with clean engine oil.

Position the head gasket on the block and make sure it matches the bores in the block. Place the cylinder head onto the block. Make sure that the dowel pins are in place and that the head and block are properly aligned.

Tighten the head bolts according to the recommended sequence **(Figure 13–35)** and to the specified torque. Most heads are tightened in a sequence that starts in the middle and moves out to the ends. The bolts are generally tightened in two or three stages.

For OHV engines, before inserting the pushrods, check their straightness by rolling them on a flat, level surface. Inspect the ends for wear and make sure the internal passage is clear. When installing, apply some assembly lube to both ends. Liberally coat the rocker arms with assembly lube or clean engine oil. Then install the pushrods and rocker arms. Many OHV engines have positive stop rocker arm adjustments. This means that when torquing the rocker arms to spec, the plunger of the hydraulic lifter is properly positioned, giving the correct lifter adjustment.

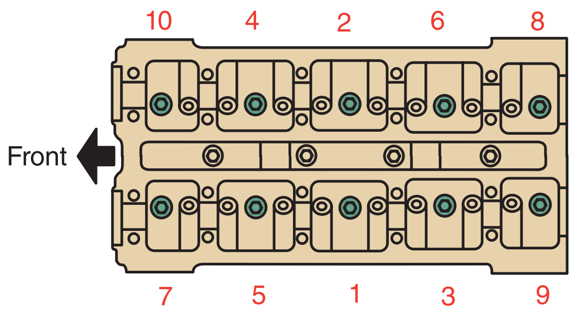


FIGURE 13-35 Always follow the specified tightening sequence when torquing cylinder head bolts.

> **SHOP TALK**
>
> When changing a timing belt or chain, a camshaft locking tool can be used to hold the camshaft in place. Camshaft tools are vehicle specific, so make sure you have the correct tool for the engine you are working on. Often these tools come with a kit that allows you to align the camshaft(s) with the crankshaft.

Timing Belts

The alignment of the camshaft(s) with the crankshaft is critical. The alignment marks and the correct procedure for doing this vary with the engine design. Many engines have primary (cam) belts and secondary belts for the balance shafts. These must be properly timed. Check the service information for the correct alignment and tension adjustment procedures. Make sure that the belt tensioners are set properly.

Timing belts can be replaced with the engine in the vehicle or when the engine is on a stand. Photo Sequence 10 shows a typical procedure for changing a timing belt with the engine in a vehicle.

After the belt is installed, adjust its tension according to the manufacturer's recommendations. Then, by turning the crankshaft, rotate the engine through two complete turns and recheck the tension. Now rotate the engine through at least two more revolutions. Recheck the timing marks on the crankshaft and camshaft. If necessary, readjust the timing and tension.

Timing Chains

Many engines use timing chains instead of belts. An engine may have a single chain, as most OHV V8 engines, or have three or more chains. DOHC engines may have individual chains that connect to each of the camshafts. Engines with multiple chains often have multi-step timing procedures, which must be followed exactly to ensure correct timing and prevent engine damage.

> **USING SERVICE INFORMATION**
>
> Normally, camshaft timing marks are shown in the engine section of the service information under the heading of Timing Belt or Chain R&R.

These are general procedures to replace timing chain on a late-model V6 with the engine still in the vehicle. Always follow the manufacturer's service information when replacing a timing chain and make sure to use the most up-to-date components.

1. Remove the upper intake manifold and valve covers to access the camshafts.
2. Remove the crankshaft pulley and timing cover.
3. Set the crankshaft to the first alignment position.

Note: This may be to set the timing for one bank of the engine and further crank movement will be necessary to set the other bank. Remove the chain tensioner, guides, and chain for the first bank.

4. Rotate the crank to the second alignment position. Remove the tensioner, guides, and primary timing chain. Remove the tensions, guides, and chain for the second bank.
5. When replacing the camshaft sprockets or VVT phasers, use a wrench to hold the cams in place when loosening and torquing the sprockets.
6. Install the new chain on the second bank. Note any painted links on the chain **(Figure 13–36)**. These are typically used to align with timing marks on the cam sprockets and other drive gears. Align

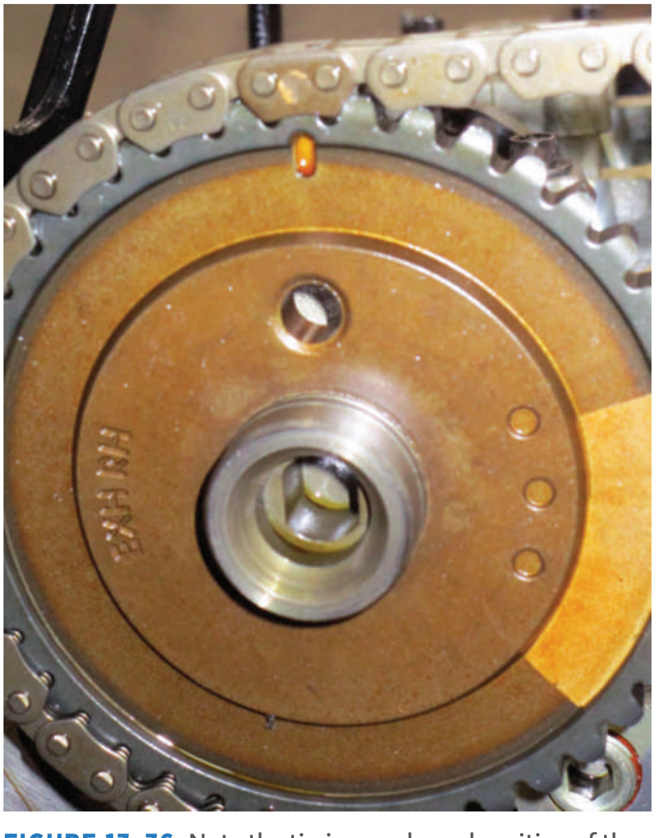


FIGURE 13-36 Note the timing marks and position of the chain links on this DOHC engine.

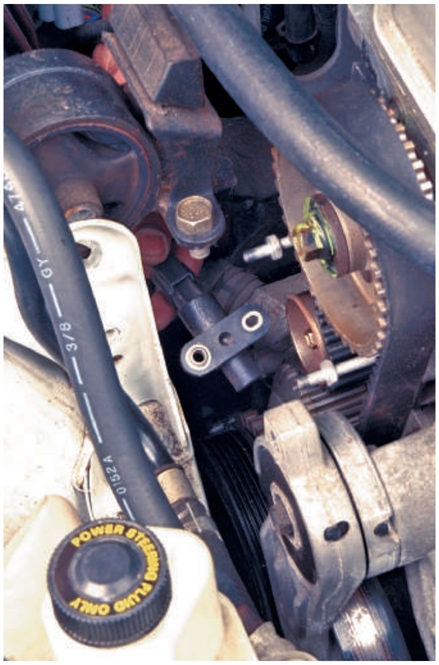
PHOTO SEQUENCE 10

Replacing a Timing Belt on an OHC Engine

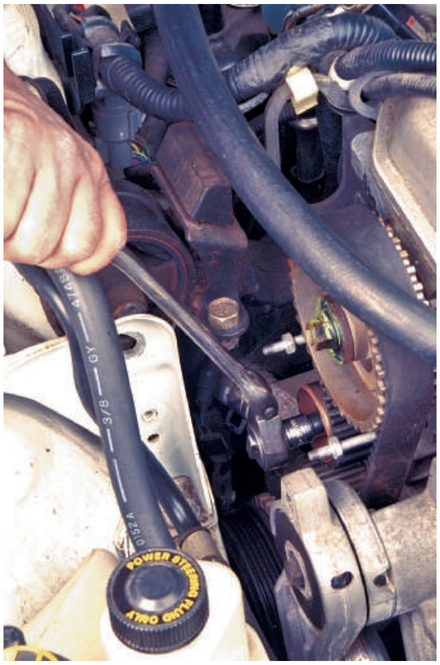
P10-1 Disconnect the negative cable from the battery prior to removing and replacing the timing belt.

P10-2 Carefully remove the timing cover. Be careful not to distort or damage it while pulling it up. With the cover removed, check the immediate area around the belt for wires and other obstacles. If some are found, move them out of the way.

P10-3 Align the timing marks on the camshaft's sprocket with the mark on the cylinder head. If the marks are not obvious, use a paint stick or chalk to clearly mark them.



P10-4 Carefully remove the crankshaft timing sensor and probe holder.

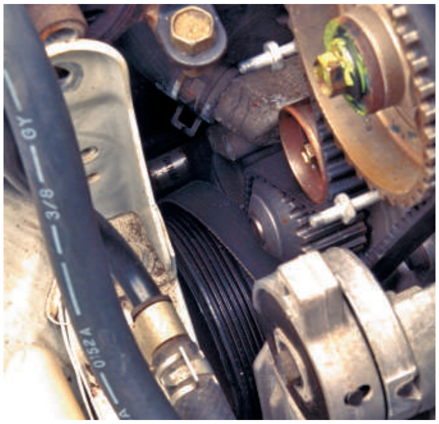


P10-5 Loosen the adjustment bolt on the belt tensioner pulley. It is normally not necessary to remove the tensioner assembly.

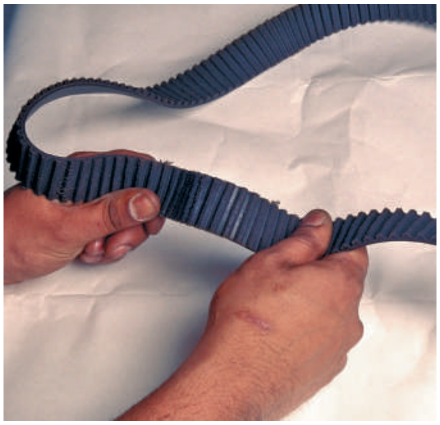
P10-6 Slide the belt off the crankshaft sprocket. Do not allow the crankshaft pulley to rotate while doing this.

PHOTO SEQUENCE 10

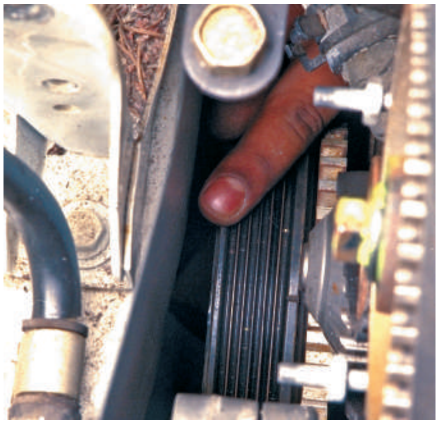
Replacing a Timing Belt on an OHC Engine *(continued)*



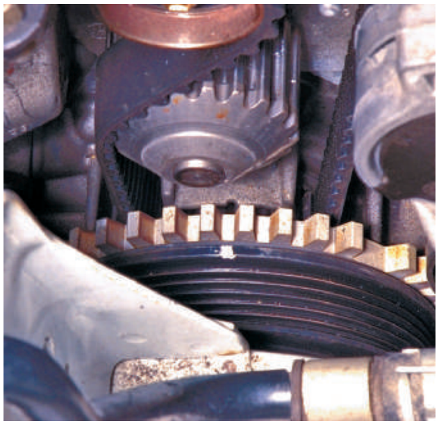
P10-7 To remove the belt from the engine, the crankshaft pulley must be removed. Then the belt can be slipped off the crankshaft sprocket.



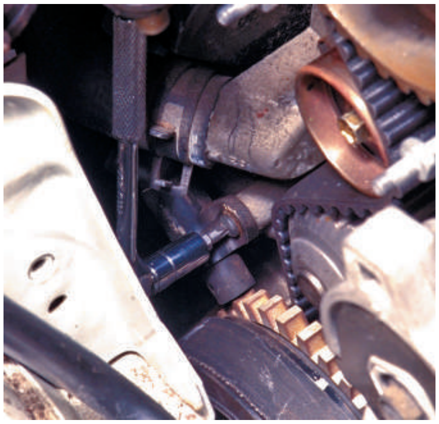
P10-8 After the belt has been removed, inspect it for cracks and other damage. Cracks will become more obvious if the belt is twisted slightly. Any defects in the belt indicate it must be replaced.



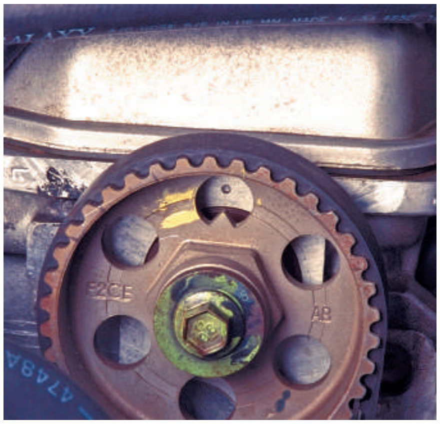
P10-9 To begin reassembly, place the belt around the crankshaft sprocket. Then reinstall the crankshaft pulley.



P10-10 Make sure the timing marks on the crankshaft pulley are lined up with the marks on the engine block. If they are not, carefully rock the crankshaft until the marks are lined up.



P10-11 With the timing belt fitted onto the crankshaft sprocket and the crankshaft pulley tightened in place, the crankshaft timing sensor and probe can be reinstalled.



P10-12 Align the camshaft sprocket with the timing marks on the cylinder head. Then wrap the timing belt around the camshaft sprocket and allow the belt tensioner to put a slight amount of pressure on the belt.

the chain per the service information. Install and torque the guides and tensioner. Recheck all timing marks and release the tensioner.

7. Install the primary chain with the timing marks aligned properly. Install the chain guides and tensioner. Recheck all timing marks and release the tensioner.
8. Rotate the crank back to the first alignment position and install the chain. Make sure the painted marks align with the sprockets and other drive gears. Install the guides and tensioner. Recheck all timing marks and release the tensioner.

Adjusting Valves

Nearly all engines must have their valve clearance set before starting after a rebuild. Engines with solid lifters require periodic valve adjustments. Valve clearance is called **valve lash** and is checked by inserting a feeler gauge between the valve tip and the rocker arm or cam lobe. The proper amount of valve lash allows for the expansion of parts as the engine's temperature rises. This prevents excessive wear and/or damage to the valve train. It also minimizes valve train noise. Always refer to the service information before adjusting valve lash.

Valve lash is adjusted in many different ways, depending on engine design. It is extremely important to make sure the valves are totally closed before making the adjustment. Most OHV engines with hydraulic lifters are adjusted, one cylinder at a time, by bringing a cylinder to exact TDC. At this point the intake and exhaust valves are fully closed and the lifter is on the heel of the cam lobe. Rotate a valve's pushrod with your fingers while tightening the rocker arm's pivot nut. When the pushrod has some resistance, turn the nut an additional ⅛ to ½ turn. Once the valves of that cylinder are adjusted, the next cylinder in the firing order is brought to TDC and its valves adjusted. The process is repeated until all valves have been adjusted. Valve lash can be adjusted with the engine in or out of the vehicle.

SHOP TALK

Pay close attention to the valve lash specs. Typically the exhaust valves have a different lash spec than the intakes. Incorrect adjustment can cause misfires and other performance concerns.

FIGURE 13–37 Some overhead cam engines feature a cam follower with an adjustment screw.

The procedure for adjusting an OHV with solid lifters is similar, except there must be a clearance between the top of the valve stem and the rocker arm tip. The lash is measured with a feeler gauge and adjusted with a screw. Once the desired lash is present, a locking nut is tightened while the screw is held in position so the adjustment does not change.

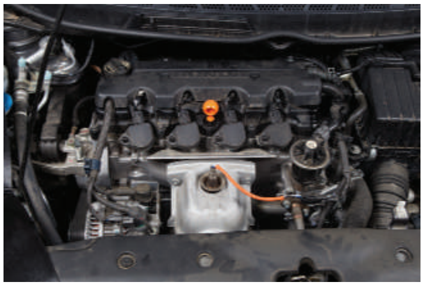
Similar lash adjustment procedures are used on some OHC engines. An adjustment screw at one end of the rocker arm is tightened or loosened to obtain the desired lash **(Figure 13–37)**.

Valve lash may be controlled by select shims on many OHC engines **(Figure 13–38)**. The shim sits between the cam lobe and cam follower placed over the valve assembly. Valve lash is adjusted by inserting a shim of a different thickness into the follower. Photo Sequence 11 shows the steps in adjusting valves by replacing a shim.

Some engines rely on cam followers of different thicknesses to provide proper valve lash. To adjust lash on these engines, the valve clearance of all valves should be measured while the valves are closed. Once the lash measurements have been taken, the camshaft is removed. Then the thickness of the cam follower on the valves that were out of spec should be measured. The desired cam follower is determined in the same way as deciding the correct shim thickness. The thickness of the new follower should equal the thickness of the old follower plus the measured lash. The desired lash is then

PHOTO SEQUENCE 11

Adjusting Valve Lash



P11-1 This late model four cylinder has adjustable rocker arms.

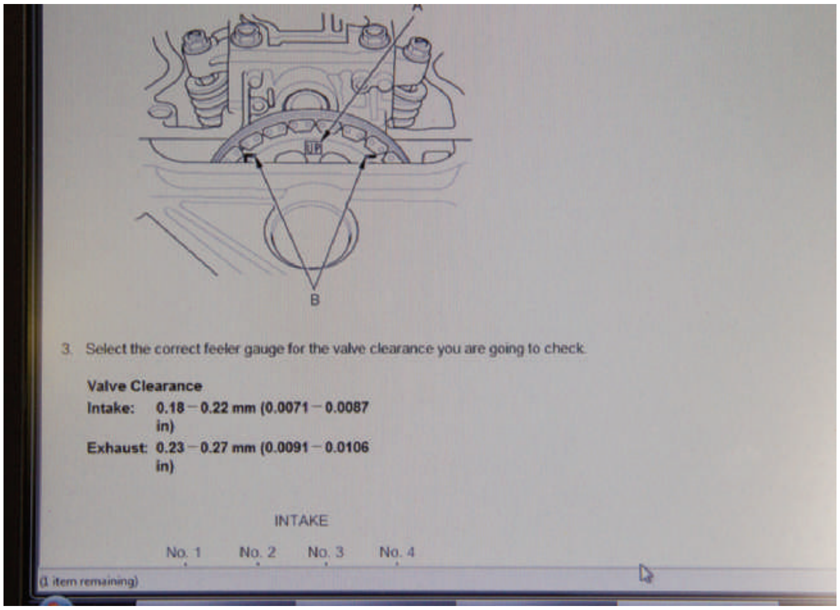
P11-2 Place fender covers on vehicle to protect finish.

P11-3 Remove the bolts securing the valve cover.

P11-4 Remove the valve cover.

P11-5 Notice there is a screw secured by a locking nut to hold the screw in position. NOTE: It is important that the valve being adjusted is fully closed.

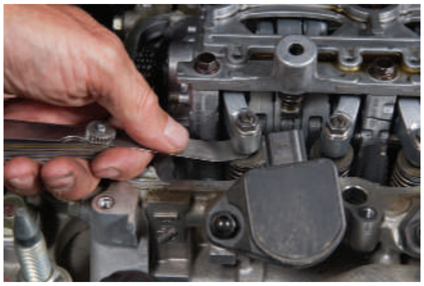
P11-6 With a socket and ratchet rotate the crankshaft until its reference point aligns with TDC on the timing cover.



P11-7 Here are the specifications for valve lash on this engine.

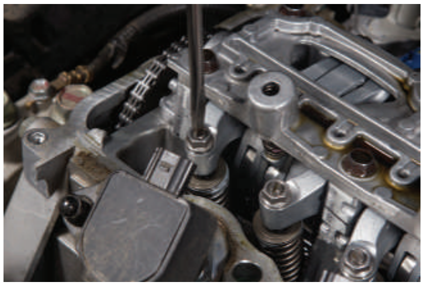
PHOTO SEQUENCE 11

Adjusting Valve Lash *(continued)*

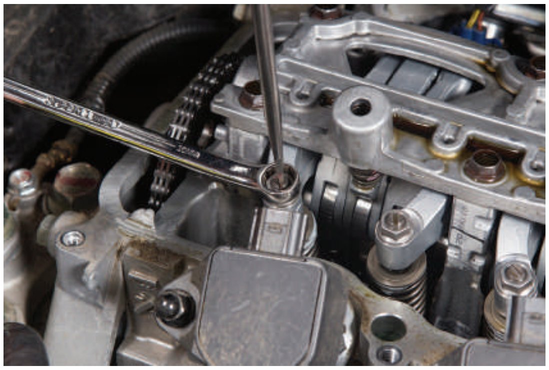


P11-8 Place a feeler gauge sized to the specifications between the adjustment screw and the top of the valve. If it feels that the gauge is too small or large, try different leaves of the gauge.

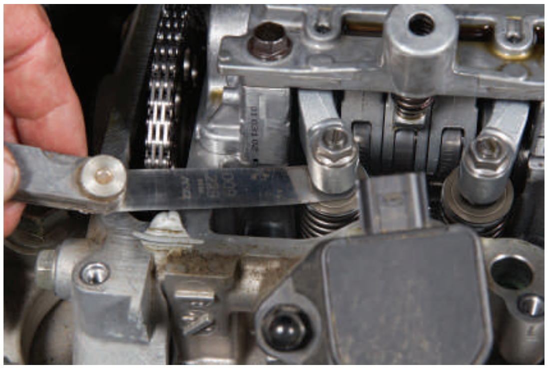
P11-9 Once you have found a leaf that feels right, read the dimension on the leaf—this is the lash present on that valve.



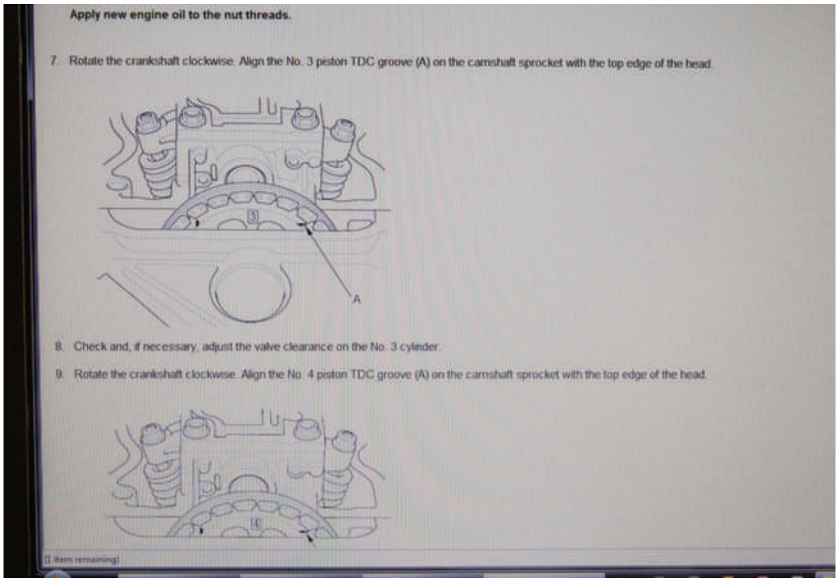
P11-10 To bring the lash to the specified clearance, loosen the locking nut and turn the adjusting screw until the desired clearance is met.



P11-11 Once the lash is within specifications, hold the adjusting screw in place while tightening the locking nut.



P11-12 Double check the lash with a feeler gauge.



P11-13 Check the service information for instructions on adjusting the remaining cylinders.

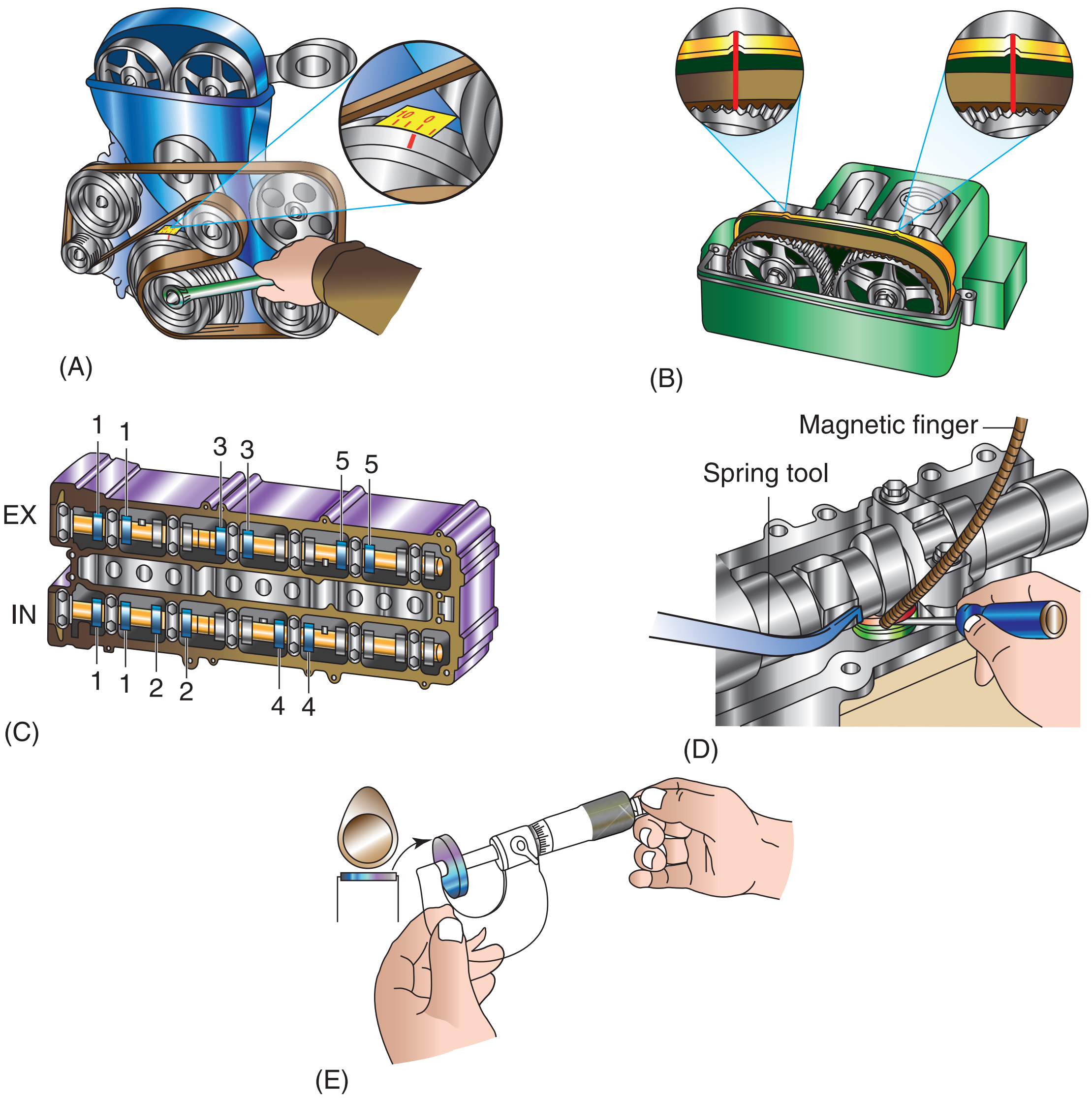


FIGURE 13-38 To adjust valve lash: (A) Rotate the crankshaft so that it is at TDC. (B) Check the camshaft alignment marks. (C) Measure and record the valve lash of the valves that are totally closed. (D) Use a small screwdriver and a magnetic finger to remove the adjusting shim. (E) Measure the thickness of the shim with a micrometer to determine the correct shim to install.

subtracted from that sum. The result is the required thickness for the replacement follower.

Final Reassembly Steps

The final steps in engine reassembly involve installing various covers, pulleys, sensors, and other related items that mount directly to the engine.

Coolant Drains and Plugs Make sure all coolant drains and plugs are installed in the block. Drains are normally threaded into the block with a thread sealant. This is also true for all threaded plugs.

Timing Sensors Proper installation of the crankshaft and camshaft timing sensors is critical. Make sure to coat new O-rings with clean oil before they are installed. Some sensors have a specified gap that must be set during installation. Also make sure that the trigger wheel for each sensor is properly aligned. This may require setting the engine to number 1 TDC and verifying an alignment hole in the sensor drive.

Timing Cover When replacing the timing cover, install the new seals with a press, seal driver, or hammer and a clean block of wood. When installing seals, be sure to support the underside of the cover to prevent damage. The gasket for the cover can be made of a variety of materials. Some require that a light coat of adhesive be applied to hold the gasket in place during assembly. Do not do this unless the

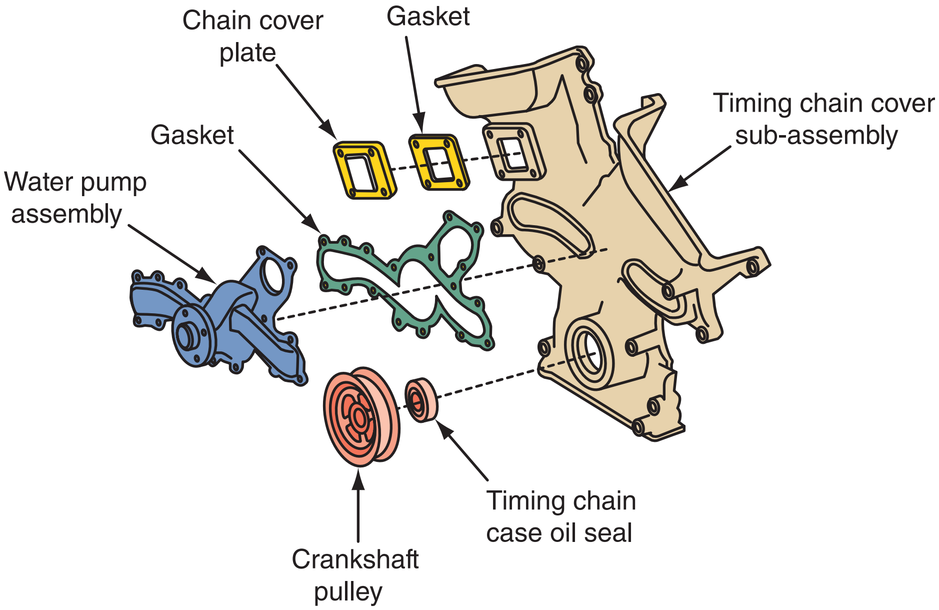


FIGURE 13–39 A timing chain cover and water pump assembly.

manufacturer recommends doing so. Position the gasket on the cover. Mount the cover onto the block and torque the bolts to specifications **(Figure 13–39)**.

Vibration Damper Install the vibration damper onto the snout of the crankshaft using the proper tool. Make sure the woodruff key is in place. Some dampers are not pressed-fit onto the crankshaft. Be sure to install the large washer behind the damper-retaining bolt on these engines. Some newer engines do not use a keyway on the damper; it is just installed on the snout and torqued in place with the crank bolt.

Mount the crankshaft pulley to the outside of the damper and tighten its mounting bolts to specifications. Often, the crankshaft will need to be held to prevent it from turning while the pulley's bolts are tightened. A special tool is normally required to do this.

Valve (Cam) Cover Before installing a stamped valve cover, make sure the cover's sealing flange is flat, then apply contact adhesive to the valve cover's sealing surfaces in small dabs. Mount the valve cover gasket on the valve cover and align it. If the gasket has mounting tabs, use them in tandem with the contact adhesive. Allow the adhesive to dry completely before mounting the valve cover on the cylinder head. Torque the mounting bolts to specifications.

Cast plastic and aluminum cam and valve covers normally have a rubber gasket. Do not apply an adhesive or sealant to the gasket unless instructed to do so. Start all of the mounting bolts before beginning the tightening sequence.

Water Pump In many cases, a coating of waterproof sealer should be applied to both sides of the new gasket. Position the pump against the block. Install the mounting bolts and tighten them to specifications. Careless tightening could cause the pump housing to crack. After tightening, check the pump to make sure it rotates freely. Then, install the drive pulley onto the pump's shaft.

Oil Pan Before installing a stamped oil pan, check the flanges for warpage. Use a straightedge **(Figure 13–40)** or lay the pan, flange side down, on a flat surface with a flashlight underneath it to spot

FIGURE 13–40 Checking the flatness of an oil pan flange.

uneven edges. Carefully check the flange around the bolt holes. Minor distortions can be corrected with a hammer and block of wood. If the flanges are too bent to be repaired in this manner, the pan should be replaced. Once it has been determined that the flanges are flat, install the oil pan with a new gasket.

Cast pans are replaced if they are warped or damaged. Their mounting bolts should be tightened in the proper sequence and to the specified torque.

Intake Manifold Before installing the manifold, thoroughly clean all of the sealing surfaces, bolt holes, and bolts. Inspect the surfaces for damage. Check the gaskets for any markings or installation instructions that may be stamped on them. Check the manufacturer's instructions for recommendations on the use of a supplementary sealant. Some intake manifold gaskets should be coated with a nonhardening sealer.

When installing an intake manifold on a V engine, it is wise to use guide bolts. These guides will make sure that the gaskets and the manifold are perfectly aligned before tightening them. They also prevent the manifold from shifting and rupturing the sealant. When tightening the bolts or nuts, make sure you tighten them to the proper torque and in the order specified.

On some V engines, there may be rubber or cork-rubber end seals for the front and the rear of the manifold. Before installing these seals, thoroughly clean all oil from the mating surfaces. Apply adhesive to the surface to hold the seals in place during installation. Once the gaskets and seals are in place, apply a small bead (approximately ⅛ inch) of silicone RTV to the point where the seals meet the gasket. Other engines may have a large one-piece intake manifold gasket with a splash guard. These are installed with the same care as other intake manifold gaskets.

Thermostat and Water Outlet Housing Install the thermostat with the temperature sensor facing into the block. If the thermostat is installed upside down, the engine will overheat. Also install any coolant pipes and hoses that route the coolant in and out of the engine.

Exhaust Manifold When installing the exhaust manifold(s), tighten the bolts in the center of the manifold first to prevent cracking it. If there are dowel holes in the exhaust manifold that align with dowels in the cylinder head, make sure these holes are larger than the dowels. If the dowels do not have enough clearance because of the buildup of foreign material, the manifold will not be able to expand properly and may crack. Be sure to install all heat shields **(Figure 13–41)**.

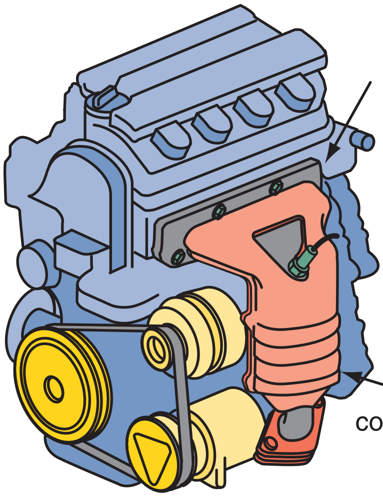


FIGURE 13–41 Exhaust manifold and heat shield for a four-cylinder engine.

Flywheel or Flexplate Reinstall the engine sling. Raise the engine and remove the engine stand mounting head. Set the assembled engine on the floor and support it on blocks of wood while attaching the flywheel or flexplate. Be sure to use the right flywheel bolts and lock washers. The bolt's heads and washers are very thin. If normal bolts or washers are used, they may cause interference with the clutch disc or the torque converter. Manufacturers often recommend coating the bolts with an adhesive. A flywheel holding tool is often required to tighten the bolts to specifications **(Figure 13–42)**. Always follow the specified sequence while tightening.

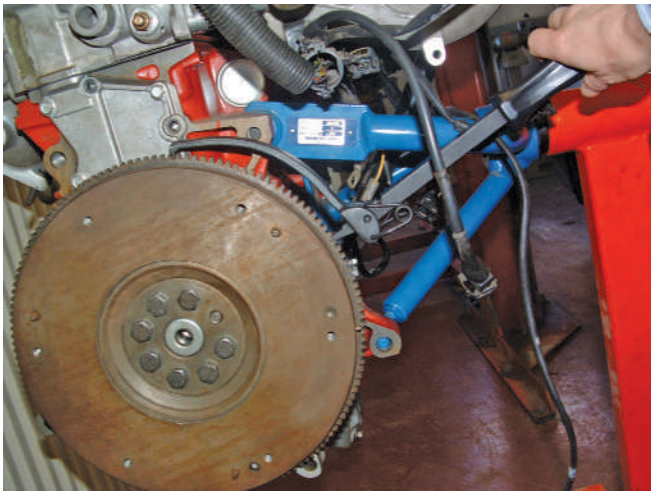


FIGURE 13–42 A flywheel holding and rotating tool.

Caution! On Honda and some other hybrids, extreme care must be taken when installing the rotor to the rear of the engine. The rotor assembly has very strong magnets. Anyone who has a pacemaker or other magnetically sensitive medical device should not handle the rotor assembly. The rotor should only be installed with the proper tools (Figure 13–43) and not with your hands. During installation, the rotor may be suddenly drawn toward the stator with great force, which can cause serious hand or finger injury.

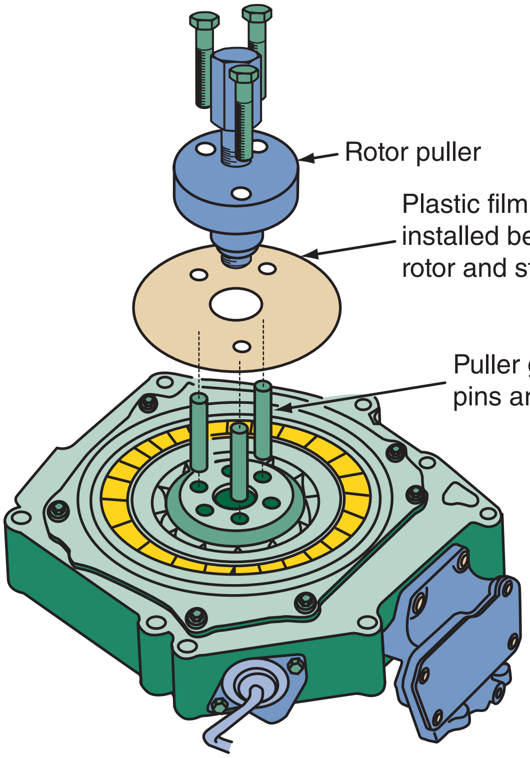


FIGURE 13–43 The special tools required to remove and install the rotor in a Honda hybrid.

Clutch Parts If the vehicle has a manual transmission, install the clutch assembly. Make sure that the transmission's pilot bushing or bearing is in place in the rear of the crankshaft and that it is in good condition.

Using a clutch-aligning tool, or an old transmission input shaft, align the clutch disc. Then, tighten the disc and clutch pressure plate to the flywheel. Make sure the disc is installed in the right direction. There should be a marking on it that says "flywheel side." The flywheel may need to be held to tighten the bolts. Then install the bell housing if it was removed from the transmission. If the engine was removed with the transmission, reattach it now.

GO TO Chapter 37 for the procedures for installing a clutch assembly.

Torque Converter On cars equipped with automatic transmissions, replace the transmission's front pump seal before attaching it to the engine.

Install the torque converter, making sure that it is correctly engaged with the transmission's front pump. The drive lugs on the converter should be felt engaging the transmission front pump gear. Failure to correctly install the converter can result in damage to the transmission's front pump. If the engine was removed with the transmission, reattach it now.

Motor Mounts Check the condition of all motor mounts and replace any that are damaged. Loosely attach the mounts to their location on the engine. This allows for easy alignment of the mounts while installing the engine into the vehicle. After the engine is aligned in the vehicle, the bolts should be tightened to specifications.

Other Parts There are many other parts that can be reinstalled before the engine is put back into the vehicle. These vary with the model of car. Always check with the service information before installing anything onto the engine. The following are a few of things that may be installed with the engine out of the vehicle:

- Starter
- Oil dipstick guide
- Engine coolant temperature sensor
- Engine oil pressure switch
- Engine oil level sensor
- Knock sensor
- Fuel injectors
- Fuel rail
- PCV valve
- Camshaft timing control valve
- Drive belt tensioner
- A/C compressor
- Generator
- Drive belts
- Ignition coils
- Spark plugs

Installing the Engine

Installing a computer-controlled engine can be a complex task requiring special procedures. Referring to the vehicle's service information is essential for this procedure. Typically the procedure is the reverse of the removal procedure.

SHOP TALK The mounting bolts for some engines should be installed and tightened according to a specified sequence. Excessive noise and vibration may result from not following this sequence. Always refer to the appropriate service information when installing an engine.

Installing an Engine into a FWD Vehicle

If the engine will be installed through the top, connect the engine to a sling and then connect the sling to the crane **(Figure 13–44)**. Slowly lower the engine into the engine compartment. Guide the engine around all wires and hoses to make sure nothing gets damaged. As the engine approaches its position in the engine compartment, align the engine and transmission mounts. Then, lower the engine so you can connect the engine and transmission mounts. Now raise the vehicle to a good working height.

If the engine must be installed from under the car, mount the engine onto the engine cradle and dolly. Lift the vehicle on a hoist and position the engine under the engine compartment. Carefully lower the vehicle until the engine and transmission are properly positioned in the compartment. While doing this, guide all wires and hoses out of the way and make sure that the vehicle does not contact or rest on any part of the engine or transmission. With an engine hoist, raise the engine/transmission into place. Align the engine and transmission mounts and tighten the bolts. Remove the engine cradle and dolly. Then raise the vehicle to a good working height.

While working under the vehicle, align and tighten all remaining engine/transmission mounts. Install the drive axle shafts and hubs. Connect the exhaust manifold to the exhaust system. Install any heat

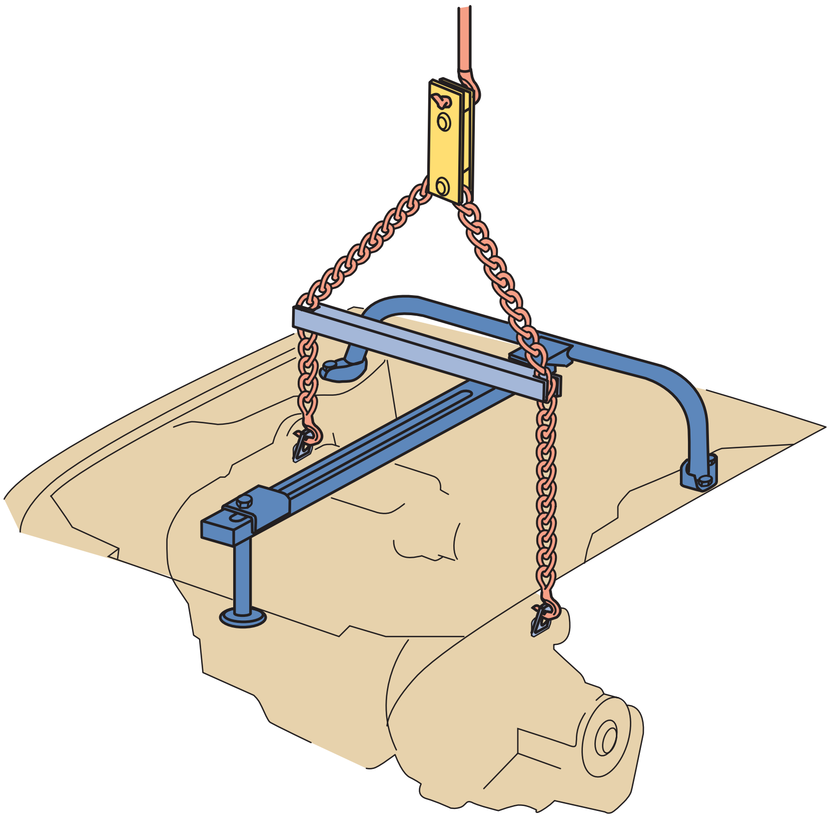


FIGURE 13–44 Equipment needed to install an engine from the top of a FWD vehicle.

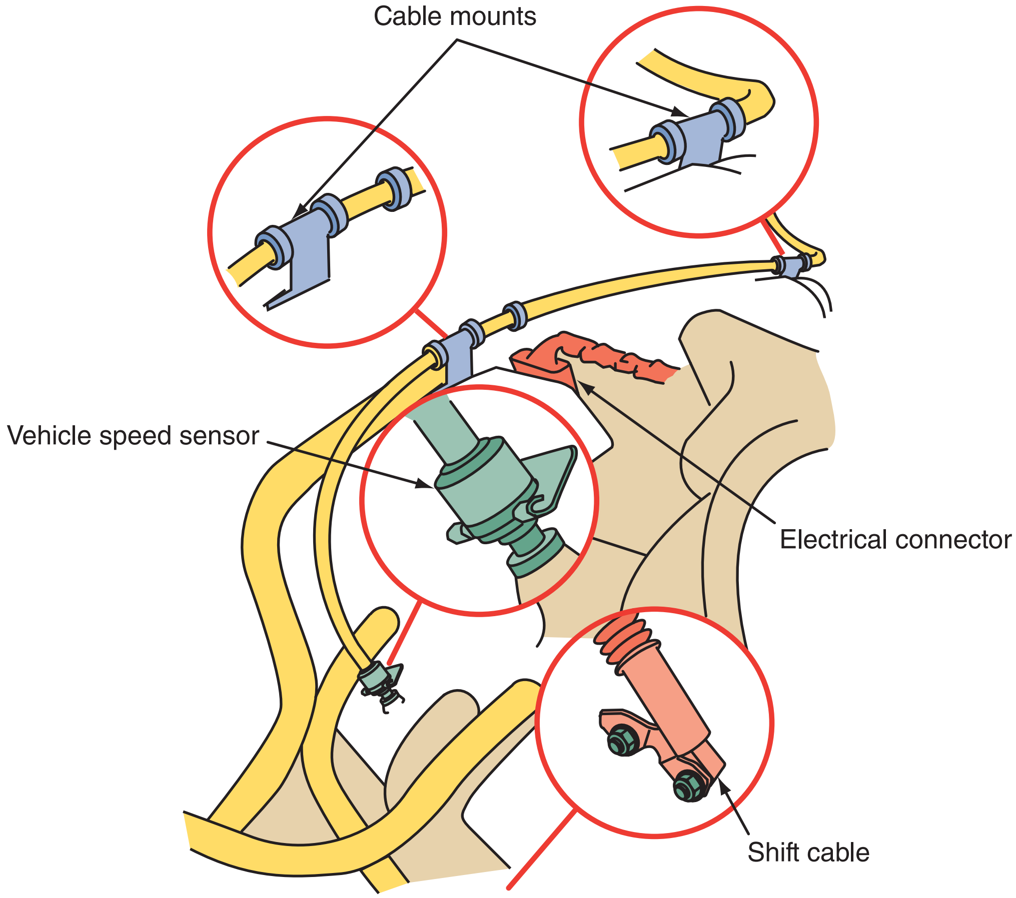


FIGURE 13–45 Various connections for a transaxle.

shields that were removed when the engine was removed. Connect all linkages, lines, hoses, and electrical wiring to the transmission **(Figure 13–45)**. Now reconnect all suspension and steering parts that were disconnected or removed. Check and replenish the fluid in the transaxle.

Lower the vehicle and remove the engine support bar or sling. Install all splash shields that were removed, then install the tire/wheel assemblies.

Lower the vehicle so its weight is on the tires. Tighten the axle hub nuts. Connect the fuel lines with their clamps. Install the canister purge valves and related hoses. Make sure all connections are secure. Now connect the engine wiring harness, ground straps, and all other electrical connectors and wires.

SHOP TALK

Many FWD vehicles require the powertrain cradle to be properly aligned after it is reconnected. This ensures correct steering and suspension alignment. After engine installation is completed, the vehicle's wheel alignment may need to be checked and adjusted.

Caution! If working on a hybrid vehicle, make sure that the high-voltage system is isolated before making any connection. The high-voltage cables and connectors are orange in color (Figure 13–46).

Connect all vacuum hoses. Then connect the throttle linkage and adjust it if necessary. Install the radiator, cooling fan(s), and overflow tank. Install the upper and lower radiator hoses. Then install the heater hoses. Hybrid vehicles have coolant hoses at the inverter; make sure these are properly tightened.

Install the automatic transmission fluid (ATF) cooler hoses to the transmission. Now install the A/C compressor with the drive belt, condenser fan

Caution! On some vehicles the A/C compressor is powered by high voltage; make sure the high-voltage system is off. Also make sure that the power cables are secure in their mounting clamps.

shroud, and the electrical connectors for the fan motor and compressor clutch. Also connect the wiring to the steering linkage. Then, reinstall the engine compartment support strut.

Now install the air induction system and connect any remaining items, including the battery and cables. Check the engine for fuel leaks. Do this by turning the ignition switch to the ON position and allowing the fuel pump to run for a few seconds. Turn the power off and check for signs of leaks. If there are any leaks, repair them before proceeding.

Make sure everything that was removed is reinstalled and secure. If the vehicle's hood was removed, carefully reattach it. Refill the radiator with coolant, and bleed air from the system with the heater valve open. Visually check for leaks. Prelubricate the engine and make sure the oil level is correct. On hybrid vehicles, the high-voltage system should be activated after everything is connected **(Figure 13–46)**.

Caution! Once the high-voltage system is activated, lineman gloves should be worn while doing any under-the-hood work.

FIGURE 13–46 The high-voltage connectors and cables in a hybrid are colored orange for identification.

CUSTOMER CARE After the engine has been started and everything checked out, the wheels must be aligned. Failure to do this can make a customer very unhappy.

Installing an Engine in a RWD Vehicle

Connect the engine to a sling and then connect the sling to the crane. Place a transmission jack under the transmission to hold it in position. Now slowly lower the engine into the engine compartment. Guide the engine around all wires and hoses to make sure nothing gets damaged. As the engine approaches its position in the engine compartment, align the engine to the input shaft of the transmission or the torque converter hub into the front pump. Carefully wiggle the engine until the input shaft slides through clutch disc splines or the torque converter seats fully into the transmission. Install and tighten the transmission to the engine bolts. Start the engine mount bolts into their bores; you may need to wiggle the engine some to do this. Once the mount bolts are in place, tighten them and remove the transmission jack and engine sling.

Raise the vehicle to a good working height and install all remaining engine and transmission mounts. Connect the exhaust manifold to the exhaust system. Install any heat shields that were removed when the engine was removed. Reconnect the fuel line from the fuel tank to the engine. Install the drive shaft if it was removed. Make sure to align it with the index marks made during removal. Connect all electrical connectors, hoses, and linkages that are accessible from under the vehicle. Reinstall any suspension and steering part that was removed.

Lower the vehicle so you can work under the hood. Mount the A/C compressor and connect all lines and electrical connectors. Install the radiator and the cooling fan(s) and connect the rest of the hoses for the cooling system. Connect all vacuum and other hoses. Now connect the throttle linkage and adjust it if necessary. Connect all remaining electrical connectors.

Connect any remaining disconnected fuel lines. Make sure all connections are secure. Connect the

Caution! Do not force the engine and transmission together with the bolts.

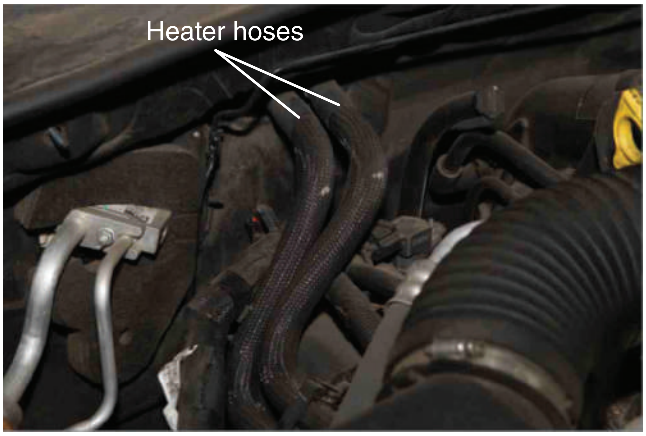


FIGURE 13–47 Heater hose connecting points on the fire wall.

radiator and heater hoses; use new clamps. Connect the engine electrical harness to the PCM or fire wall connector **(Figure 13–47)**. Connect the engine ground straps. Install the battery and connect the battery cables. Turn the ignition switch to the ON position and allow the fuel pump to run for a few seconds. Turn the power off and check for signs of leaks. If there are any leaks, repair them before proceeding.

Now install the air induction system and connect any remaining items, including the throttle sensor. Fill the radiator with coolant and check for leaks. If the engine is not filled with oil already, add the specified amount of the proper type oil. Prime the oil pump of the engine and prepare the engine for startup. Install and align the hood.

Prelubrication

Not prelubing a new or rebuilt engine before starting it can cause premature bearing failure due to poor lubrication. Other parts such as pistons, rings, and cylinder walls need immediate lubrication to prevent scuffing, scoring, and damage. It can take as long as 5 minutes after the engine has started before oil is distributed through all of the vital parts of an engine. It is claimed that more than 80 percent of all engine wear occurs when an engine is first started.

SHOP TALK

While prelubing an engine, make sure there is a continuous flow of the correct type of oil. If the preluber runs out of oil during priming, an air pocket can form within the engine's lubrication system.

These problems can be prevented by lubricating the parts as they are assembled and by forcing oil into the oil galleries. This is the purpose of prelubing. A prelubricator forces oil throughout the engine before it is started. There are several ways to prelubricate, or prime, an engine. One of the most common ways is to use an air-operated prelubricator.

Distributor-Driven Oil Pumps On engines with a distributor-driven oil pump, the engine can be primed by driving the oil pump with an electric drill. A fabricated oil pump drive shaft is chucked in an electric drill motor and inserted through the distributor bore into the drive on the oil pump. Take the valve covers off but loosely set them over the valves to control oil splash. After running the oil pump for several minutes, remove the valve cover and check for oil flow to the rocker arms. If oil reached the cylinder head, the engine's lubrication system is full of oil and is operating properly. If no oil reached the cylinder head, there is a problem with the pump, with an alignment of an oil hole in a bearing, or a plugged gallery.

Starting Procedure

On engines with an ignition distributor, set the ignition timing as accurately as possible before starting the engine. The timing can be properly set after it has been started by using an engine analyzer or timing light. Fill the gasoline tank with several gallons of fresh gasoline. Start the engine and run it at around 1,500 rpm. When the engine coolant reaches normal operating temperature, turn off the engine. Recheck all adjustments, ignition timing, and valve clearance. Look for signs of coolant or oil leaks.

Break-In Procedure

To prevent engine damage after it has been rebuilt and to ensure good initial oil control and long engine life, the proper **break-in** procedure must be followed. Make a test run at 30 mph and accelerate at full throttle to 50 mph. Repeat the acceleration cycle from 30 to 50 mph at least ten times. No further break-in is necessary. If traffic conditions will not permit this procedure, accelerate the engine rapidly several times through the intermediate gears during the road test. The objective is to apply a load to the engine for short periods and in rapid succession soon after the engine warms up. This action thrusts the piston rings against the cylinder wall with increased pressure and results in accelerated ring seating.

SHOP TALK

Hybrid vehicles have special initialization procedures. These systems automatically shut off the engine when the vehicle is stopped and restart it when certain conditions are present. In many cases, the PCM must know the exact position of the electric assist motor's rotor. If the PCM cannot recognize the rotor's position, the motor may not be able to run. In general, if initialization is not completed, the hybrid system will not work normally. The service information for the vehicle will give the procedures for each system that needs to be initialized.

SHOP TALK

Some manufacturers recommend retorquing the cylinder head after a rebuilt engine has been run for the first time. With the engine at normal operating temperature, retighten each head bolt using the specified tightening sequence. If the engine has an aluminum head or block, do not retorque the bolts until the engine has cooled. On some engines it may be necessary to retorque the head, again, after a specified time or mileage interval. Always follow the manufacturer's recommendations.

Relearn Procedures

The computer in most late-model vehicles must undergo a relearn or initialization procedure after the battery has been reconnected. This procedure allows the computers to learn the condition of the engine and make adjustments according to the engine's restored condition. The last time the engine was run, the computer made adjustments based on the engine faults present. This procedure allows the computer to see that those faults were corrected. Initialization also resets the reference for the crankshaft position sensor and PCM. Always follow the manufacturer's procedures as outlined in the service information.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2014	**Make:** Hyundai	**Model:** Sonata	**Mileage:** 48,316	**RO:** 16474
Concern:	Customer states engine is running poorly and lacks power.			
History:	Warranty long block installed at 47,855 miles, RO 15877			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				
Cause:	Confirmed poor running and lack of power. Coolant level low, no external leaks found. Removed valve cover and checked head bolt torque. Found several bolts below torque specifications.			
Correction:	Removed cylinder head and replaced head gasket and head bolts. Retorqued head bolts after initial engine operation and cool-down. Engine runs normally.			

KEY TERMS

Break-in
Elasticity
Gasket
Graphite
Polyacrylate
Room temperature vulcanizing (RTV)
Torque-to-yield (TTY)
Valve lash
Yield

SUMMARY

- Elasticity means that a bolt can be stretched a certain amount before it can return to its original size when the load is reduced.
- Bolt yield means that a stretched bolt takes a permanent set and never returns to normal.
- Some fasteners are intentionally torqued into a yield condition. These torque-to-yield (TTY) bolts are designed to stretch when properly tightened. When a bolt is stretched to its yield point, it exerts its maximum clamping force. TTY bolts should not be reused.
- Gaskets serve as sealers, spacers, wear insulators, and vibration dampeners.
- Gaskets can be made of paper, fiber, steel, cork, synthetic rubber, and combinations of these materials.
- Never reuse old gaskets; handle new gaskets carefully; use sealants only when instructed; thoroughly clean all mating surfaces; and use the right gasket in the right position.
- Cylinder head gaskets must seal the combustion chambers and the coolant and oil passages between the head and the block.
- Common causes of cylinder head gasket failure include improper installation, overheating, hot spots, and detonation or preignition.
- Adhesives are used to hold a gasket in place during assembly.
- Bolts that pass through a liquid passage should be coated with Teflon® thread or a brush-on thread sealant.
- Silicone gasketing, of which RTV is the best known, is used on oil pans, valve covers, thermostat housing, timing covers, and water pumps.
- Anaerobic formed-in-place sealants are used for both thread locking and gasketing.
- Oil seals keep oil and other fluids from escaping around a rotating shaft.
- All engines with mechanical lifters have some method of adjustment to bring valve lash (clearance) back into specification.
- The best method of prelubricating an engine under pressure without running it is to use a prelubricator.
- A proper break-in procedure is necessary to ensure good initial oil contact and long engine life.

REVIEW QUESTIONS

Short Answer

1. What are the major differences between aerobic and anaerobic sealants?
2. How does a torque-to-yield bolt differ from a standard bolt?
3. How do seals differ from gaskets?
4. Where are thread sealers most often used?
5. On hybrid vehicles, how can you identify the high-voltage cables and connectors?

True or False

1. *True or False?* Make sure you locate and adhere to the "wet" torque specs when tightening a bolt that has been lubricated with oil or any other liquid.
2. *True or False?* The computer in most late-model vehicles must undergo a relearn or initialization procedure after the vehicle's battery has been disconnected and reconnected.
3. *True or False?* Some crankshaft and camshaft timing sensors have a specified gap that must be set during installation.
4. *True or False?* Valve lash is adjusted in many different ways; however, on many OHC engines, the clearance is set by replacing a shim.

Multiple Choice

1. Which of the following statements is incorrect?
   a. Cylinder head bolts must be tightened to the proper amount of torque.
   b. Most cylinder head bolts are tightened in a sequence that starts on one end.
   c. On some engines, the head bolts are retorqued after the engine has been run and is hot.
   d. Many engines use head bolts of different lengths.
2. Which of the following statements about the purpose of a cylinder head gasket is *not* true?
   a. It seals intake stroke vacuum, combustion pressure, and the heat of combustion.
   b. It prevents coolant leakage and resists rust, corrosion and, in many cases, meters coolant flow.
   c. It allows for lateral and vertical head movement as the engine heats and cools.
   d. It meters lubricating oil onto the engine's cylinder walls.

3. Graphite is ___.
   a. an anaerobic substance
   b. an RTV
   c. an aerobic substance
   d. none of these
4. Which of the following are considered soft, cut gaskets?
   a. Paper gaskets
   b. Cork gaskets
   c. Cork/rubber gaskets
   d. All of the above
5. What material is typically not used to form a rear main bearing oil seal?
   a. Polyacrylate
   b. RTV
   c. Silicone synthetic rubber
   d. Viton
6. Which of the following statements about preparing to assemble an engine is *not* true?
   a. Discard and replace all bolts that are damaged.
   b. Identify what bolts go into the specific bores.
   c. Use a thread locker on all bolts.
   d. Clean bolt and cylinder block threads with a thread chaser or tap.

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that TTY bolts can be used after they were removed if there are no signs of distortion or stretching. Technician B says that head bolts that pass through a coolant passage should be coated with a nonhardening sealer prior to installing them. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. Technician A uses adhesives to hold gaskets in place while installing them. Technician B uses RTV sealant on all surfaces that are prone to leaks. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. Technician A uses soft gaskets on valve covers. Technician B uses soft gaskets on water pumps. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. While installing a timing belt: Technician A installs the belt, turns the crankshaft two full rotations, then applies tension to the belt. Technician B installs the belt, applies tension, then turns the crankshaft two full rotations. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Technician A says that oil pan gaskets are often made of cork due to its ability to conform to small imperfections in the oil pan. Technician B says oil pan and valve cover gaskets are often MLS gaskets to account for the different expansion rates between components. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. Technician A says that aluminum expands at a different rate than cast iron. Technician B says that cast iron has a coefficient of thermal expansion two or three times greater than aluminum. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. While discussing proper engine break-in: Technician A says that the engine should run at idle speed for at least 2 hours. Technician B says that the engine should be accelerated from a stop at full throttle to 50 mph and that this cycle should be repeated at least ten times. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

8. While tightening a TTY bolt: Technician A initially tightens the bolt to the specified torque. Technician B turns the bolt an additional amount after the bolt has been tightened to the specified torque. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. Before reusing head or other critical bolts: Technician A measures their length and compares the measurement to specifications. Technician B lubricates the threads and the bottom of the bolt head with engine oil before installing them. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While selecting the proper RTV for a particular application: Technician A uses RTV in a black tube for all high-temperature applications. Technician B uses RTV in a red tube for most general applications. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER

14 LUBRICATING AND COOLING SYSTEMS

OBJECTIVES

- Name and describe the components of a typical lubricating system.
- Describe the purpose of a crankcase ventilation system.
- Describe the operation of the cooling system.
- List and describe the major components of the cooling system.
- Describe the purpose of the water pump, radiator, radiator cap, and thermostat.
- Diagnose the cause of engine overheating.
- Test and service the cooling system.

The life of an engine largely depends on its lubricating and cooling systems. If an engine does not have a supply of oil or cannot rid itself of high temperatures, it will be quickly destroyed.

Lubrication System

An engine's lubricating system does several important things. The main components of a typical lubricating system **(Figure 14–1)** are described here.

Engine Oil

Engine oil is specially formulated to lubricate and cool engine parts. The moving parts of an engine are fed a constant supply of oil. Engine oil is stored in the oil pan or sump. The oil pump draws the oil from the sump and passes it through a filter where dirt is removed. The oil is then moved throughout the engine via oil passages or galleries. After circulating through the engine, the oil returns to the sump.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2006	**Make:** Ford	**Model:** F150	**Mileage:** 173,502	**RO:** 18082
Concern:	Engine overheats. Coolant temperature gauge reads high. Customer states gauge went up to the red on highway. No signs of coolant leaks. Customer replaced thermostat; still overheats.			
Given this concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

GO TO Chapter 8 for a detailed discussion of engine oil.

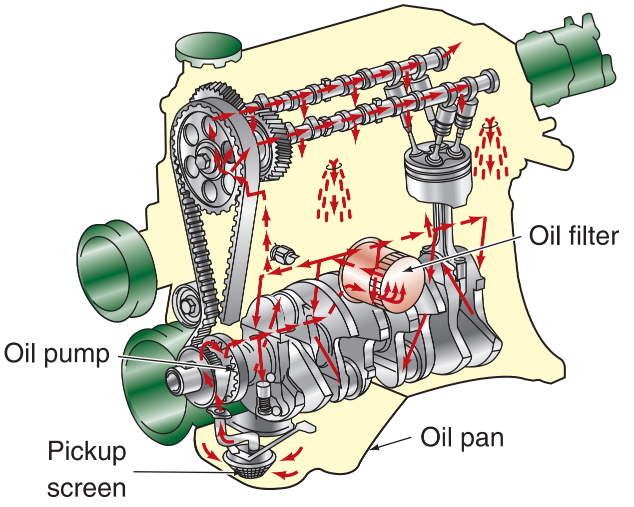


FIGURE 14–1 The direction of oil flow through this engine.

Oil Pump

The oil pump is the heart of the lubricating system. The oil pump pulls oil from the oil pan through a pickup tube. The part of the tube that is in the oil pan has a filter screen, which is submerged in the oil **(Figure 14–2)**. The screen keeps large particles from entering the oil pump. This screen should be cleaned any time the oil pan is removed. The pickup may also contain a bypass valve that allows oil to enter the pump if the screen becomes totally plugged.

The oil pump may be located in the oil pan or mounted at the front of the engine **(Figure 14–3)**. Its purpose is to supply oil to cool, clean, and lubricate the various moving parts in the engine. The pump is normally driven by the crankshaft and creates suction to draw oil from the oil pan through a strainer. The pump then forces the oil through the oil filter and to various passages throughout the engine. The oil then returns to the oil pan.

An oil pump does not create oil pressure; it merely moves oil from one place to another. Oil pumps are positive displacement pumps; that is, the amount of oil that leaves the pump is the same amount that enters it. Output volume is proportional to pump speed. As engine rpm increases, pump output also increases. As the oil leaves the pump, it passes through many passages. These passages restrict oil flow. These restrictions are what cause oil pressure. Small passages cause the pressure to increase; larger ones decrease the pressure.

This is why excessive bearing clearances will decrease oil pressure. The increased clearances reduce the resistance to oil flow and, consequently, increase the volume of oil circulating through the engine. This decreased resistance and increased volume lower the pressure of the oil. The ability of an oil pump to deliver more than the required volume of oil is a safety measure to ensure lubrication of vital parts as the engine wears.

Oil pressure is also determined by the viscosity, temperature, and condition of the oil. High-viscosity oil has more flow resistance than low-viscosity oil.

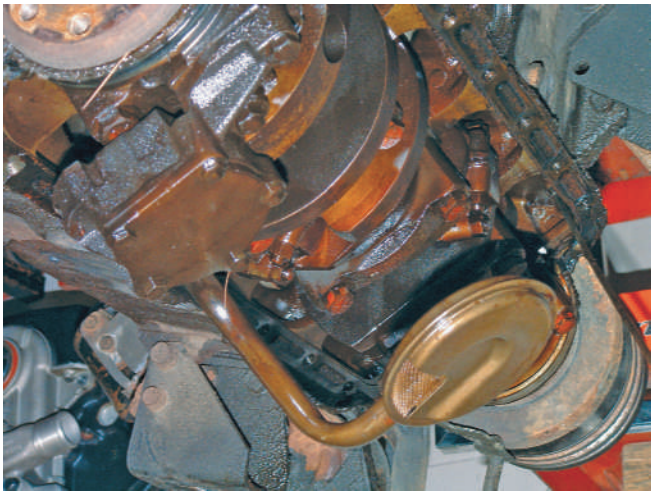


FIGURE 14–2 An oil pickup and screen.

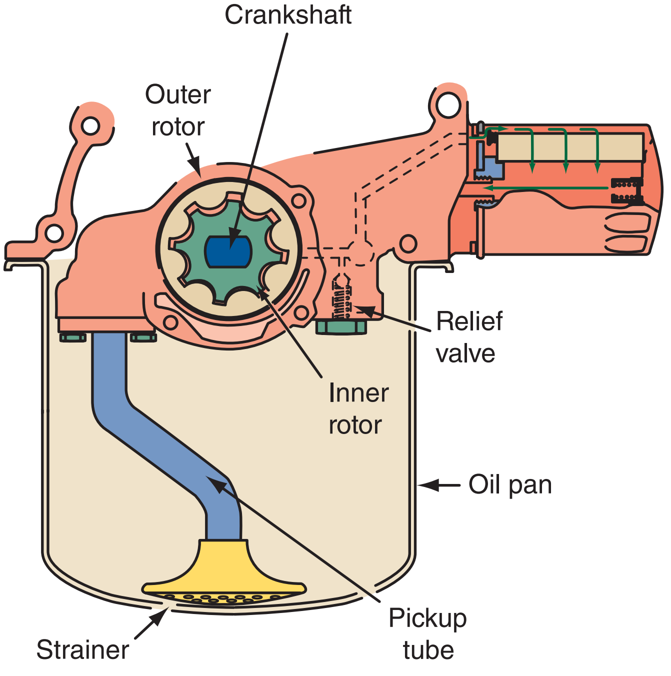


FIGURE 14–3 A rotor-type oil pump and lubrication system.

Types of Oil Pumps Oil pumps are driven by the camshaft or crankshaft. How the pump is driven is dictated by the location of the pump. Some oil pumps have an intermediate or drive shaft that is driven by a gear on the camshaft. Other pumps are driven by the crankshaft via a chain or gears.

Two basic types of oil pumps are used in today's engines. A **rotor-type oil pump** has an inner rotor and an outer rotor. The outer rotor is driven by the inner rotor. The outer rotor always has one more lobe than the inner rotor. When the rotors turn and the rotors' lobes unmesh, oil is drawn into that space. As the rotors continue to turn, oil becomes trapped between the lobes, cover plate, and top of the pump cavity. It is then forced out of the pump body by the meshing of the lobes. This squeezes the oil out and directs it through the engine. The amount of oil forced out of the pump depends on the diameter and thickness of the pump's rotors.

Gear-type pumps use a drive gear, connected to an input shaft, and a driven gear. Both gears trap oil between their teeth and the pump cavity wall. As the gears rotate, oil is forced out as the gear teeth unmesh. The output volume per revolution depends on the length and depth of the gear teeth. Another style of gear-type oil pump uses an idler gear with internal teeth that spins around the drive gear. In this style of pump, often called a crescent or trochoidal type, the gears are eccentric **(Figure 14–4)**. That is, as the larger gear turns, it walks around the smaller one, moving the oil in the space between.

The rotor type moves a greater volume of oil than the gear type because the space in the open lobe of the outer rotor is greater than the space between the teeth of the gears of a gear-type pump.

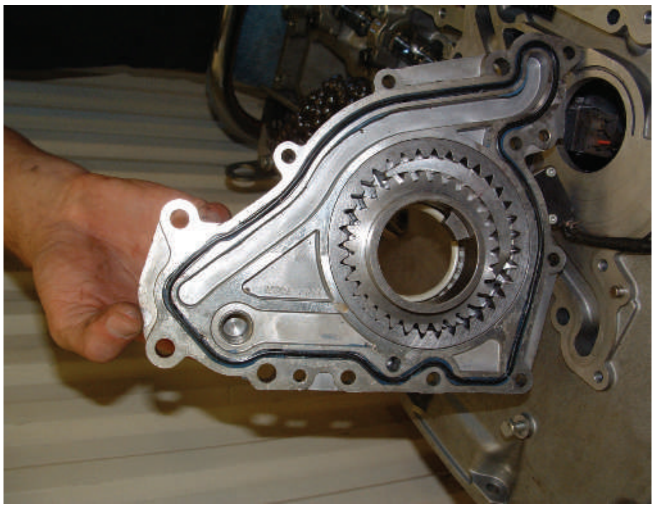


FIGURE 14-4 A gear-type oil pump.

High-volume pumps are often installed by engine rebuilders. High-volume pumps have larger gears or rotors. The increase in oil volume is proportional to the increase in the size of the gears. Gears that are 20 percent larger will provide 20 percent more oil volume.

Pressure Regulation Oil pumps have an oil **pressure relief valve** to prevent excessively high system pressures from occurring as engine speed increases **(Figure 14–5)**. When the oil pressure exceeds a preset limit, the spring-loaded relief valve opens and allows oil to directly return to the sump. Excessive oil pressure can lead to poor lubrication due to the oil blowing past parts rather than flowing over them. A pressure regulator valve is loaded with a calibrated spring that allows oil to bleed off at a given pressure. When the pressure from the pump reaches a preset level, a check valve, ball, or plunger unseats and allows the oil to return to either the inlet side of the pump or to the crankcase.

Oil Pan or Sump

The oil pan is mounted to the bottom of the engine block. It serves as the reservoir for the engine's oil and is designed to hold a certain amount of oil. The oil pan also helps to cool the oil through its contact with the outside air.

Oil is drawn out by the oil pump. After the oil moves through the engine's lubrication circuits, it drains back into the pan. This describes a **wet sump** oil system because the sump always has oil in it.

Pan Baffles With a wet sump, oil can slosh around during hard cornering or braking. During these times it is possible for the oil to move away from the oil pump's pickup. This will cause a temporary halt in oil flow through the engine, which can destroy it. To help prevent sloshing, many engines have baffles (windage trays) in the oil pan to limit the movement of the oil **(Figure 14–6)**.

Dry Sump To prevent oil sloshing, some OEM engines have a **dry sump** oil system, as do most race engines. In a dry sump system, the oil pan does not store oil. A dry oil pan merely seals the bottom of the crankcase. The oil reservoir is a remote container set apart from the engine. Rather than having a single path for oil travel, the oil pump in dry sump feeds oil directly to the crankshaft, valve train, and turbocharger. Normally one external oil pump **(Figure 14–7)** is used; however, some systems have two pumps. The second pump pulls the oil out of the sump and returns it

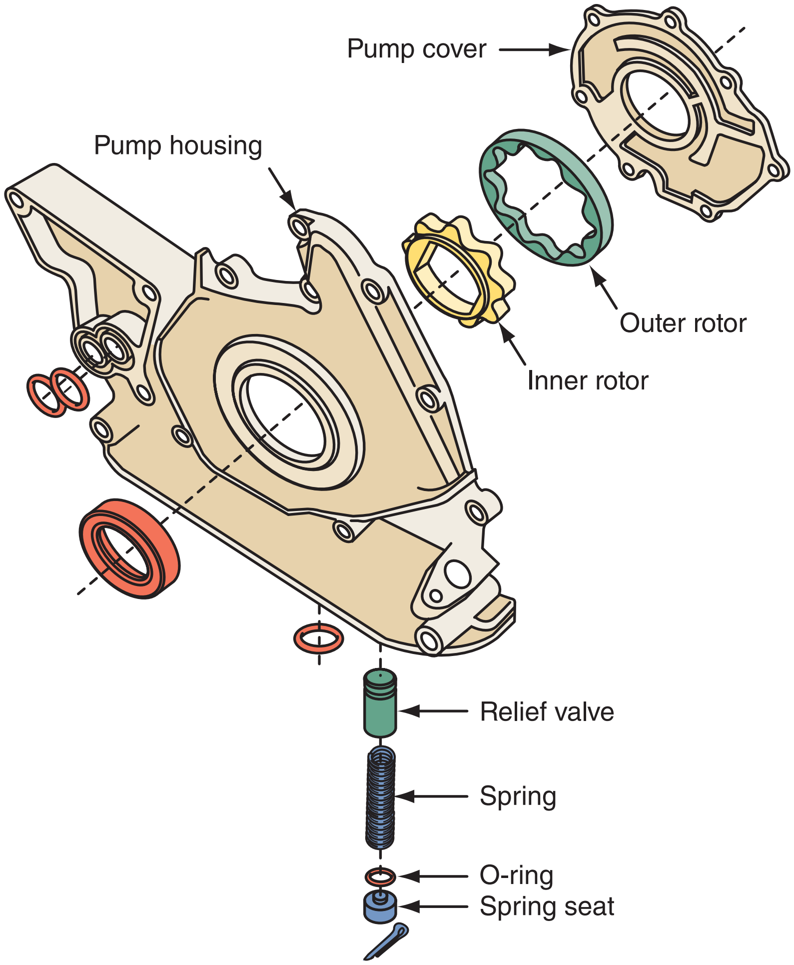


FIGURE 14–5 A rotor-type oil pump.

to the reservoir. This pump also lowers the pressure inside the crankcase.

Dry sump systems provide immediate oil delivery to critical areas of the engine. They also prevent oil starvation caused by acceleration, braking, and cornering forces. Because the dry sump is smaller than a wet sump, the engine can be placed lower in the frame to improve overall handling.

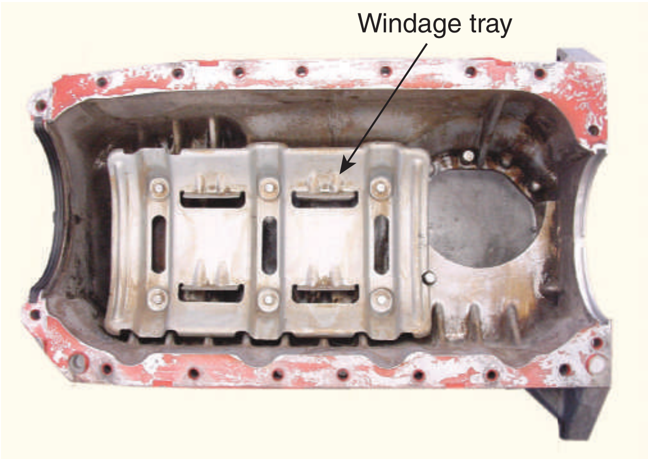


FIGURE 14–6 This oil pan was manufactured with a windage tray.

Oil Filter

As the oil leaves the oil pump, it flows through an oil filter **(Figure 14–8)**. The filter prevents the small particles of dirt and metal suspended in the oil from reaching the close-fitting engine parts. If the impurities are not filtered from the oil, the engine will wear prematurely and excessively. Filtering also increases the usable life of the oil. The filter assembly attaches directly onto the main oil gallery tube. The oil from the pump enters the filter and passes through the element of the filter. From the element, the oil flows back into the engine's main oil gallery.

The oil filter is typically a disposable metal container filled with a special type of treated paper or other filter substance (cotton, felt, and the like). Some engines have a separate cartridge that fits into

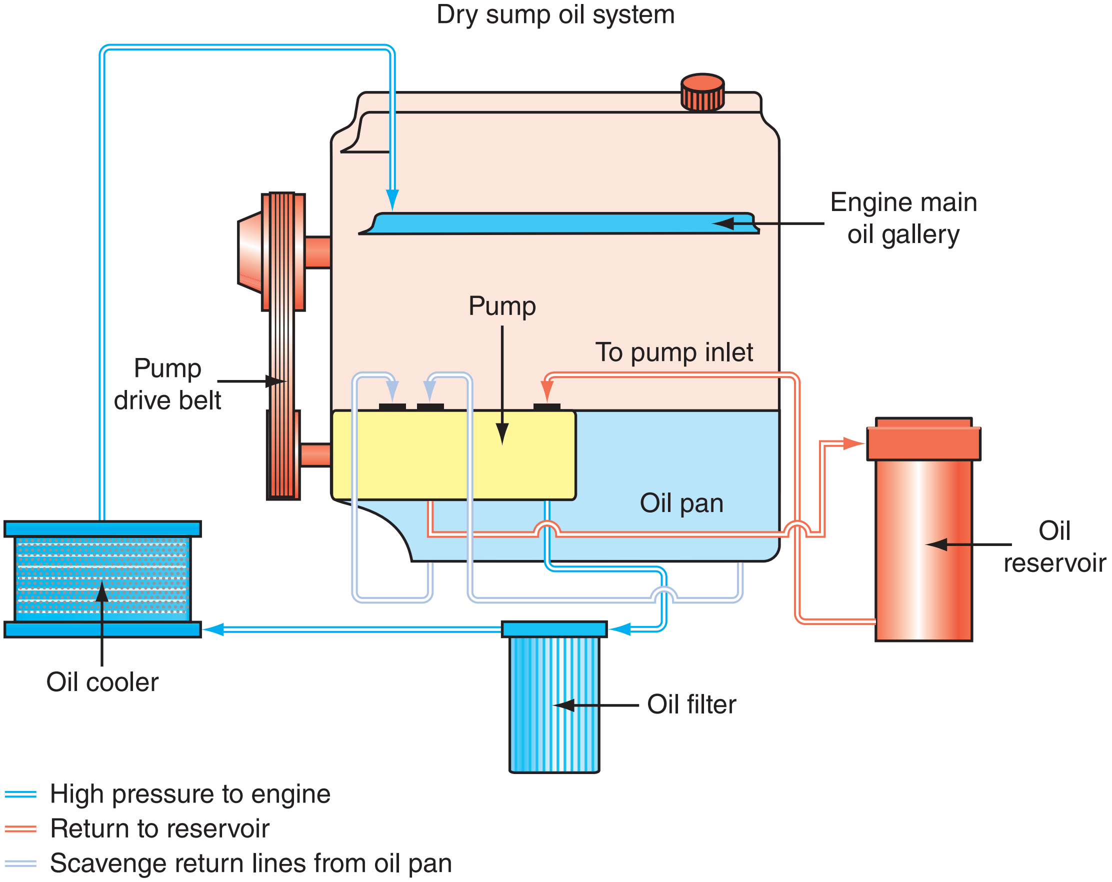


FIGURE 14–7 A typical dry sump engine lubrication system.

FIGURE 14–8 An oil filter being installed on an engine block.

the block or a separate metal housing **(Figure 14–9)**. This filter is mounted on and sealed to an adapter bolted to the block. However, it may be attached to the timing cover or remotely mounted with oil lines connecting the filter to the oil galleries in the block **(Figure 14–10)**.

Oil filters may have an anti-drain back valve. This valve prevents oil drainage from the filter when the engine is not running. This allows for a supply of filtered oil as soon as the engine is started and has oil pressure.

All of the oil going through the engine goes through the filter first. However, if the filter becomes plugged, a relief valve in the filter will open and allow oil to bypass and go directly to the engine's oil passages **(Figure 14–11)**. This provides the engine with necessary, though unfiltered, lubrication.

Oil Coolers

To control oil temperature, many diesel, high-performance, and super- or turbocharged engines have an external engine oil cooler. Hot oil mixed with oxygen breaks down (oxidizes) and forms carbon and varnish. The higher the temperature, the faster these

FIGURE 14-9 An oil filter assembly with a replaceable element.

FIGURE 14-10 Oil lines carry the engine oil in and out of this remote filter before it moves through the engine to lubricate parts.

deposits build. An oil cooler helps keep the oil at its normal operating temperature. Oil flows from the pump through the cooler and then to the engine.

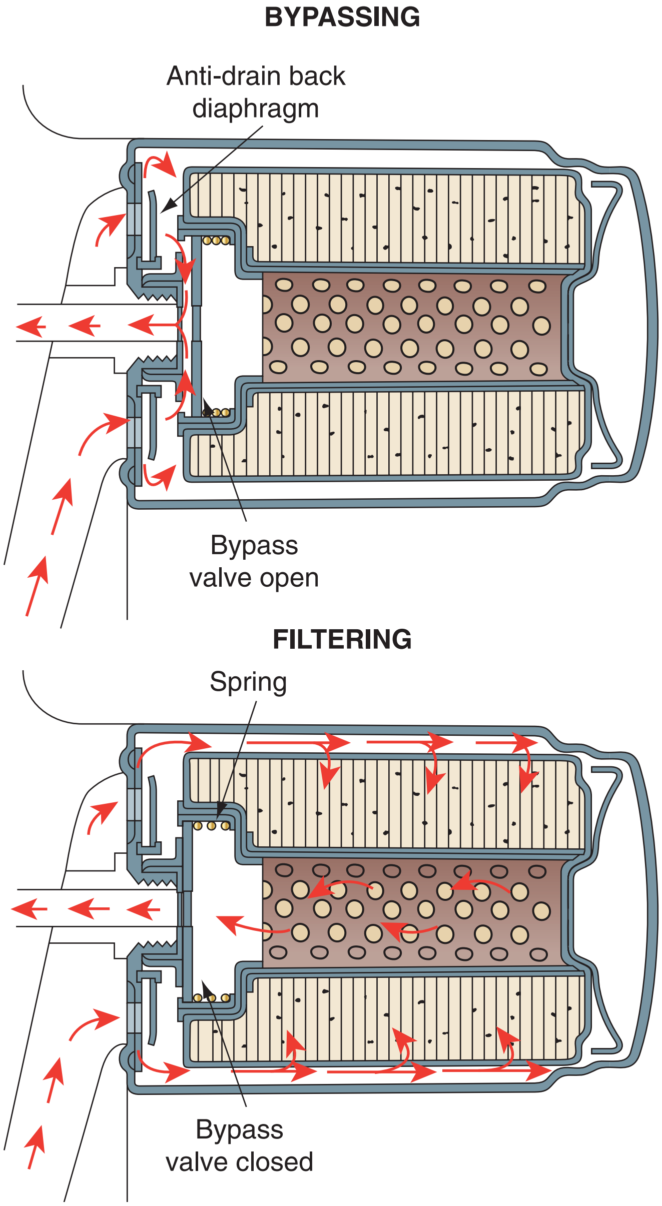


FIGURE 14-11 Oil flow through the filter.

An oil cooler is a small radiator mounted near the front of the engine or within the radiator. Heat is removed from the oil as engine coolant flows around the cooler and air passes through it.

Engine Oil Passages or Galleries

From the filter, the oil flows into the engine's oil galleries. These galleries are interconnecting passages that were drilled into the block. The crankshaft also has oil passages (oilways) that route the oil from the main bearings to the connecting rod bearings. Engines with a remote oil filter, an oil cooler, or a dry sump system have external oil lines that move the oil to designated areas.

Dipstick

A dipstick is used to measure the level of oil in the oil pan. The end of the stick is marked to indicate where the oil level should be. Obviously, if the oil level is below that mark, oil needs to be added. Some late-model engines do not have a dipstick, instead, engine oil level is measured through the oil level sensor. The oil level is then displayed on the driver information center.

Oil Pressure Indicator

All vehicles have an oil pressure gauge and/or a low-pressure indicator light. Oil gauges are either mechanically or electrically operated and display the actual oil pressure of the engine. The indicator light only warns the driver of low oil pressure.

In a mechanical gauge, oil travels up to the back of the gauge where a flexible, hollow tube, called a Bourdon tube, uncoils as the pressure increases. A needle attached to the Bourdon tube moves over a scale to indicate the oil pressure.

Most pressure gauges are electrically controlled. An oil pressure sensor or sending unit is screwed into an oil gallery. As oil passes through an oil pressure sender **(Figure 14–12)**, it moves a diaphragm, which is connected to a variable resistor. This resistor changes the amount of current passing through the circuit. The gauge then reacts to the current and moves a needle over a scale to indicate the oil pressure, or the current is translated into a digital reading on the gauge.

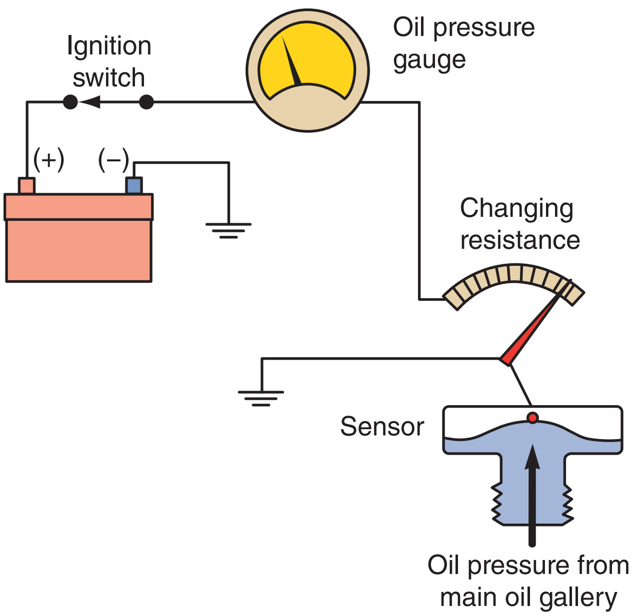


FIGURE 14-12 As oil pressure changes, the resistance in the oil pressure gauge circuit and the reading on the gauge change accordingly.

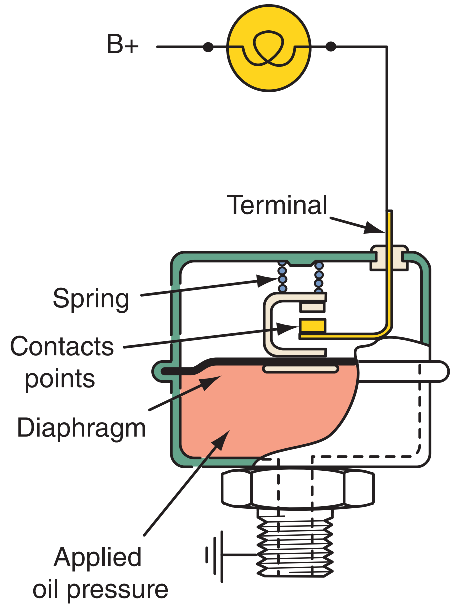


FIGURE 14-13 An oil pressure sensor for a warning gauge.

Warning light systems are basically simple electrical circuits. The indicator light comes on when the circuit is completed by a sensor. This sensor has a diaphragm connected to a switch inside the sensor. Under normal conditions, the sender switch is open. When oil pressure falls below a certain level, the reduction of pressure causes the diaphragm to move and close the sender switch **(Figure 14–13)**, which completes the electrical circuit. When this happens, the warning light turns on.

GO TO Chapter 21 for further discussions on oil and other gauges.

Basic Lubrication System Diagnosis and Service

Other than engine destruction, engine lubrication problems can cause other engine concerns, such as noise, exhaust smoke, and the need to add oil to the crankcase.

Oil Passages, Galleries, and Lines

All oil passages, galleries, and lines should be thoroughly cleaned and flushed during and after an engine has been overhauled.

Oil Consumption

Excessive oil consumption can result from external and internal leaks or worn piston rings, valve seals,

or valve guides. Internal leaks allow oil to enter the combustion chamber where it is burned. Blue exhaust smoke is an indication that an engine is burning oil.

If the valve guides are worn or the valve seals are worn, cracked, or improperly installed, oil will be drawn into the cylinder during the intake stroke. If there are worn or broken piston rings or worn cylinder walls, the affected cylinders will have low compression. The oil in the cylinder also tends to foul the spark plugs, which will cause misfires, high emissions, and possible damage to the catalytic converter.

External leaks are a common cause of excessive oil consumption. These leaks can occur at the valve or cam cover gasket, head gasket, oil filter, front and rear seals, oil pan gasket, and timing gear cover. Fresh oil on the clutch housing, oil pan **(Figure 14–14)**, edges of valve covers, external oil lines, crankcase filler tube, or at the bottom of the timing gear or chain cover usually indicates that the leak is close to or above that point.

When crankcase pressure is abnormally high, oil is forced out through joints that normally would not leak. Pressure develops when the positive crankcase ventilation (PCV) system is not working properly. **Blowby** is a term used for the gases that leak from the combustion chamber and enter the crankcase. Blowby gases are composed of pressurized intake gases and/or pressurized exhaust gases. The PCV system provides a continuous flow of fresh air through the crankcase to relieve the pressure and to prevent the formation of corrosive contaminants **(Figure 14–15)**.

PCV valves are designed for a particular engine's operating characteristics. Using the wrong valve can

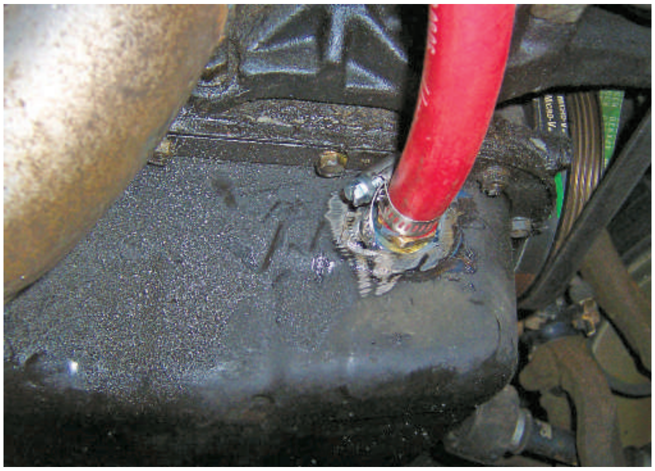


FIGURE 14–14 The presence of oil and dirt buildup around the oil pan indicates a leaky pan gasket.

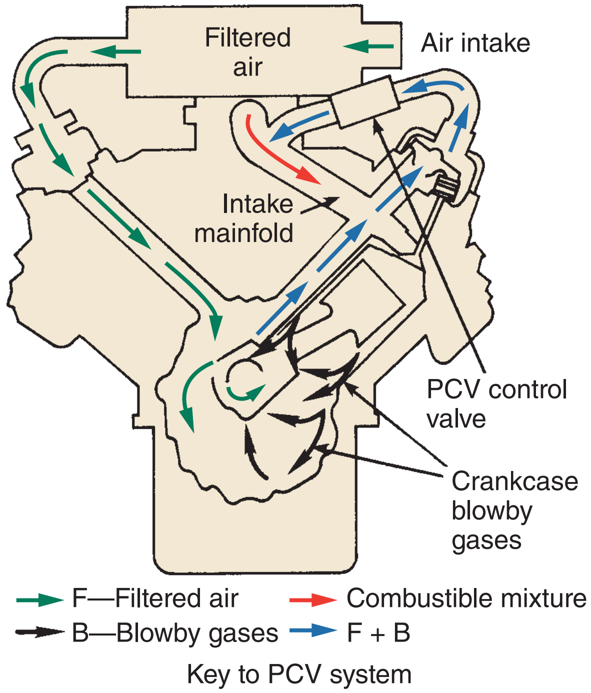


FIGURE 14–15 The operation of a PCV system.

cause oil consumption as well as other problems. If the PCV valve or connecting hoses become clogged, excessive pressure will develop in the crankcase. The pressure can cause oil to leak past gaskets and seals. It might also force oil into the air cleaner or cause it to be drawn into the intake manifold.

Oil Usage Even the smallest oil leak can cause excessive oil consumption. Losing three drops of oil every 100 feet (30.48 m) equals 3 quarts (2.8 L) of oil lost every 1,000 miles. Typically, engines use less than a quart per 1,000–2,000 miles (1,609–3,218 km). As the engine wears, its oil usage may increase. It is not unusual for a high-mileage engine to use a quart (0.946 L) of oil every 1,000 miles (1,609 km). Oil usage, that burned in the engine, can vary depending on the type and weight of the oil and the driving conditions of the vehicle.

Sludge

A typical sign of poor maintenance is the buildup of yellow sludge inside the engine. **Sludge (Figure 14–16)** results from the oxidation of oil. When oil oxidizes, chemical compounds in the oil begin to break down and solidify, forming a gel substance. The gelled oil cannot circulate through the engine and collects on engine parts. This buildup of sludge can also block normal lubrication paths. Sludge can also result from using oil that does not meet the performance requirements for the engine.

FIGURE 14–16 Sludge buildup on the lower parts of an engine.

Initial signs of sludge buildup include lower than normal oil pressure, increased fuel consumption, increased emissions, and poor driveability.

A slight buildup of sludge on the inside of the oil filler cap is normal. This is caused by condensation. However, if there is quite a bit of sludge, there is probably sludge throughout the engine. Excessive sludge can also be caused by a plugged PCV hose or valve. Because the PCV purges the crankcase of vapor and moisture, a plugged system will allow condensation to build up and contaminate the oil. If the sludge on the filler cap is white, suspect a blown head gasket. The whitish gel is caused by coolant mixing with the oil.

Often, sludge can be removed by flushing the system. However, if the buildup is great, the engine should be torn down and cleaned.

Flushing the System

Flushing the lubrication system periodically is recommended by some manufacturers. However, there are others that do not recommend flushing the engine. Flushing involves running a solvent through the engine and then draining the system. The ways to do this vary, as do the solvents used. The concern of those that do not recommend flushing is simply that the solvents may loosen up some dirt or sludge that will not drain out with the oil. These contaminants can block passages and restrict oil flow.

Oil flushing solvents can be added to the engine's oil before an oil change. The engine is run for about one-half hour and then the oil and filter are changed. Flushing machines connect to the filter housing and the drain plug port after the old oil has been drained. A heated solution is pumped through the oil reservoir, passages, oil pump, and up into the valve train. The solvent back flushes the oil pump and pickup screen and breaks up and dissolves the sludge. The remains are drawn out by a vacuum. After flushing, a new oil filter and clean oil are put into the engine.

Oil Cooler

If the engine has an external oil cooler, it and its lines should be checked for leaks. If leaks are evident, replace the lines and/or cooler. The cooler assembly should be flushed or replaced whenever there is sludge buildup in the engine. If the engine was rebuilt, the cooler should be replaced and the lines cleaned. Metal debris trapped in the cooler may become dislodged when the engine is run and cause oil starvation.

Cooling Systems

Today's engines create a tremendous amount of heat. Most of this heat is generated during combustion. Metal temperatures around the combustion chamber can run as high as 1,000 °F (537.7 °C). This heat can destroy the engine and must be removed. This is the purpose of the engine's cooling system **(Figure 14–17)**. The system must also allow the engine to quickly warm up to a desired operating temperature and keep it there regardless of operating conditions.

Heat is removed by a heat-absorbing liquid (coolant) circulating inside the engine. Coolant then flows to the radiator where its heat is transferred to the outside air. A pump moves the coolant through the engine block and then through the cylinder head. The coolant flows to the top of the radiator and loses heat as it flows down through the radiator. Ram air and airflow from the cooling fan pass through the radiator to cool the coolant. The cooled coolant leaves the radiator and enters the water pump and then is sent back through the engine.

Coolant

GO TO Chapter 8 for a detailed discussion of engine coolant.

Engine coolant is a mixture of pure water and antifreeze/coolant. Engine coolant has a higher boiling temperature and a lower freezing point than water. The exact boiling or freezing temperatures depend on the mixture. The typical recommended mixture is a 50/50 solution of water and antifreeze/coolant.

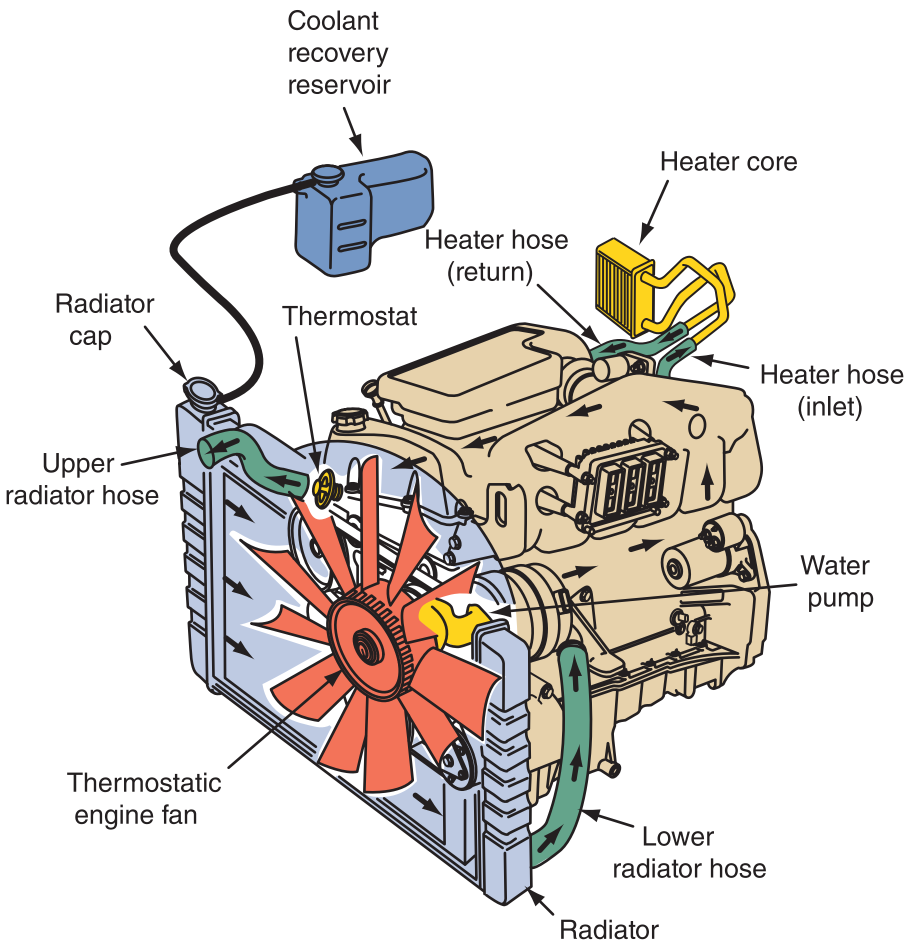


FIGURE 14–17 Major components of a liquid-cooling system. Arrows indicate the coolant flow.

Thermostat

The **thermostat** controls the minimum operating temperature of the engine. The maximum operating temperature is controlled by the amount of heat produced by the engine and the cooling system's ability to dissipate the heat.

A thermostat is a temperature-responsive coolant flow control valve. It controls the temperature and amount of coolant entering the radiator. While the engine is cold, the thermostat is closed **(Figure 14–18A)**, allowing coolant to only circulate in the engine. This allows the engine to uniformly warm up. When the coolant reaches a specified temperature, the thermostat opens and allows coolant to flow to the radiator. The hotter the coolant gets, the more the thermostat opens **(Figure 14–18B)**, sending more coolant to the radiator. Once the coolant passes through the radiator, it reenters the water pump. From there it is pushed through the engine and the cycle starts again.

The thermostat permits fast engine warmup. Slow warmup causes condensation in the crankcase, which can cause sludge. The thermostat also keeps the coolant above a specific minimum temperature to ensure efficient engine performance.

Today's thermostats have a specially formulated wax and powdered metal pellet contained in a heat-conducting copper cup that has a piston inside a rubber boot. Heat causes the wax to expand, forcing the piston outward, which opens the thermostat's valve. The pellet responds to temperature changes and moves the valve to control coolant temperature and flow. Thermostats are also designed to slow the flow of coolant when they are open. This prevents the coolant from moving too quickly through the engine. Fast-moving coolant may not have enough time to absorb heat and, therefore, overheating can result.

Most thermostats are located on the top and front of an engine **(Figure 14–19)**. The heat element fits into a recess in the block where it is exposed to hot coolant. The top of the thermostat is then covered by the water outlet housing, which holds it in place and provides a connection to the upper radiator hose.

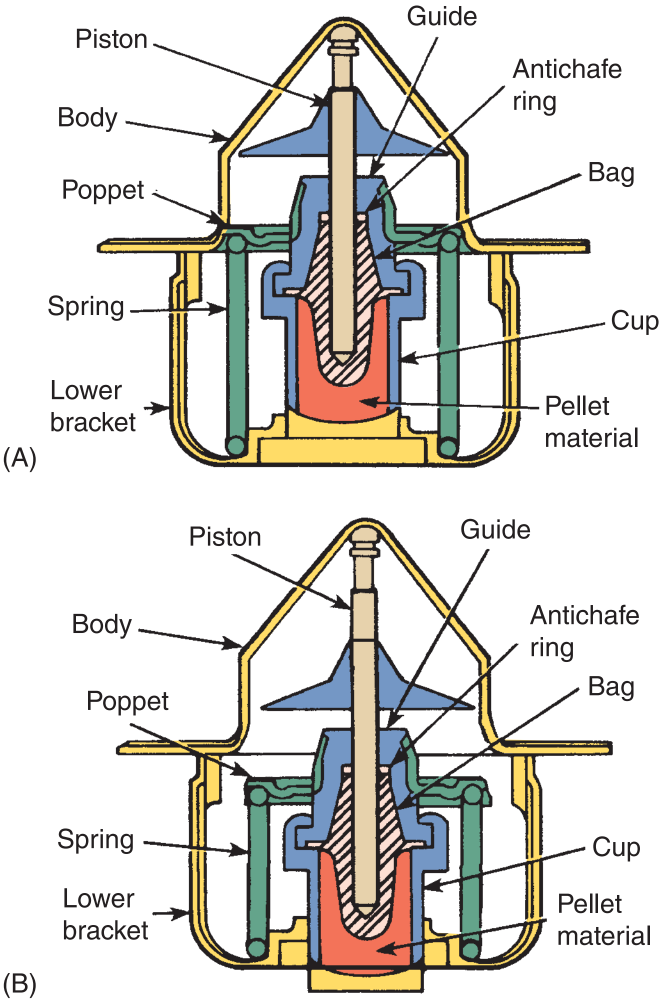


FIGURE 14–18 (A) Thermostat closed; (B) thermostat open.

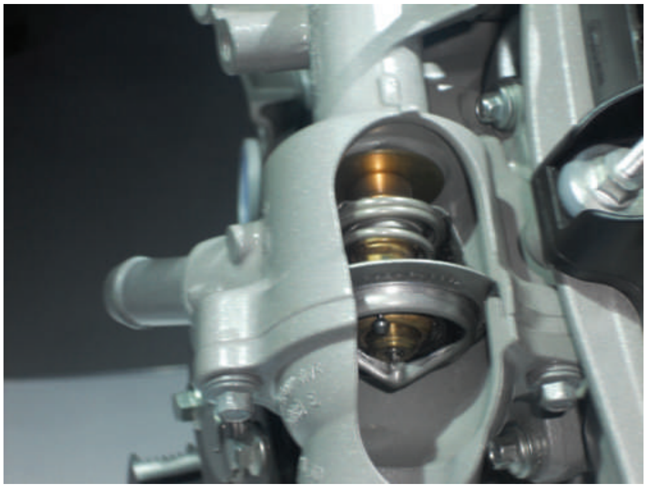


FIGURE 14–19 A typical thermostat located in the water outlet.

Water Pump

The heart of the cooling system is the water pump. Its job is to move the coolant through the system. Typically the water pump is driven by the crankshaft through pulleys and a drive belt **(Figure 14–20** and **Figure 14–21)**. On some engines the pump is driven by the camshaft, timing belt or chain, or an electric motor. The pumps are centrifugal-type pumps **(Figure 14–22)** with a rotating impeller to move the coolant. The shaft is mounted in the water pump housing and rotates on bearings. The pump has a seal to keep the coolant from passing through it. The inlet of the pump connects to the lower radiator hose, and its outlet connects to the engine block.

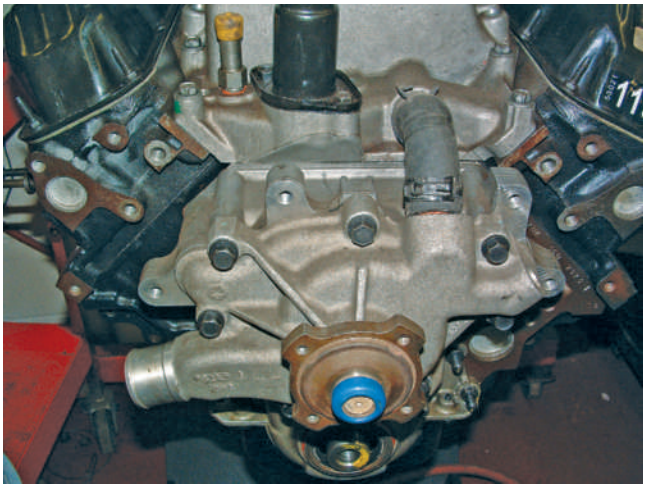


FIGURE 14–20 A water pump bolted to the front of an engine.

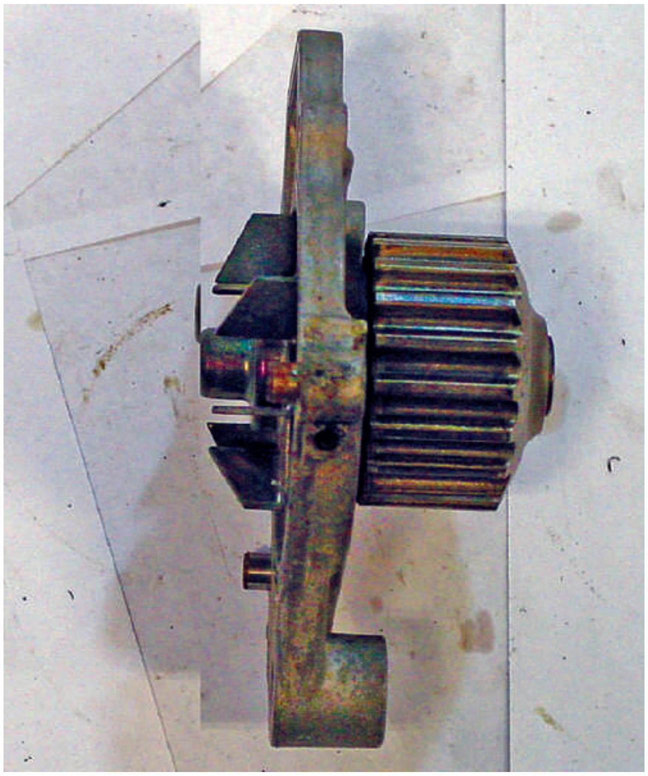


FIGURE 14–21 This water pump is driven by the timing belt.

FIGURE 14–22 An impeller-type water pump.

Electric Water Pumps Some engines have an electric water pump for the engine cooling system. The pump is driven by a brushless DC motor that is controlled by the ECM. The ECM regulates the amount of coolant circulating through the engine according to the operating conditions. An electric water pump provides improved fuel efficiency, efficient cooling system operation, ideal flow rates at all times, improved heater performance, and decreased engine warm-up times. The operation of these pumps can be monitored with a scan tool.

Radiator

The radiator is a heat exchanger, transferring heat from the engine to the air passing through it. The radiator is a series of tubes and fins (collectively called the core) that expose the coolant's heat to as much surface area as possible **(Figure 14–23)**. Attached to the sides or top and bottom of the core are plastic or aluminum tanks **(Figure 14–24)**. One tank holds hot coolant and the other holds the cooled coolant. Cores are normally comprised of flattened aluminum tubes surrounded by thin aluminum fins. The fins conduct the heat from the tubes to the air flowing through the radiator. Most

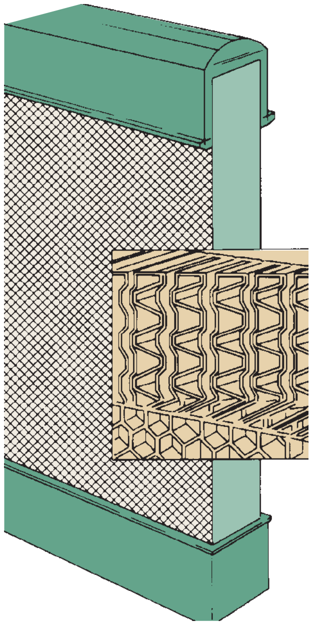


FIGURE 14–23 A radiator core is made of a series of tubes and fins that expose the coolant's heat to as much surface area as possible.

radiators have drain petcocks or plugs near the bottom. Coolant is added at the radiator cap or the recovery tank.

The efficiency of a radiator depends on its basic design, the area and thickness of the core, the amount of coolant going through the radiator, and the temperature of the cooling air. Today's radiators are designed to keep the coolant somewhat hot at all times. Keeping engines operating at a high temperature is necessary to maintain low emission levels.

Radiators are normally based on one of two designs: cross flow or down flow. In a cross-flow radiator, coolant enters on one side, travels through tubes, and collects on the opposite side. In a down-flow radiator, coolant enters the top of the radiator and is drawn downward by gravity. Cross-flow radiators are used in many late-model cars because all of the coolant flows through the fan's airstream, and the design allows for body designs with lower hood profiles.

Transmission Cooler Radiators used in vehicles with automatic transmissions have a sealed heat exchanger, or a form of radiator, located in the coolant outlet tank of the engine's radiator. Metal or rubber hoses carry hot automatic transmission fluid to the oil cooler. The coolant passing over the sealed oil cooler cools the fluid, which is then returned to the transmission. Cooling the transmission fluid is essential to the efficiency and durability of an automatic transmission.

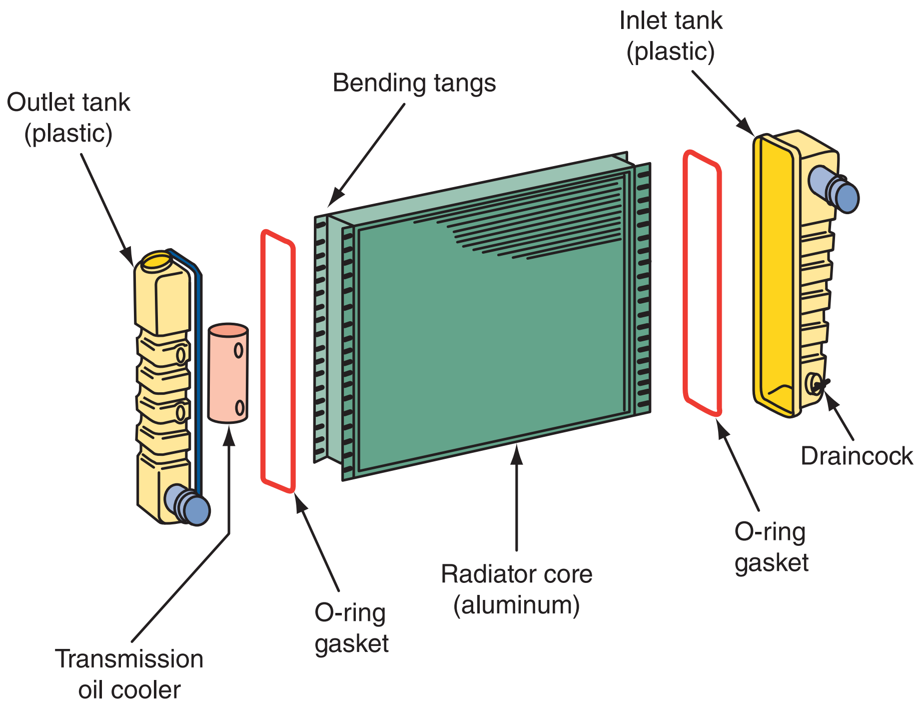


FIGURE 14–24 The core of a radiator is placed between plastic or aluminum tanks. One tank may contain the oil cooler for an automatic transmission and/or the engine.

Radiator Pressure Cap

Radiator caps **(Figure 14–25)** keep the coolant from splashing out of the radiator. They also keep the coolant's temperature within a desired range. It does this by keeping the coolant pressurized to a specified level.

The pressure raises the boiling point of the coolant. For every pound of pressure put on the coolant, the boiling point is raised about 3¼ degrees Fahrenheit (1.8 °C). Today's caps are designed to hold between 14 and 25 psi (93 and 172 kPa). This allows the coolant to reach higher-than-normal temperatures without boiling. This also allows the coolant to absorb more heat from the engine and more heat to transfer from the radiator core to outside air. This is due to a basic law of nature that states that the greater the heat difference is between two objects, the faster the heat of the hotter object will move to the cooler object.

The pressure in the system is regulated by a pressure relief or vent valve in the radiator cap **(Figure 14–26)**. When the cap is tightened on the radiator's filler neck, it seals the upper and lower sealing surfaces of the neck. The pressure relief valve is compressed against the lower seal. Coolant pressure builds up as the temperature of the

FIGURE 14–25 A radiator cap on a late-model engine.

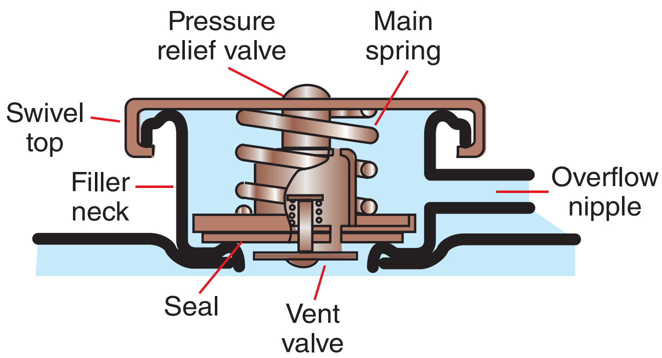


FIGURE 14–26 Parts of a radiator pressure cap assembly.

coolant rises. When the pressure reaches the pressure rating of the cap, it pushes up on the spring in the pressure relief valve. This opens the valve and allows excess pressure to exit the radiator through a bore between the upper and lower seals. The bore is connected, by a tube, to the expansion or recovery tank. When enough pressure has been released to drop system pressure below the cap's rating, the spring will close the pressure relief valve. When the coolant cools, its pressure drops. The low pressure opens the vacuum relief valve. The low pressure then draws coolant from the expansion tank to refill the radiator.

Warning! Never remove the radiator cap from a hot engine. Doing so can allow hot coolant and steam to shoot out and seriously burn you.

Radiator pressure cap specifications require that the cap must not leak below the low limit of the pressure range and must open above the high limit. They are labeled by the amount of pressure they should hold. For domestic vehicles, the pressure is stated in psi or kPa. Normally kPa ratings are expressed as a number times 100 kPa, for example: 1.3 × 100 kPa. This is a 130 kPa cap.

Radiator caps for some imported vehicles may have different markings. Some may be marked "0.9 Bar." This indicates that the pressure rating of the cap is 0.9 times normal atmospheric pressure. Because atmospheric pressure is 14.7 psi, a 0.9 cap has a pressure rating of about 13.2 psi (14.7 × 0.9). Another common rating is "100." The "100" indicates that the pressure rating of the cap is 100 percent of atmospheric pressure, or 14.7 psi.

Expansion Tank All late-model cooling systems have an **expansion** or **recovery tank (Figure 14–27)**. These systems are called closed-cooling systems. They are designed to catch and hold any coolant that passes through the pressure cap. As the engine warms up, the coolant expands. This eventually causes the pressure cap to release and allows some coolant to move into the expansion tank. When the engine is shut down, the coolant begins to shrink. Eventually, the vacuum spring inside the pressure cap opens and the coolant in the expansion tank is drawn back into the cooling system.

Many vehicles use a degas bottle or pressure tank, which is similar to an expansion tank. These systems do not have a separate radiator cap, instead, the degas bottle cap is the fill point and pressure cap for the system. A hose connects the degas bottle to the engine, typically near the thermostat housing. If any air is trapped in the system from a repair or service, the air will pass through the hose to the degas bottle and dissipate.

FIGURE 14–27 A coolant expansion tank.

Hoses

Coolant flows from the engine to the radiator and from the radiator to the engine through radiator hoses. The hoses are usually made of butyl or neoprene rubber hoses to cushion engine vibrations and prevent damage to the radiator.

A hose is typically made up of three parts: an inner rubber tube, some reinforcement material, and an outer rubber cover. Different covers and reinforcements are used depending on the application of the hose. All three parts are bonded together. Basically the difference in hose construction lies in what the hose will carry, where it is located, and the temperature and pressure it will face. Cooling system hoses must be able to endure heavy vibrations and be resistant to oil, heat, abrasion, weathering, and pressure.

Most vehicles have at least four hoses in the cooling system; some have five or more **(Figure 14–28)**. Two small diameter hoses send hot coolant from the water pump to the heater core and back. Two larger diameter hoses move the coolant from the water pump to the radiator and back into the engine block. The fifth hose is a small diameter bypass hose that allows coolant to circulate within the engine when the thermostat is closed. This hose is not required on all engines because the bypass feature is built into the engine block or cylinder head.

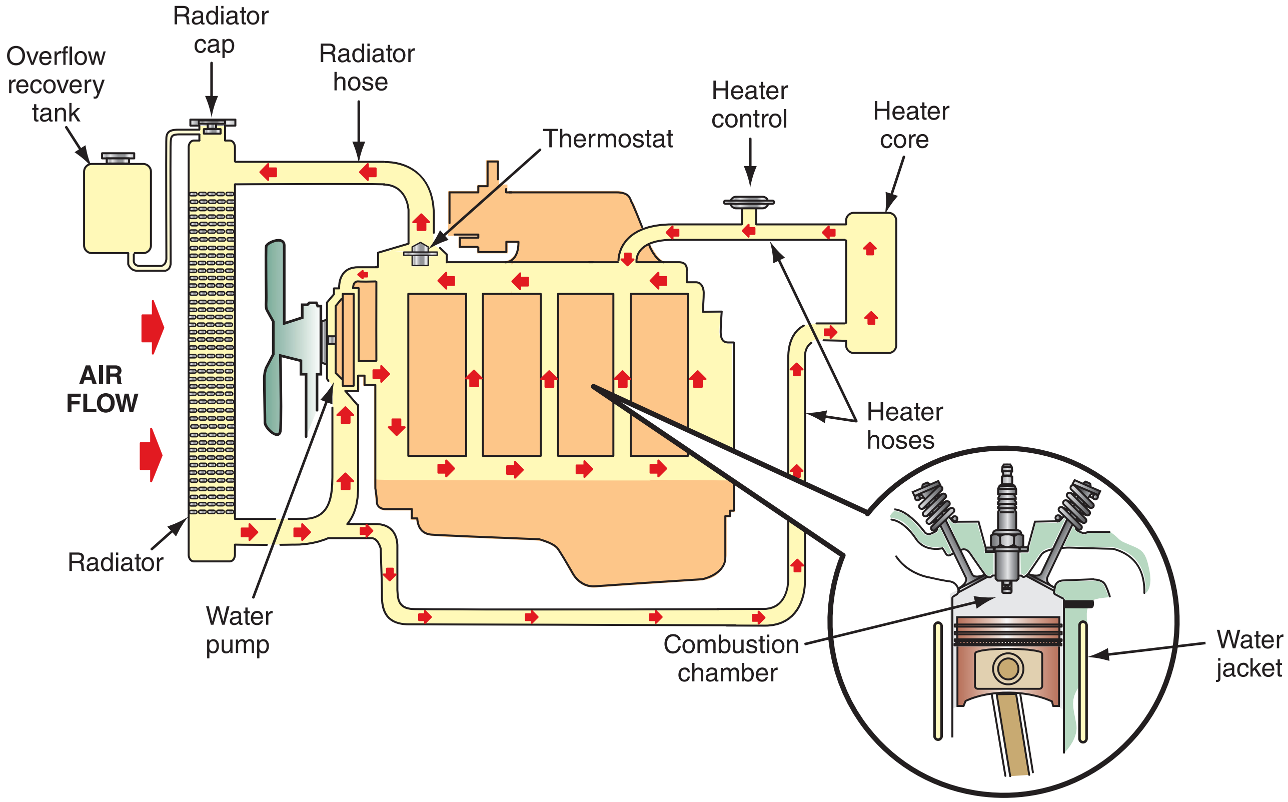


FIGURE 14–28 Routing of coolant through the cooling system hoses.

Hoses are sized according to their inside diameter. For example, common heater hoses are ⅝ or ¾ inch. Radiator hoses are larger and have reinforcements that allow them to withstand about six times the normal operating pressure of the cooling system.

Radiator hoses are seldom straight tubes. They need to bend or curve around parts to make a good connection without kinking. Most original equipment radiator hoses are molded to a specific shape to fit specific applications. Lower radiator hoses are normally reinforced with wire to prevent them from collapsing due to the suction of the water pump.

Heater hoses are made with reinforcements to help keep their shape. Some applications require a molded shape due to complex routing or curves.

Water Outlet The water outlet is the connection between the engine and the upper radiator hose through which hot coolant from the engine is pumped into the radiator. It has been called a gooseneck, an elbow, an inlet, an outlet, or thermostat housing. Generally, it covers and seals the thermostat and, in some cases, includes the thermostat bypass. Most water outlets are made of cast aluminum or stamped steel.

Water Jackets Hollow passages in the block and cylinder heads surround the areas closest to the cylinders and combustion chambers **(Figure 14–29)**.

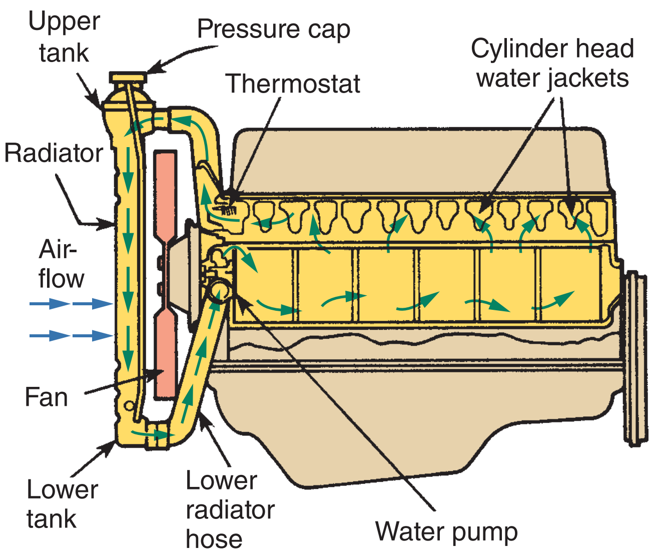


FIGURE 14–29 The cooling system circulates coolant through the engine's water jackets.

Some engines are equipped with plastic liners that direct coolant flow around critical areas.

Hose Clamps

Hoses are attached to the engine and radiator with clamps **(Figure 14–30)**. Hose clamps are designed to apply clamping pressure around the outside of

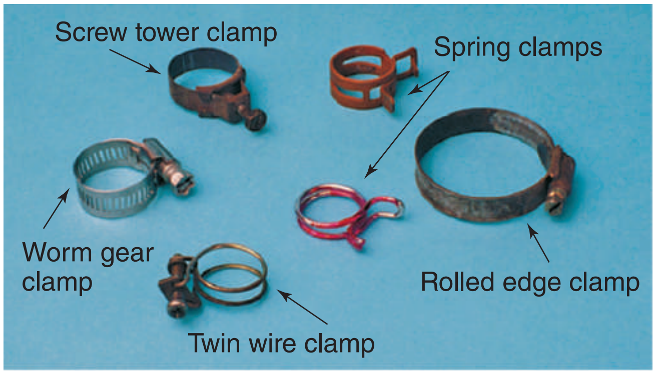


FIGURE 14–30 Common types of hose clamps.

the hose at the point where it connects to the inlet and outlet connections at the radiator, engine block, water pump, or heater core. The pressure exerted on this connection is important to making and maintaining a seal at that point.

Belt Drives

Belt drives are used to power the water pump and/or cooling fan on many engines. The belts must be in good condition and properly tensioned in order to drive the pump and/or fan at the correct speed.

GO TO Chapter 8 for a detailed discussion of drive belts.

Heater System

A hot liquid passenger compartment heater is part of the engine's cooling system. Heated coolant flows from the engine through heater hoses and a heater control valve to a heater core located on either side of the fire wall **(Figure 14–31)**. Air is directed or blown over the heater core, and the heated air flows into the passenger compartment. Movable doors can be controlled to blend cool air with heated air for more or less heat.

Cooling Fans

The efficiency of the cooling system depends on the amount of heat that can be removed from the system and transferred to the air. At highway speeds, the ram air through the radiator should be sufficient to maintain proper cooling. At low speeds and idle, the system needs additional air. This air is delivered by a fan. The fan may be driven by the engine, via a belt, driven by an electric motor, or hydraulically through the power-steering system. A belt-driven fan is bolted to a pulley on the water pump and turns

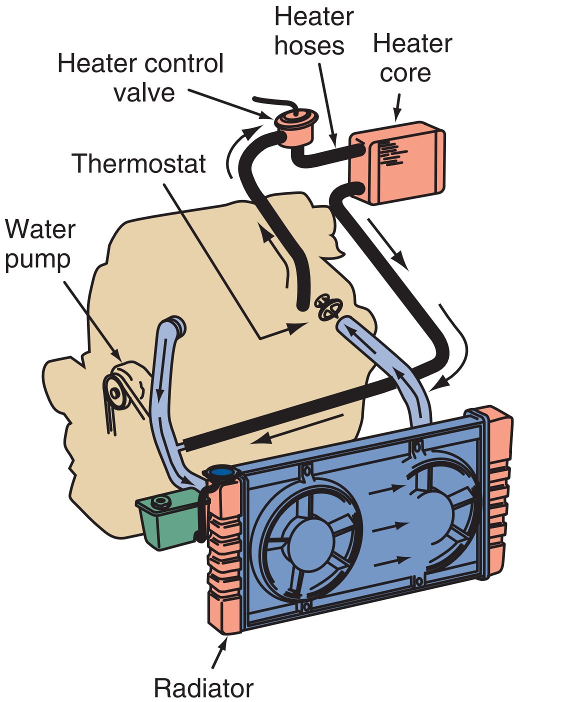


FIGURE 14–31 The coolant for the heater core is sent from the upper part of the engine through the heater core and back to the inlet side of the water pump.

constantly with the engine. Thus, belt-driven fans always draw air through the radiator from the rear. The fan has several blades made of steel, nylon, or fiberglass, which are attached to a metal hub.

A fan that is placed more than 3 inches from the radiator is ineffective. This is why most radiators are equipped with shrouds. A shroud is a large, circular piece of plastic, metal, or cardboardlike material that extends outward from the radiator to enclose the fan and increase its effectiveness.

Because fan air is usually only necessary at idle and low-speed operation, various design concepts are used to limit the fan's operation at higher speeds. Horsepower is required to turn the fan. Therefore, the operation of a cooling fan reduces the available horsepower to the drive wheels as well as the fuel economy of the vehicle. Fans are also very noisy at high speeds, adding to driver fatigue and total vehicle noise.

To eliminate this power drain during times when fan operation is not needed, many of today's belt-driven fans operate only when the engine and radiator heat up. This is accomplished by a **fan clutch (Figure 14–32)** located between the water pump pulley and the fan. When the engine and fan clutch are cold, the fan moves independently from the clutch and moves little air. The clutch locks the fan to its hub when the temperature of the air around the fan reaches a particular point. In most cases, the clutch slips at high speeds; therefore, it is not

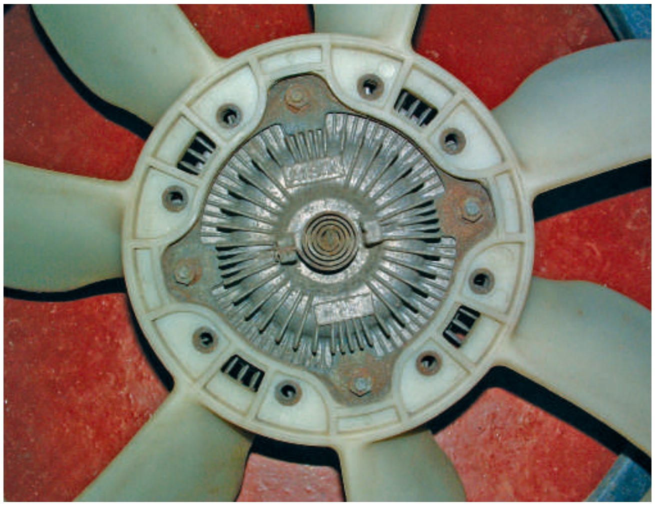


FIGURE 14–32 A viscous-type fan clutch.

FIGURE 14–33 This car has two separate electric cooling fans.

turning at full engine speed. The clutch assemblies rely on a thermostatic spring or silicone fluid.

Electric Cooling Fans In most late-model applications, to save power and reduce the noise level, there is an electrically driven fan **(Figure 14–33)**. This fan and motor are mounted to a shroud. The 12-volt, motor-driven fan is controlled by an engine coolant temperature switch and/or the air conditioner switch.

As the schematic in **Figure 14–34** shows, the cooling fan motors are connected to the battery through a normally open (NO) set of contacts in the cooling fan relays. During normal operation, with the air conditioner off and the engine coolant below a predetermined temperature of approximately 215 °F (101.6 °C), the relay contacts are open and the fan motors do not operate.

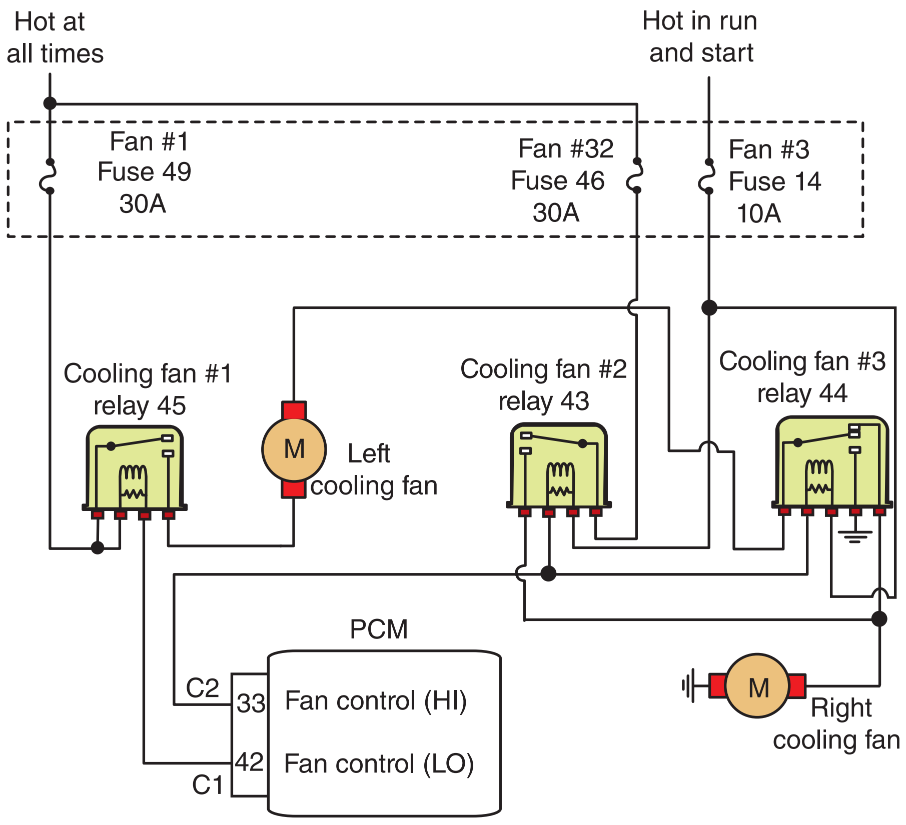


FIGURE 14–34 A simple schematic for an electric cooling fan.

When coolant temperatures exceed approximately 220 °F–230 °F (104 °C–110 °C), the PCM closes the low-speed relay control circuit. This energizes fan relay number one's coil, which in turn closes the relay contacts. This causes the fans to run at low speed. When the air conditioner switch is set to any cool position or additional engine cooling is needed, the PCM completes the high-speed fan circuit. Fan relay one remains closed, relays two and three now close, providing 12 volts to each fan motor.

There are many types of electric cooling fans. Some provide a cool-down period, which means the fan continues to run after the engine has been stopped and the ignition switch is turned off. These systems have a second temperature sensor. The fan stops only when the engine coolant falls to a predetermined temperature, usually about 210 °F (98.8 °C). In some systems, the fan does not start when the air conditioner is turned on unless the high side of the A/C system is above a predetermined temperature and/or pressure.

Some late-model cars control the cooling fan by completing the circuit through both the engine control computer and a fan control module. Check the service information to see how an electric cooling fan is controlled before working with it.

Hydraulic Cooling Fans

Some Ford and many Jeep vehicles use hydraulically operated cooling fans, called the hydraulic cooling module. In these systems, the power-steering pump supplies fluid to the fan assembly. The PCM controls a solenoid that controls fan speed based on engine temperature and A/C system demand. When engine temperature reaches 220 °F (105 °C), the fan should be receiving full power-steering fluid flow and operating at full speed.

Temperature Sensors Proper electric cooling fan operation depends on the operation of a temperature sensor. The sensor responds to changes in temperature. Some vehicles use more than one sensor to control the fans and to send engine temperature readings to the PCM. Based on this information, the PCM will adjust the fuel injection and ignition systems to provide efficient engine operation.

> **Caution!** The electric cooling fan can come on at any time without warning even if the engine is not running. Always remove the negative terminal at the battery or the connector at the cooling fan motor while working around an electric fan. Make sure you reconnect the connector before giving the car back to the customer.

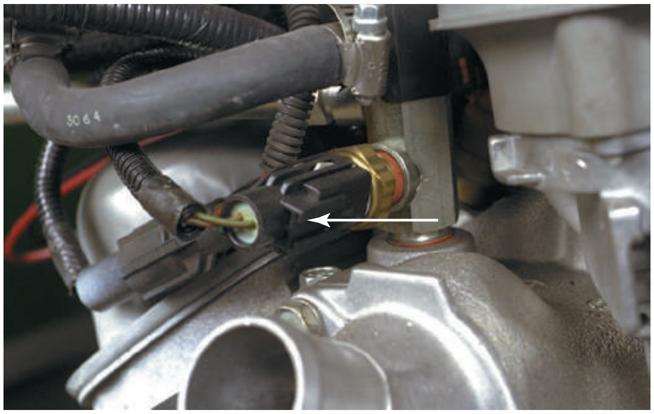


FIGURE 14-35 A coolant temperature sensor.

Temperature Indicators

Coolant temperature indicators alert the driver of an overheating condition. These indicators are a temperature gauge and/or a warning light. A temperature sensor is threaded into a bore in a water jacket **(Figure 14–35)**.

Cooling System Diagnosis

The cooling system must be inspected and serviced as a system. Replacing one damaged part while leaving others dirty or clogged will not increase system efficiency. Diagnosis of the system involves both a visual inspection of the parts, simple checks and tests, and leak testing. One of the first checks of the cooling system is the checking of coolant level and condition. These checks should be done during normal preventive maintenance and when there is a problem.

GO TO Chapter 8 for a general discussion of checking the coolant level and condition.

There are marks on most expansion tanks that show where coolant levels should be when the car is hot and when it is cold. The condition or effectiveness of the coolant should be checked with a hydrometer, a refractometer, or alkaline test strips.

Caution! When working on the cooling system, remember that at operating temperature the coolant is extremely hot. Touching the coolant or spilling it can cause serious body burns. Never remove the radiator cap when the engine is hot.

The proper mixture of water and antifreeze also reduces the amount of rust and lime deposits that can form in the system. These deposits tend to insulate the walls of the water jackets. As a result, the coolant is less able to absorb the engine's heat at the points where there is scale. This causes engine hot spots that result in increased component wear and make overheating more likely **(Figure 14–36)**.

Regardless of the mixture of the coolant or the type of antifreeze used, some lime, rust, and scale will always build in a cooling system. Any deposit on the walls of the water jackets will affect engine cooling. Changes in engine temperature cause the engine parts to expand and contract. Some of these deposits then break off and become suspended in the coolant. The coolant then becomes contaminated and the deposits may collect at a narrow passage, making the passage narrower. This restriction would further lessen the effectiveness of the cooling system. For these reasons and others, the engine's coolant should be replaced and the cooling system flushed according to the manufacturer's recommendations.

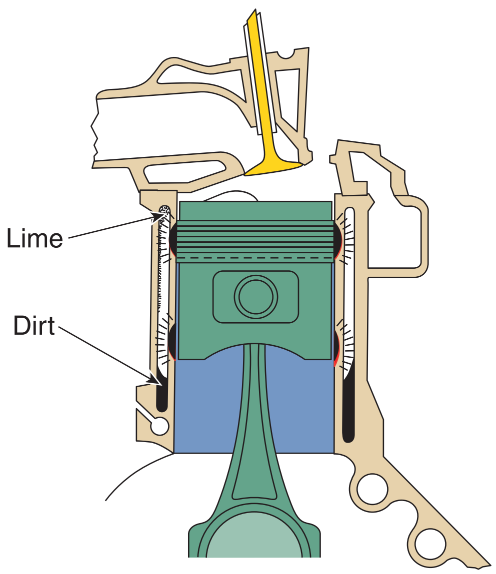


FIGURE 14–36 Lime and dirt buildup in the coolant passages tend to insulate the walls of the water jackets and can cause hot spots that result in increased wear and make overheating more likely.

Testing for Electrolysis in Cooling Systems

Electrolysis is a process in which an electrical current is passed through water, causing the separation of hydrogen and oxygen molecules. In a cooling system, electrolysis removes the protective layer on the inside of the radiator tubes. It also can cause serious engine failures. Electrolysis occurs when there is improper grounding of electrical accessories and equipment or static electricity buildup somewhere in the vehicle. Checking for these should be a part of all checks of the coolant.

To check for the conditions prone to electrolysis, use a voltmeter that is capable of measuring AC and DC voltage. Set the meter so it can read in tenths of a volt DC. Attach the negative meter lead to a good ground. Place the positive lead into the coolant **(Figure 14–37)**. Look at the meter while the engine is cranked with the starter and record the readings. Take another reading with the engine running and all accessories turned on. Record that reading. Voltage readings of 0 to 0.3 volt are normal for a cast-iron engine; normal readings for a bimetal or aluminum engine are half that amount. Repeat the test with the DMM in the AC voltage mode. There will be AC voltage if the problem is static electricity. Any readings above normal indicate a problem.

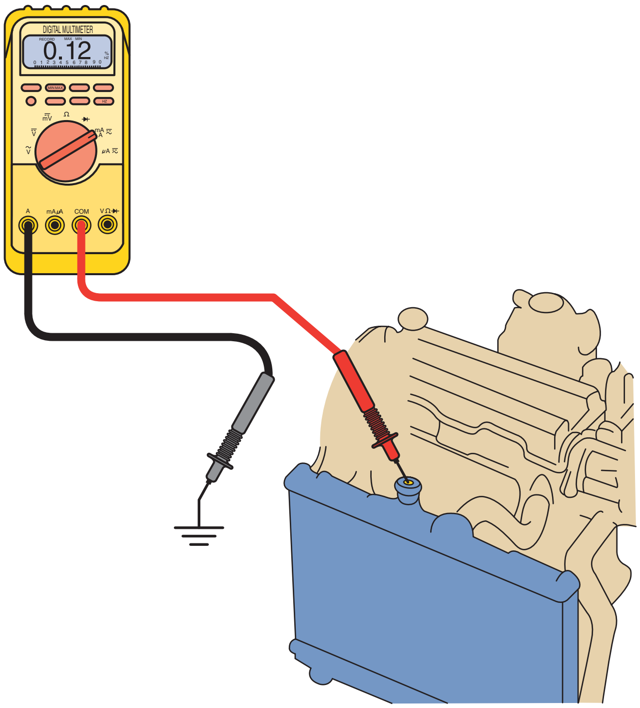


FIGURE 14–37 The setup for checking for conditions that can cause electrolysis.

To isolate the problem, look at where the high voltage was measured and think about the systems that were energized during that time. If the voltage was high when all of the accessories were turned on, turn them off one at a time until the voltage drops to normal. The circuit that was turned off prior to the drop in voltage has ground problems. After the electrical problems have been corrected, flush and replace the coolant.

Inspection of Cooling System

The most common cooling system problem is overheating. There are many reasons for this. Diagnosis of this condition involves many steps, simply because many things can cause this problem **(Figure 14–38)**. Basically, overheating can be caused by anything that decreases the cooling system's ability to absorb, transport, and dissipate heat: The first step is to determine whether the engine is indeed overheating.

An overheating concern normally begins with high readings on the vehicle's temperature gauge or the illumination of the temperature warning lamp. These can be caused by a cooling system problem or a faulty temperature sensor, although when the engine is greatly overheating, it is obvious by the steam emitted by the system or by smell. The best way to check the accuracy of the temperature indicators is to measure the temperature of the coolant. If the indicators seem to be wrong, troubleshoot and repair the electrical circuit. Then recheck the system's temperature.

SHOP TALK

It is difficult to measure the actual temperature of the coolant on most late-model engines because the only access to the coolant is through the expansion tank. The coolant in the tank does not represent the coolant in the engine and it is not heated. Use a temperature probe or infrared sensor to measure the temperature of the inlet radiator tank. This will give an accurate measurement of system temperature.

Condition	Cause
Overheats in heavy traffic or after idling for a long time	■ Low coolant level ■ Faulty radiator cap ■ Faulty thermostat ■ Cooling fan is not turning on ■ Restricted airflow through the radiator ■ Leaking head gasket ■ Restricted exhaust ■ Water pump impeller is corroded
Overheats when driving at speed, or after repeated heavy acceleration	■ Radiator and/or block are internally clogged with rust, scale, silt, or gel ■ Restricted airflow through the radiator ■ Faulty radiator cap ■ Faulty thermostat ■ Radiator fins are corroded and falling off ■ Water pump impeller is corroded ■ Collapsed lower radiator hose ■ Dragging brakes
Overheats any time or erratically	■ Low coolant level ■ Faulty radiator cap ■ Faulty thermostat ■ Temperature sender or related electrical problem ■ Cooling fan is not turning on
Overheats shortly after the engine is started	■ Temperature sender or related electrical problem
Seems slightly too hot all of the time; gauge nears the red zone at times	■ Radiator and/or block are internally clogged with rust, scale, silt, or gel ■ Restricted airflow through the radiator ■ Faulty radiator cap ■ Faulty thermostat ■ Radiator fins are corroded and falling off ■ Collapsed lower radiator hose ■ Cooling fan is not turning on
Bubbles in the coolant expansion tank	■ Faulty radiator cap ■ Failed head gasket
Air in the radiator but the expansion tank is full	■ Coolant leak ■ Faulty radiator cap ■ Air in the system ■ Faulty seal between the radiator cap and expansion tank ■ Failed head gasket

FIGURE 14–38 Common causes of engine overheating.

Normal operating temperature for most engines is 195 °F to 220 °F (91 °C to 104 °C). To maintain this temperature, the coolant must circulate through the engine and radiator. Anything that will interfere with the movement of coolant, such as a faulty water pump or thermostat, or a loss of coolant, will cause overheating. Likewise anything that interferes with the passing of air through the radiator will also cause overheating.

Effects of Overheating

Engine overheating can cause the following problems:

- Detonation
- Preignition
- Blown head gasket
- Warped cylinder head
- OHC cam seizure and breakage
- Blown hoses
- Radiator leaks
- Cylinder damage due to swelling pistons
- Sticky exhaust valve stems
- Engine bearing damage

Temperature Test

A temperature test can be performed with an infrared temperature sensor, thermometer, or temperature probe. The latter may be a feature of a digital multimeter (DMM). A temperature test monitors temperature changes through the cooling system. When a cold engine is started, the opening temperature of the thermostat can be observed as the engine warms. This can be compared to specifications to determine if the thermostat is bad. Once the engine has warmed up, the probe can be used to scan for cool spots in the radiator. These indicate an area where coolant is not flowing freely through the radiator. The cooling fan temperature switch can also be checked.

Radiator Checks

Cold spots on the radiator indicate internal restrictions. In most cases, this requires removal of the radiator so it can be deeply flushed or replaced. Normal cooling system flushing may not remove the restrictions. The restrictions are typically caused by internal corrosion or a buildup of scale and lime.

The radiator should also be inspected for external restrictions and for evidence of leaks. Dirt, bugs, and other debris on the surface of the radiator will block airflow. These should be removed by careful cleaning. Also, check for loose cooling fins. Salt and other road debris can corrode the solder used to attach the fins around the radiator's tubes. When the fins are not attached to the tubes, heat is not as easily transferred to the outside air.

Checking Hoses

Carefully check all cooling hoses for leakage, swelling, and chafing. Also replace any hose that feels mushy or extremely brittle when squeezed firmly **(Figure 14–39)**. When a hose becomes soft, it is deteriorating and should be replaced before more serious problems result. Hard hoses will resist flexing and may crack rather than bend and should be replaced.

Normally, hoses begin to deteriorate from the inside. Pieces of deteriorated hose will circulate through the system until they find a place to rest. This place is usually the radiator core, causing clogging. Deterioration can also cause leaks. Any external bulging or cracking of hoses is a definite sign of failure. When one hose fails, all of the others should be carefully inspected.

The upper radiator hose has the roughest service life of any hose in the cooling system. It must absorb more engine motion than the other hoses. It is exposed to the coolant at its hottest stage, and it is insulated by the hood during hot soak periods. These conditions make the upper hose the most likely to fail.

Check the firmness of the lower radiator hose to make sure the internal reinforcement spring is in place and not damaged. Without this reinforcement,

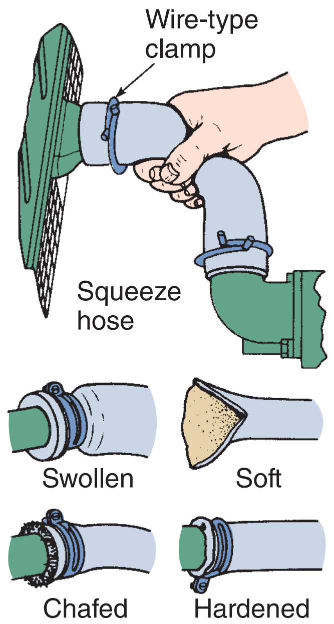


FIGURE 14–39 Defects in cooling hoses.

FIGURE 14-40 An ECD-damaged hose.

the hose can collapse under vacuum at high engine speeds and restrict coolant flow from the radiator to the engine.

Squeeze each hose and look for splits. These splits can burst wide open under pressure. Also look for rust stains around the clamps. Rust stains indicate a leak, possibly because the clamp has eaten into the hose. Loosen the clamp, slide it back, and check the hose for cuts.

A major cause of hose failure is an electrochemical attack on the rubber hose. This is known as **electrochemical degradation (ECD)**. It occurs because the hose, engine coolant, and the engine/radiator fittings form a galvanic (battery) cell. This chemical reaction causes very small cracks in the hose, allowing the coolant to attack and weaken the reinforcement in the hose **(Figure 14–40)**. ECD can cause pinhole leaks or hose rupture under normal operating pressures. The effects of ECD are accelerated by high temperatures and vibrations.

The best way to check hoses for ECD is to squeeze the hose near the clamps or connectors. ECD occurs within 2 inches of the ends of the hose—not in the middle. Compare the feel of the hose between the middle and the ends. Gaps can be felt along the length of the hose where it has been weakened by ECD. If the ends are soft and feel mushy, chances are the hose is under attack by ECD and the hose should be replaced.

Oil is another enemy to rubber hoses. A hose damaged by oil is swollen, soft, and sticky. If the oil leak is external, eliminate the oil leak or try to reroute the hose away from the oil leak to prevent oil damage to a new hose. At times, the oil damage occurs inside the hose. This can be caused by transmission fluid leaking into the coolant or an internal engine oil leak.

Belt Drives

Excessive heat, due to belt slippage, tends to cause the belts to overcure. This causes the rubber to harden and crack. Slippage can be caused by improper belt tension or oily conditions. When slippage occurs, heat not only overcures the belt but it also travels through the drive pulley and down the shaft to the support bearings. The heat can damage the bearings if the slippage is allowed to continue. As a V-belt wears, it rides deeper in the pulley groove. This reduces its tension and promotes slippage. Carefully inspect all drive belts and replace them as necessary.

GO TO Chapter 8 for the correct procedure for changing a belt and adjusting its tension.

Checking Fans and Fan Clutches

Most engine-driven fans have a clutch, and many overheating problems are caused by a defective clutch. However, the fan itself as well as the fan shroud must be thoroughly checked. The fan shroud should be securely fastened to the radiator bracket. Any damage or distortion to the fan will cause it to be out of balance. This can cause major problems, including rapid and excessive water pump bearing and seal wear or damage to the radiator if the fan blades hit the radiator. A noticeable wobble as the fan spins means that the fan should be replaced. The shroud should also be checked for cracks and other damage. A damaged shroud should be replaced.

Fan clutches are filled with silicone oil. The oil responds to speed and temperature. As the engine increases speed, the oil allows the fan to slip on its hub. This reduces the drag on the engine. If the clutch allows the fan to slip during low engine speeds, overheating can occur. A loss or deterioration of the oil will cause fan slippage. Over time, the oil begins to break down and offers less of a coupling between the fan and hub.

The clutch assembly should be carefully checked for leakage. Oily streaks radiating outward from the hub shaft mean that fluid has leaked out past the bearing seal. A leaking clutch should be replaced. The clutch should also be replaced if the fan can be spun with little or no resistance with the engine off, if the clutch wobbles when the fan is moved in or out, or its fins are damaged or missing.

Electric Cooling Fans The action of the electric cooling fan should be observed. However, before doing so, check the mounting of the fan assembly

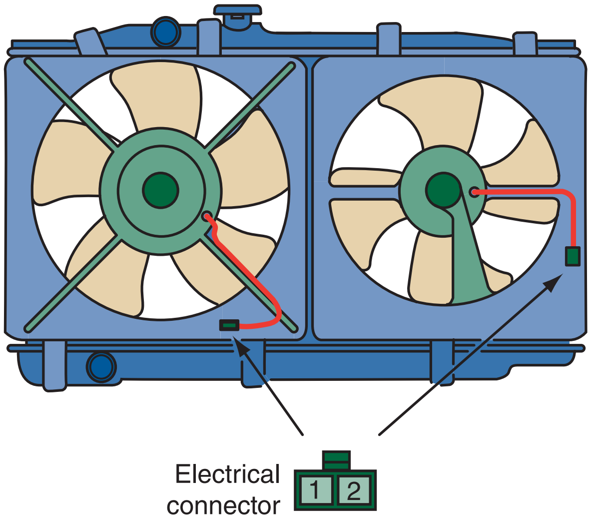


FIGURE 14–41 Test each fan motor by connecting battery power to terminal 1 and a ground to terminal 2. If either motor fails to run or does not run smoothly, replace it.

and the condition of the fan blades. The fan should be energized when the A/C is turned on and when the coolant reaches a specified temperature. If the fan does not turn on when it should, check the motor. Do this by connecting the motor directly to the battery. If the motor runs, the problem is in the motor's control circuit. Diagnosis of this problem should follow the prescribed sequence given by the manufacturer. If the jumped motor does not run, the problem is the fan motor **(Figure 14–41)**.

Testing the Thermostat

Thermostats are often the cause of overheating or poor heater performance. They can also cause an increase in fuel consumption and poor engine performance. Electronic engine control systems are programmed to deliver the ideal air–fuel mixture and ignition timing according to the engine's operating conditions. One of the conditions monitored by the ECM is engine temperature.

If the thermostat is stuck open, the coolant may not reach the desired temperature because it is cooled before it gets hot. If a thermostat is stuck closed because it failed or because there is a steam pocket below the thermostat, coolant will not flow between the engine and the radiator; the engine will, therefore, quickly overheat.

The best way to check thermostat operation is to measure engine temperature with an infrared thermometer **(Figure 14–42)**. However, you can use your hand to feel the temperature. Touch the upper and lower radiator hoses when the engine is first started. If the hoses do not become hot within several minutes, the thermostat is not opening.

FIGURE 14–42 The operation of a thermostat can be observed with an infrared thermometer.

Water Pump Checks

Water pumps are driven by a belt, the crankshaft or camshaft, or by an electrical motor. A water pump pulls coolant from the radiator and pushes it through the engine. If the water pump is not working properly, the engine will quickly overheat. Seldom does a pump merely stop working. Problems with a pump are normally noise or leakage. An exception to this is electrically operated pumps. Electric problems can cause the pump to totally stop. The cause of these problems is identified by troubleshooting the circuit.

The majority of water pump failures are attributed to leaks. When the pump bearings and seals begin to fail, coolant will seep out of the weep hole in the casting or through the outer seal **(Figure 14–43)**. The seals may be worn out due to age or abrasives in the system, or they may have cracked because of thermal shock, such as adding cold water to an overheated engine.

FIGURE 14–43 This pump shows signs of bad leaks.

Caution! As soon as a water pump begins to leak, it should be replaced. Not only will the leak get worse and cause serious overheating but there is also the chance of the pump's shaft breaking and the fan moving into and destroying the radiator.

Other failures can be attributed to bearing and shaft problems and an occasional cracked casting. Water pump bearing or seal failure can be caused by surprisingly small out-of-balance conditions that are difficult to spot. Any wobble of the pump shaft or fan means the pump and/or fan should be replaced.

Through time, the impeller blades may corrode or come loose from the shaft. Both of these situations will cause the pump not to work and it must be replaced. In less extreme cases, corrosion may cause the impeller to be loose on the shaft and not rotate all of the time. This can cause an intermittent cooling problem. Unfortunately, the only sure way of knowing the condition of the impeller is to remove the pump and inspect it.

To check the operation of the water pump, start the engine and allow it to warm up. Squeeze the upper radiator hose **(Figure 14–44)** and accelerate the engine. If a surge is felt in the hose, the pump is working.

Air in the cooling system can prevent the pump from working properly. To check for the presence of air, attach one end of a small hose to the radiator overflow outlet and put the other end into a jar of water. Then make sure all hose connections are tight, and the coolant level is correct. Run the engine and bring it to its normal operating temperature. Then run the engine at a fast idle. If a steady stream of bubbles appears in the jar, air is getting into the system.

FIGURE 14–44 The operation of the water pump can be checked by squeezing the upper radiator hose while accelerating the engine. If a surge is felt in the hose, the pump is working.

Air may enter the system because of a bad head gasket. Conduct a combustion leak or compression test. If the results of the compression test show that two adjacent cylinders tested have low compression, the gasket is probably bad.

On belt-driven pumps, turn the engine off and remove the drive belt and shroud. Grasp the fan and attempt to move it in and out, and up and down. More than 1⁄16 inch (1.58 mm) of movement indicates worn bearings that require water pump replacement.

If the concern is excessive noise, start the engine and listen for a bad pump bearing. Place the tip of a stethoscope on the bearing or pump shaft. If a louder-than-normal noise is heard, the bearing is defective.

Caution! Whenever working near a running engine, keep your hands and clothing away from the moving fan, pulleys, and belts. Do not allow the stethoscope or rubber tubing to be caught by the moving parts.

Testing for Leaks

The most common cause of overheating is low coolant levels due to a leak. Leaks can occur anywhere in the system. The most common leak points include the hoses, radiator, heater core, water pump, thermostat housing, engine freeze plugs, transmission oil cooler, cylinder head(s), head gasket, and engine block. Often only a visual inspection of the cooling system and engine is necessary to find the source of a leak. The point of the leak may be wet or have a light gray color, the result of the coolant evaporating at that point.

Pressure Testing

A radiator pressure tester is a common tool used to test a cooling system. It is extremely handy for finding the source of any leak in the cooling system. The tester applies pressure to the entire cooling system. A good cooling system should be able to hold about 14 psi (93 kPa) for 15 minutes or more without losing pressure. The procedure for using a pressure tester is given in Photo Sequence 12.

The tester is fastened to the radiator filler neck or degas bottle. The engine runs until it is warm. The tester's handle is moved back and forth to create pressure in the cooling system. Once the pressure in the system is equal to the pressure noted on the

radiator cap, the tester's gauge is observed. If the pressure drops off, there is a leak. Carefully check the hoses, radiator, heater core, and water pump for leaks. Often the leak will initially be obvious because coolant will spray out of the leak. Also look for bulges in the hoses. These indicate that the hose is soft and weak and should be replaced. If the pressure drops but there are no external leaks, suspect an internal leak. The source of internal leaks is found through additional testing.

An internal leak caused by a bad head gasket can be verified with the tester. Relieve all pressure in the cooling system. Install the pressure tester onto the radiator filler neck and start the engine. Allow the engine to idle and watch the gauge on the tester. If the pressure begins to build, it is more than likely that the head gasket is blown and combustion gases are entering the coolant.

Leak Detection with Dye Another common way to identify the source of an external leak is to use dye penetrant and a black light. The dye is poured into the cooling system and the engine run until it reaches operating temperature. With the engine off, the engine and cooling system are inspected with the black light. Where the dyed coolant leaks, a bright or fluorescent green color will be seen **(Figure 14–45)**.

Combustion Leak Check Internal leaks are typically caused by a cracked cylinder head or block, or a bad head gasket that is allowing coolant to leak into the cylinders or combustion gases to leak into the cooling system. Sometimes steam, white smoke, or water in the exhaust, or coolant in the oil or oil in the coolant, will give a hint that there is a bad head gasket.

Courtesy of Tracer Products.

FIGURE 14–45 A common way to identify the source of an external leak is to use dye penetrant and a black light. Where the dyed coolant leaks, a bright or fluorescent green color will be seen.

A combustion leak tester is used to determine whether combustion gases are entering the cooling system. This tester is basically a glass tube with a rubber bulb. The tube is fit with a one-way valve at the bottom. To check for combustion gas leaks, follow this procedure:

PROCEDURE

1. **Start the engine and allow it to reach normal operating temperature.**
2. **Fill the tester's glass tube with the test fluid (normally a blue liquid).**
3. **Carefully remove the radiator cap.**
4. **Make sure the coolant level in the radiator is below the lower sealing area of the filler neck.**
5. **Place the tester's tube into the filler neck.**
6. **Rapidly squeeze and release the rubber bulb. This will force air from the radiator up through the test fluid.**
7. **Observe the liquid. Combustion gases will change the color of the liquid to yellow. If the liquid remains blue, combustion gases were not present.**
8. **Dispose of the test fluid; never return used test fluid to its original container.**

A bad head gasket normally results from another problem. Make sure that problem is corrected before replacing the gasket. Bad head gaskets should be replaced as soon as possible. The excessive heat and pressures resulting from this problem are far greater than what a cooling system can handle and can lead to serious engine problems.

SHOP TALK

The O_2 sensor should be replaced after a head gasket is replaced or if there was a crack in the head or block. Coolant contains silicone and silicates that may contaminate the sensor.

PHOTO SEQUENCE 12

Using a Cooling System Pressure Tester

P12-1 Remove the radiator cap.

P12-2 Top off the coolant level.

P12-3 Connect the tester to the radiator's filler tube and apply pressure to the system by pumping the handle of the tester.

P12-4 Once the pressure is equal to the rating of the pressure cap, watch for a pressure decrease and look for leaks.

PHOTO SEQUENCE 12

Using a Cooling System Pressure Tester *(continued)*

P12-5 Using the appropriate adapter, mount the pressure cap to the tester.

P12-6 Apply pressure to the cap that is equal to the cap's rating. If the cap does not hold that pressure, replace it. Then apply more pressure. If the cap is good, the excess pressure will vent through the cap.

P12-7 Correct any leaks and top off the fluid level.

Testing the Radiator Pressure Cap

The opening pressure of the radiator cap should be measured and the cap checked for gasket cracking, brittleness, or deterioration **(Figure 14–46)**. Also check the sealing surfaces in the radiator filler neck.

Over time the spring in the cap can weaken and that will lower the coolant's boiling point. This will cause the engine to lose coolant through the overflow tube whenever it gets hot. To check the cap, install the correct cap adapter and the radiator's pressure cap to the tester head. Pump the tester until the gauge reads the pressure rating of the cap. The cap should hold that pressure for at least 1 minute. If it does not, replace it. Apply a pressure greater than the cap's rating. A good cap will vent the excess pressure. Remove the cap from the tester and visually inspect the condition of the cap's pressure valve and upper and lower sealing gaskets. If the gaskets are hard, brittle, or deteriorated, the cap may leak when exposed to hot, pressurized coolant. It should be replaced with a new cap in the same pressure range.

Warning! The radiator cap should never be removed when the radiator is hot to the touch. When the pressure in the radiator is suddenly released, the coolant's boiling temperature is reduced. This causes the coolant to immediately boil. Because coolant is a liquid, it will stick to your skin and can cause severe burns. The radiator should be allowed to cool. When the cap is cool and the engine is shut off, use a cloth over the cap and turn it counterclockwise one-quarter, turn to its safety stop, and release the pressure. Let the cap remain in this position until all pressure is released. Then press the cap down and turn it counterclockwise to remove it.

Water Outlet

Internal corrosion contributes to the failure of water outlets. Cast-iron water outlets are more resistant to corrosion than stamped steel or cast aluminum outlets. A more common cause of water outlet problems is uneven torquing of the mounting bolts, which can cause a mounting ear to crack or break off. When this happens, the outlet must be replaced.

FIGURE 14–46 Radiator cap inspection.

Cooling System Service

Service to the cooling system involves replacing leaking or broken parts as well as emptying, flushing, and refilling the system. One of the common services is replacing the drive belt. Belts are a common wear item and should be installed at the correct tension. A loose belt will slip and prevent the water pump from moving coolant fast enough through the engine and/or turn the fan fast enough to cool the coolant.

GO TO Chapter 8 for a detailed discussion of drive belts and the correct procedure for changing a belt and adjusting its tension.

The water pump on many late-model engines is driven by the engine's timing belt or chain. When replacing the water pump on these engines, always replace the timing belt. Make sure all pulleys and gears are aligned according to specifications when installing the belt.

Hoses

CUSTOMER CARE Hoses should be inspected regularly and replaced per the manufacturer's maintenance guidelines.

Replacement hoses must be made of the right material and have the correct diameter, length, and shape. The hose's part number is often printed on

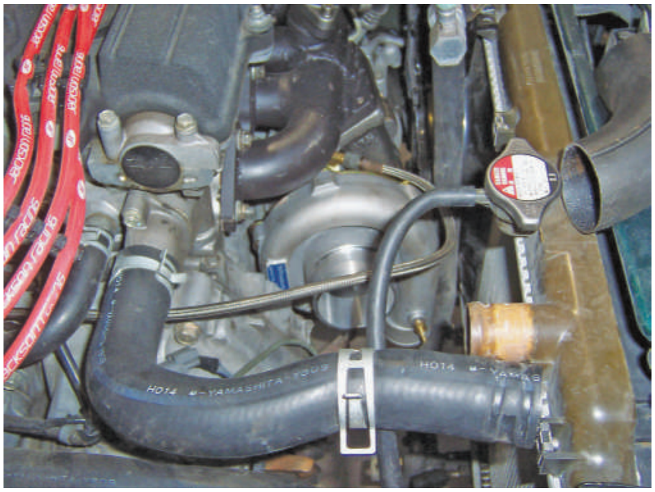


FIGURE 14-47 Nearly all radiator hoses have a part number painted on the outside of the hose. These should be used when replacing a hose.

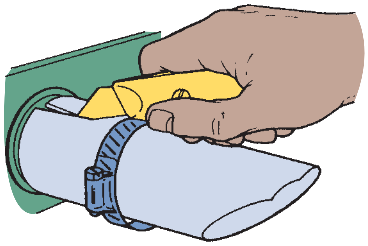


FIGURE 14-48 Cutting off an old hose.

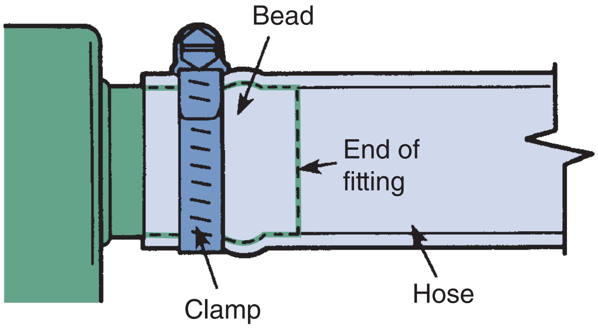


FIGURE 14-49 New clamps should be placed immediately after the bead of the fitting.

the outside of the hose and replacement hoses should correspond to those numbers **(Figure 14–47)**.

Nearly all OEM hoses are of the molded, curved design. Molded hoses designed to fit many applications are often sold. The hose is cut to fit a specific application. Some have printed cutoff marks on them to show where they should be cut. Others should be compared to the old hose for a cut reference.

Aftermarket hoses are either molded or flex types. A flex-type hose allows greater vehicle coverage per part number. Flex hoses are available in different lengths and diameters. They can flex or bend into most required shapes without causing a restriction. Flex hoses may not be desirable for some systems that require radical bends and shapes.

Rather than replacing heater hoses with the molded type, formable heater hoses are available. This hose design has a wire spine. The wire spine allows the hose to bend into a curve without collapsing at the bend. Once the desired shape is obtained, the hose is cut to length and then installed.

All cooling system hoses are basically installed the same way. The hose is clamped onto inlet/outlet nipples on the radiator, water pump, and heater.

When replacing a hose, drain the coolant system below the level that is being worked on. Loosen or carefully cut the old clamp. With a knife, carefully cut the end off of the old hose **(Figure 14–48)** so it can slide off its fitting. If the hose is stuck, do not pry it off. You could possibly damage the inlet/outlet nipple or the attachment between the end of the hose and the bead. Simply make more cuts in the hose.

Always clean the neck of the hose fitting or nipple with a wire brush or emery cloth after the old hose has been removed. Burrs or sharp edges can cut the hose and lead to premature failure. Dirty connections will prevent a good seal.

Dip the ends of the hose in coolant and slip the clamps over each end. Do not reuse clamps, even if they look good. Slip the hose over its fittings. In cold weather, the hose may be stiff; it can be soaked in warm water to make it more flexible. If the hose does not fit properly, remove it and reverse the ends. Then slide the clamps to secure the hose just behind the bead on the neck **(Figure 14–49)**. Tighten the clamp securely, but do not overtighten.

Hose Clamps Original equipment clamps are usually spring steel wires that are removed and replaced with special pliers. A worm drive hose clamp is often used as a replacement for many reasons. It provides even pressure around the outside of the hose. It is also easy to install and requires no special tools.

Rather than using steel clamps, some engines have thermoplastic clamps **(Figure 14–50)**. These heat-sensitive clamps are installed on the hose ends and a heat gun is used to shrink the clamp. The shrinking of the clamp tightens the connection. As the engine runs, the heat of the coolant further tightens the connection.

It is a good idea to readjust the clamp of a newly installed hose after a brief run-in period. The hose does not contract and expand at the same rate as the metal of the inlet/outlet nipple. Rubber hoses, warmed by the hot coolant and hot engine, will

Courtesy of Gates Corporation.

FIGURE 14-50 Thermoplastic clamps are tightened with a heat gun.

expand. When the engine cools, the fitting contracts more than the rubber, and the hose will not be as secure. This can result in cold coolant leaks at the inlet/outlet nipple. Retightening the clamp eliminates the problem.

Thermostat

When replacing the thermostat, the replacement should always have the same temperature rating as the original. Using a thermostat with a different opening temperature than was originally installed on a computerized engine will affect the operation of the fuel, ignition, and emissions control systems. This is due to the fact that the wrong thermostat can prevent the system from going into closed loop.

Replacement Markings on the thermostat normally indicate which end should face toward the radiator. Regardless of the markings, the sensored end must always be installed toward the engine.

When replacing the thermostat, also replace the gasket that seals the thermostat in place and is positioned between the thermostat housing and the block. Make sure the mating surfaces on the housing and block are clean and free of old gasket material **(Figure 14–51)**. Some housings are sealed with a liquid gasket. A thin line of the liquid gasket should be applied around the water passages, and the housing installed before the liquid dries.

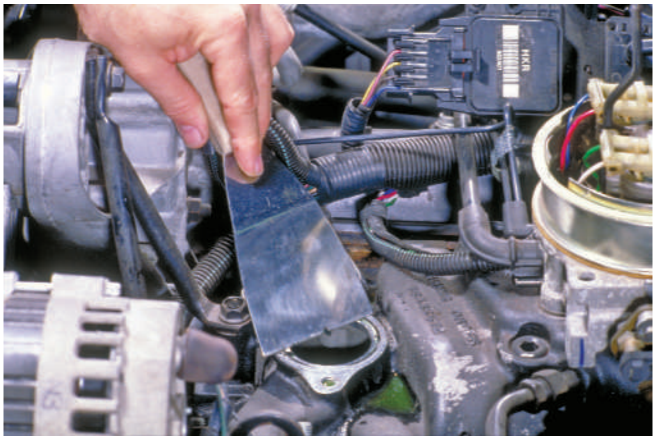


FIGURE 14-51 Make sure all old gasket material is removed before installing a new thermostat gasket and housing.

Sometimes there are locating pins or notches on the thermostat to position the thermostat in the block and housing **(Figure 14–52)**. Most thermostats and housings are sealed with gaskets or rubber seals. The gaskets may be a composition fiber material cut to match the thermostat opening and mounting bolt configuration of the housing or a rubber seal that fits around the outer edge of the thermostat. Thermostat gaskets generally come with an adhesive backing. The backing holds the thermostat securely centered in the mounting flange. This makes it easier to properly align the housing to the block.

Repairing Radiators

Most radiator leak repairs require the removal of the radiator. Coolant must be drained and all hoses and oil cooler lines disconnected. Bolts holding the cooling fans and radiator are then loosened and removed.

The actual radiator repair procedures depend on its construction and the type of damage. Most repairs are made by radiator specialty shops whose technicians have knowledge of such work. Many of today's radiators have plastic tanks, which are not repaired. If these tanks leak, they are replaced. If the radiator is badly damaged, it should be replaced.

SHOP TALK

Always refer to application charts or the service information when replacing a pressure cap to make sure that the new cap has the correct pressure range.

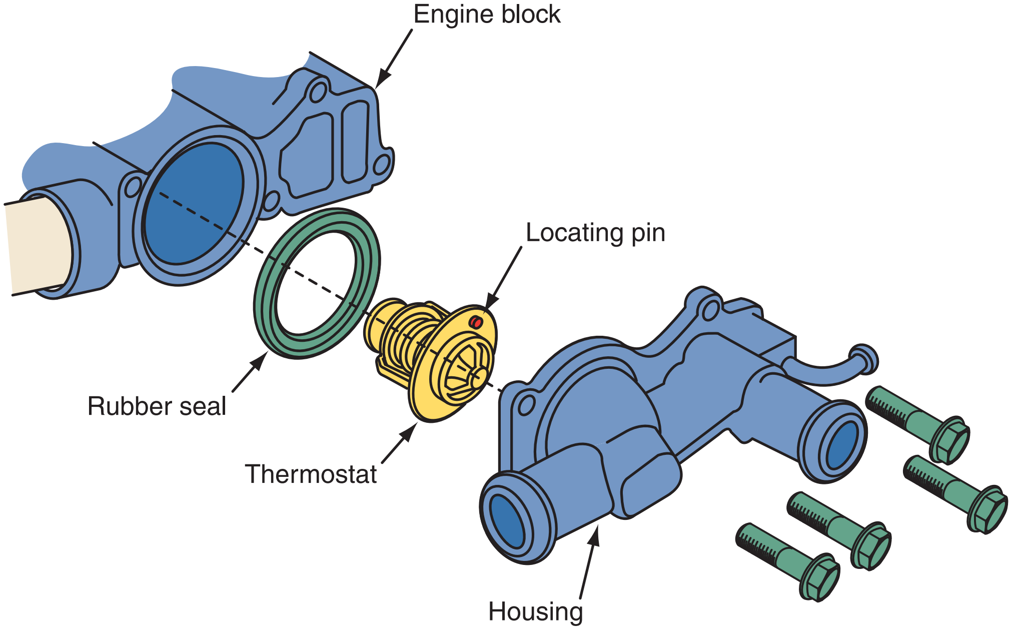


FIGURE 14-52 Normally there are locating pins on the thermostat that are used to position the thermostat in the block and housing.

> **Caution!** When working on the cooling system, for example, replacing the radiator, thermostat, or water pump, a certain amount of coolant will spill on the floor. The floor will become very slippery. Always immediately wipe up any coolant that spills to reduce or eliminate the chance of injury.

Replacing the Water Pump

When replacing a water pump, make sure the replacement is the correct one. Some engines use a clockwise driven pump and others turn the pump counter clockwise. Check for the correct part as the manufacturer can change designs while the pumps may look the same. Using the wrong pump can cause engine overheating.

Before replacing a water pump, the cooling system should be drained. Remove all parts that will interfere with the removal of the pump. This includes the drive belts, fan, fan clutch, fan shroud, and pump pulley. Special fan clutch tools are often required to remove the fan from water pump shaft **(Figure 14–53)**. Most pumps are bolted to the block. Loosen and remove the bolts in a crisscross pattern from the center outward. Insert a rag into the block opening and scrape off any remains of the old gasket. When replacing a water pump, always follow the procedures given by the manufacturer. Most often a coating of

FIGURE 14-53 Tools used to remove and install the fan clutch.

adhesive is applied to a new gasket before it is placed into position on the water pump. Some pumps are sealed to the block with an O-ring. Make sure the O-ring groove in the block is clean. When installing the O-ring, make sure it is totally inserted in the groove. Lubricate the O-ring to prevent it from tearing during installation. Position the pump against the block until it is properly seated. Install the mounting bolts and tighten them evenly in a staggered sequence to the torque specifications. Careless tightening can cause the pump housing to crack. Check the pump to make sure it rotates freely.

The water pumps on many late-model OHC engines are driven by the engine's timing belt. When replacing the water pump on these engines, always replace the timing belt. Make sure all pulleys and gears are aligned according to specifications when installing the belt.

Draining the Coolant

Part of a preventive maintenance program is changing the engine's coolant. This is done to prevent the coolant from breaking down chemically. When this happens, the coolant becomes too acidic.

Before draining the coolant, find the capacity of the system in the vehicle's specifications. This allows you to know what percentage of the coolant has been drained. Normally, 30 percent to 50 percent of the coolant will remain in the system.

Most radiators have a drain plug located in the lower part of a tank. Some have a petcock valve. Make sure the engine is cool before draining the coolant. Set the heater controls to the HOT position. Remove the radiator pressure cap. Remove the overflow reservoir and empty it into a catch can. Now, place the catch can under the drain plug and remove the plug. If the radiator has a petcock, open it fully. If the radiator does not have a drain plug, remove the lower radiator hose. Be careful not to force the hose away from the radiator. Twist the hose back and forth while pulling it off. If the hose is stuck, slip a thin screwdriver between the hose and the radiator tube to loosen it. After the coolant stops flowing out, install the drain plug or close the petcock.

Additional coolant can be drained through drain plugs in the engine block **(Figure 14–54)**. Place the catch can below the drain plug and remove the plug. Once the coolant has drained, replace the plug. Make sure to apply sealer on the threads of the plug. Clean up any spilled coolant.

Coolant Recovery and Recycle System Whenever coolant is drained, the used coolant should be drained and recycled by a coolant recovery and recycle machine. Typically additives are mixed into the used coolant during recycling. These additives either bind to contaminants in the coolant so they can be easily removed, or they restore some of the chemical properties in the coolant.

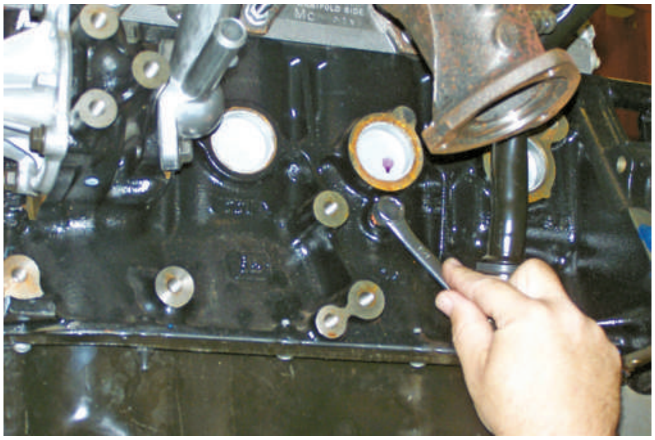


FIGURE 14–54 Most engines have drain plugs that allow for draining coolant out of the block.

Caution! Never pour engine coolant into a sewer or onto the ground. Used coolant is a hazardous waste and its disposal should be in accordance with the local laws and regulations.

Caution! Coolant can be very dangerous to children and animals. It has a sweet taste and can be deadly if ingested. Never keep coolant in an open container.

Flushing Cooling Systems

Whenever coolant is changed—and especially before a water pump is replaced—a thorough flushing should be performed. The bottom of the radiator will trap rust, dirt, and metal shavings. Draining the system will only remove the contaminants that are suspended in the drained fluid. Rust and scale will inevitably form in any cooling system. Buildups of these will affect the efficiency of the cooling system and can cause blockages inside the radiator. Flushing may not remove all debris. In fact if the radiator is plugged, the radiator should be removed and rebuilt or replaced.

The system can be flushed in many ways. Power flushing equipment forces the old coolant and

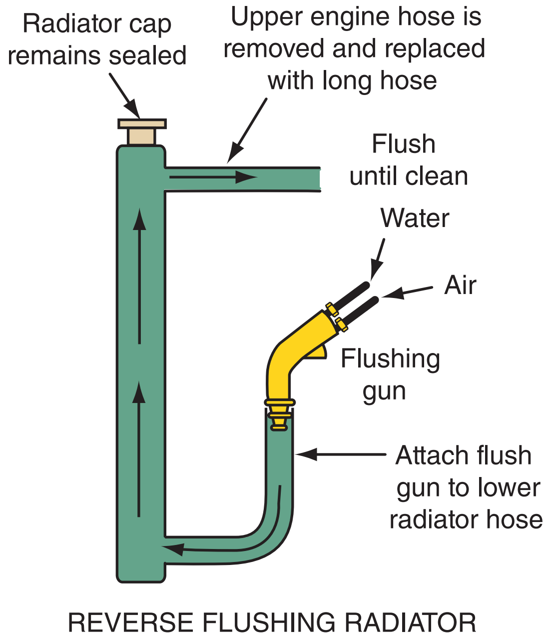


FIGURE 14-55 The typical setup for back flushing a cooling system.

contaminants out of the system. This function is often one of the operating cycles of a coolant exchanger. Back flushing forces clean water backward through the cooling system. The discharge of fluid carries away rust, scale, corrosion, and other contaminants. Flushing guns use compressed air to back flush the system and to break loose layers of dirt and other debris **(Figure 14–55)**. This method of flushing the system is not recommended on systems that use plastic and aluminum radiators. Check the service information for the proper way of cleaning the cooling system in the vehicle being serviced.

A simple way to flush the system is to drain it and fill it with water. The engine is then run and brought to its operating temperature. At this point the engine is shut down and allowed to cool. The water is then drained. These steps are repeated until the discharged fluid is clear. The clear fluid indicates that all of the old coolant has been removed. Once this occurs, the system is drained again and refilled with coolant.

Flushing Chemicals Many different flush chemicals are available. Before using any chemical, make sure it is safe for the type of radiator. Coolant exchangers often use chemicals as part of their flushing function. The typical procedure for using flushing chemicals is to drain the system. Then pour the chemical into the radiator and top off the radiator with water. Install and tighten the radiator cap. Now start the car and set the heater control to its hottest position. Allow the engine to run until it reaches normal operating temperature.

CUSTOMER CARE

Many additives, inhibitors, and quick-fix remedies are available for cooling systems. These include, but are not limited to, stop leak, water pump lubricant, engine flush, and acid neutralizers. Stop leak or sealers are often used to plug small leaks in the cooling system. These chemicals work to seal leaks in the radiator and engine (metal components). They do not seal leaking hoses and hose connections. Explain to your customers that caution should be exercised when using any additive. They must make sure the chemicals are compatible with their cooling system. For example, caustic solutions must never be used in aluminum radiators.

Then turn the engine off and allow it to cool. Once the engine has cooled, completely drain the radiator. If the flushing chemical requires a neutralizer, add it to the water remaining in the system and then refill the system with fresh coolant.

Refilling and Bleeding

After the cooling system has been drained and all services performed, the system needs to be refilled with the proper type and mixture of coolant. It is important that the correct type is put into the system. The color of the coolant does not necessarily indicate its purpose. Older inorganic acid coolants are green, extended-service coolants are often orange or yellow, while other coolants are often red, pink, or blue. The additives in long-life coolant are not chemically compatible with those in older green or red coolant; therefore, the system must be drained and refilled with the coolant specified by the vehicle manufacturer.

When refilling a system, determine the total capacity of the system. Fill the system with the correct coolant, then loosely install the radiator cap. Run the engine until it reaches operating temperature. Then turn it off and correct the level of the coolant. Tighten the radiator cap and run the engine again and check for leaks.

When refilling the system, be sure you get it completely full. Some systems are difficult to fill without

trapping air. Air pockets in the head(s), heater core, and below the thermostat can prevent proper coolant flow and cooling. If air is trapped in the engine block or cylinder head(s), it can also cause "hot spots." This can ruin the head gaskets, the cylinder walls, and the entire cooling system.

This is more of a problem on newer vehicles than older ones. In older cars, the top of the radiator sat higher than the rest of the cooling system. This positioning allowed air in the system to escape through the radiator cap. The radiator cap on many newer cars is lower than the rest of the cooling system. Because all liquids seek a natural level, that level may be above the cap and air gets trapped easily in other high places such as the block or head(s).

These new vehicles must be purged of the air after refilling. This can be done in many ways. Sometimes jacking up the front of the car will raise the radiator cap higher than the rest of the cooling system. With the radiator cap in its first lock position, start the engine. Allow it to run until the thermostat opens and the coolant circulates. Trapped air bubbles will naturally blow out the cap. When no more air escapes, shut off the engine and correct the coolant level. Then reinstall the radiator cap and tighten it to its fully locked position.

Each vehicle may have its own specific bleeding procedure. Some engines have air bleed valves located at the high point in the system **(Figure 14–56)**. Check the service information for their location. These valves allow air to escape while the system is being filled.

To use the air bleeds, make sure the engine is warm and the heater is fully on. Connect a hose to the end of the valves and place the open end in a catch can. Open all bleed valves. Slowly put the required amount of coolant into the radiator until the coolant begins to leak out of the valves. Then close the valves and top off the system.

FIGURE 14–56 Some engines have a bleed screw at a high point of the system to relieve the system of trapped air.

If the system does not have a bleeder valve, disconnect a heater hose at the highest point in the system. Once fluid flows steadily out of the hose, reconnect the hose. If the system was previously fit with a flushing Tee, remove its cap to purge the system. Always recheck the fluid level and make sure that all air is purged before putting the car back into service.

Many technicians use a vacuum fill system to refill the cooling system and prevent any air from staying trapped in the system. Vacuum fill systems connect to the radiator fill neck or expansion tank and to the shop's compressed air system. Once connected, the shop air creates a vacuum in the cooling system. Within minutes the system is purged of air and should hold a vacuum. If the vacuum bleeds off, there is a leak in the system. If the system holds a vacuum, the shop air is disconnected from the tool and a fill hose is connected and placed into a container of new coolant. Opening the valve on the vacuum fill tool forces the coolant into the system and fills it completely. Once the system is full, start the engine and make sure the coolant level is full.

Special Precautions for Hybrid Vehicles

Special coolants are required in most hybrids because the coolant cools the engine and the converter/inverter assembly. Cooling the converter/inverter is important, and checking its coolant condition and level is an additional check during preventive maintenance. The cooling systems used in some hybrids feature electric pumps and storage tanks. The tanks store heated coolant and can cause injury if the technician is not aware of how to carefully check them. To properly service the cooling systems on many hybrid vehicles, you will need a scan tool and the correct service information to perform even a coolant drain and refill.

The second generation Toyota hybrids have a system that heats a cold engine with retained hot coolant to provide reduced emissions levels. Hot coolant is stored in a container **(Figure 14–57)**. The coolant will circulate through the engine immediately after startup. The fluid also may circulate through the engine many hours after it is shut off. This fluid is under pressure and can cause serious burns to anyone who opens the system for inspection and/or repairs. To safely service this cooling system, the pump for the storage tank must be disconnected. The cooling system also is tied into the converter/inverter assembly. This presents a potential problem, because it is easy to trap air in the cooling system due to the path of coolant flow

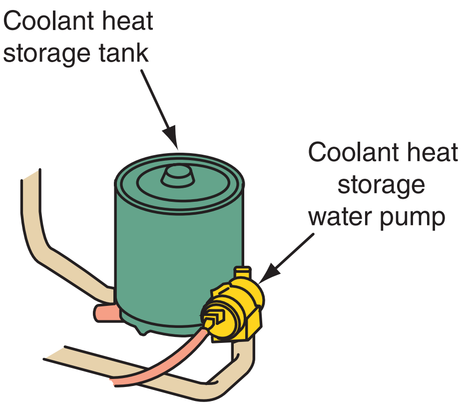


FIGURE 14-57 Toyota hybrids have a hot coolant storage container.

(Figure 14–58). To purge the system of air, there is a bleeder screw, and a scan tool is used to run the electric water pump.

PROCEDURE

The recommended procedure for draining and refilling the cooling system on a Toyota hybrid includes the following steps.

1. Remove the radiator's top cover and cap.
2. Disconnect the electrical connector on the water pump to prevent circulation of the coolant.
3. Connect a drain hose to the drain port on the bottom of the coolant heat storage tank, and then loosen the yellow drain plug on the tank.
4. Connect a drain hose to the drain port on the lower left corner of the radiator, and then loosen the yellow drain plug on the radiator.
5. Connect a drain hose to the drain port on the rear of the engine and loosen the drain plug.
6. After the coolant is drained, tighten the three drain plugs.
7. Reconnect the connector to the coolant heat storage tank's water pump.
8. Connect a hose to the radiator's bleeder valve port and place the other end of the hose into the coolant reservoir tank.
9. Loosen the radiator's bleeder plug.
10. Fill the radiator with the correct coolant.
11. Tighten the radiator's bleeder plug and install the radiator cap.
12. Connect the scan tool to DLC3.
13. Using the scan tool, run the water pump for the storage tank for 30 seconds.
14. Then loosen the radiator's bleeder plug.
15. Remove the radiator cap and top off the coolant in the radiator.
16. Repeat the refilling and bleeding sequence as often as necessary. Normally when no additional coolant is needed after the sequence, the system is bled.
17. Start the engine and allow it run for 1 to 2 minutes.
18. Turn off the engine and top off the fluid, if necessary.

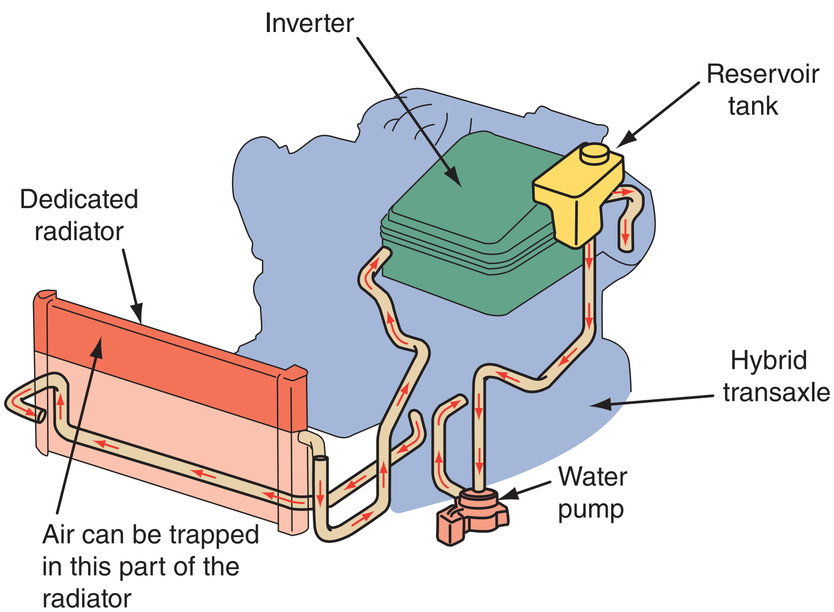


FIGURE 14-58 Since the reservoir tank and inverter is higher than the radiator cap, air is easily trapped during coolant refilling.

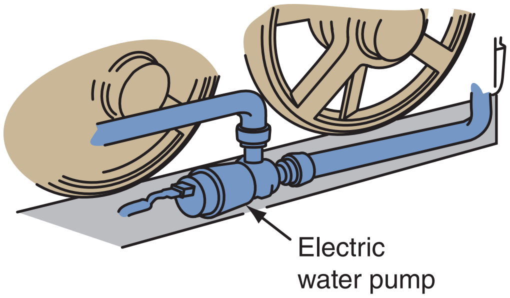


FIGURE 14–59 The electric water pump for the M/E cooling system on a Ford Escape Hybrid.

Ford hybrids have two separate cooling systems: One is for engine cooling and the other is for hybrid components, called the Motor Electronics (M/E) cooling system. The engine cooling system is conventional. The M/E cooling system uses an electric water pump **(Figure 14–59)** to move coolant through the inverter, transmission, and a separate radiator mounted next to the conventional radiator **(Figure 14–60)**. The M/E coolant reservoir is located behind the engine coolant reservoir. Although the two systems operate similarly, the M/E cooling system typically operates at lower pressures and temperatures. The fluid levels in both cooling systems must be maintained.

Air can easily be trapped in the M/E cooling system. The system has a bleeder screw at the top of the inverter **(Figure 14–61)**. When servicing the system, make sure the high-voltage system is isolated by having the service connector in the SERVICING/SHIPPING position. Also, wear lineman's gloves because the bleeder screw is very close to the high-voltage cables.

Coolant Exchangers

A coolant exchanger **(Figure 14–62)** is used to remove old coolant from the system and replace it with new coolant at the correct mixture. Some coolant exchangers will also leak test the system and flush it. Coolant exchangers are normally powered by shop air, although a few are powered by the vehicle's

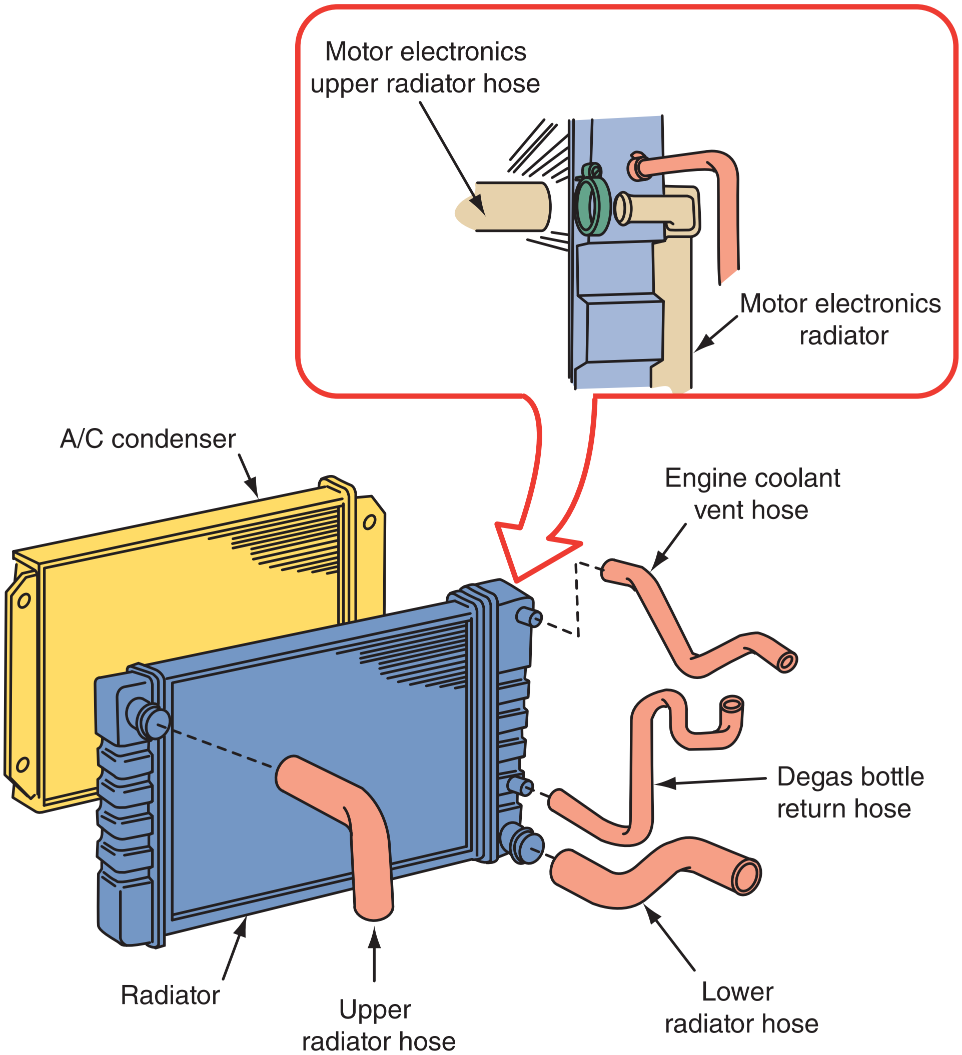


FIGURE 14–60 The radiator assembly for a Ford Escape Hybrid.

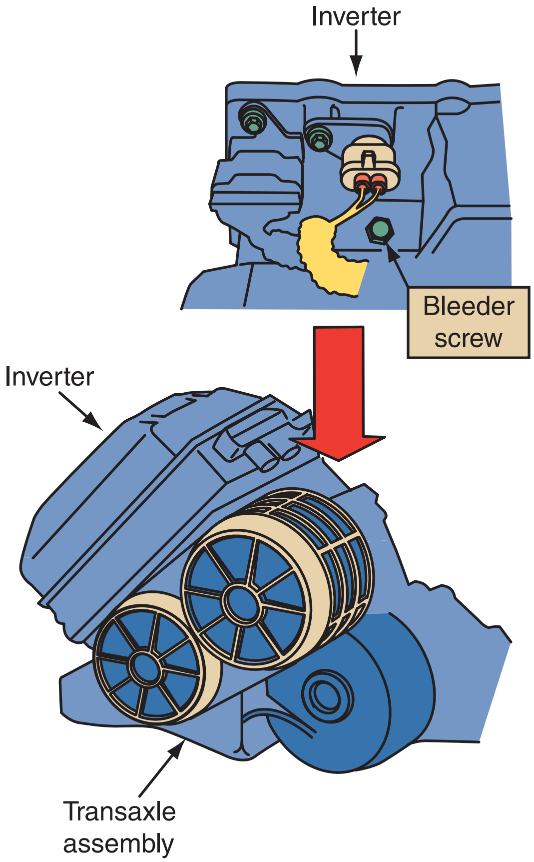


FIGURE 14-61 Location of the cooling system bleeder screw on a Ford Escape Hybrid.

FIGURE 14-62 A coolant exchanger collects the used coolant and replaces it with new coolant.

battery. Most exchangers move through their cycles with the engine off.

The machine is connected to the radiator filler neck, upper radiator hose, or a heater hose. The old coolant is siphoned out of the system and stored in a container. When all coolant is out, the low pressure in the cooling system siphons the new coolant mixture from another container. The entire process takes only a few minutes. When complete, the system is free of air and full of coolant.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2006	**Make:** Ford	**Model:** F150	**Mileage:** 173,502	**RO:** 18082
Concern:	Engine overheats. Coolant temp gauge reads high. Customer states gauge went up to the red on highway. No signs of coolant leaks. Customer replaced thermostat; still overheats.			
Given this concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				
Cause:	Checked coolant level, system was low. Refilled system and pressure tested; no leaks found. Engine ran and eventually overheated. Radiator and hoses were cold. Removed and tested thermostat. Thermostat tested good. Customer approved additional time to remove water pump. Found water pump drive shaft broken.			
Correction:	Replaced water pump and refilled cooling system. Engine temperature normal under all driving conditions.			

KEY TERMS

Blowby
Dry sump
Electrochemical degradation (ECD)
Electrolysis
Expansion tank
Fan clutch
Pressure relief valve
Recovery tank
Rotor-type oil pump
Sludge
Thermostat
Wet sump

SUMMARY

- An engine's lubricating system must provide an adequate supply of oil to cool, clean, lubricate, and seal the engine. It also must remove contaminants from the oil and deliver oil to all necessary areas of the engine.
- Engine oil is stored in the oil pan or sump. The oil pump draws the oil from the sump and passes it through a filter where dirt is removed. The oil is then moved throughout the engine via oil passages or galleries. After circulating through the engine, the oil returns to the sump.
- An oil pump is a positive displacement pump and needs a pressure relief valve to prevent high pressures during high engine speeds.
- All of the oil that leaves the oil pump is directed to an oil filter.
- Excessive oil consumption can result from external and internal leaks or worn piston rings, valve seals, or valve guides. Internal leaks allow oil to enter the combustion chamber where it is burned.
- *Blowby* is a term used for the gases that escape the combustion chamber and enter the crankcase.
- When oil oxidizes, chemical compounds in the oil begin to chemically break down and solidify and form sludge.
- The fluid used as coolant today is a mixture of water and ethylene glycol-based antifreeze/coolant.
- A water pump moves the coolant through the system.
- The radiator transfers heat from the engine to the air passing through it.
- The thermostat attempts to control the engine's operating temperature by routing the coolant either to the radiator or through the bypass, or sometimes a combination of both.
- Radiator pressure caps keep the coolant from splashing out of the radiator and keep the coolant under pressure.
- For every pound of pressure put on the coolant, the boiling point is raised about 3 °F (1.6 °C).
- Coolant flows from the engine to the radiator and from the radiator to the engine through radiator hoses.
- A temperature indicator is mounted in the dashboard to alert the driver of an overheating condition.
- A hot liquid passenger heater is part of the engine's cooling system.
- Radiators for vehicles with automatic transmissions have a sealed oil cooler located in the coolant outlet tank.
- The cooling fan delivers additional air to the radiator to maintain proper cooling at low speeds and idle.
- To save engine power and reduce noise levels, most late-model vehicles have an electrically driven cooling fan.
- The basic procedure for testing a vehicle's cooling system includes inspecting the radiator filler neck and the overflow tube for dents and other obstructions, and testing for external and internal leaks.
- The pressure cap should hold pressure within its range for 1 minute.
- Hoses should be checked for leakage, swelling, and chafing. Any hose that feels mushy or extremely brittle or shows signs of splitting when it is squeezed should be replaced.
- The majority of water pump failures are attributed to leaks of some sort. Other failures can be attributed to bearing and shaft problems and an occasional cracked casting.
- Electrolysis removes the protective layer on the inside of the radiator tubes, which can lead to serious engine failures. It occurs when there is improper grounding of electrical accessories and equipment.
- Engine overheating can cause detonation, preignition, blown head gasket, OHC cam seizure and breakage, blown hoses, radiator leaks, cylinder damage due to swelling pistons, sticky exhaust valve stems, and engine bearing damage.
- A radiator pressure test can help identify the source of any leak in the cooling system as well as check the operation of a pressure cap.
- Internal leaks can be verified with a combustion leak tester.
- When replacing a thermostat, the replacement should always have the same temperature rating as the original.
- Hybrid vehicles typically require a special coolant because the cooling system also cools the inverter assembly. Hybrids also require special service procedures.

REVIEW QUESTIONS

Short Answer

1. What is the most efficient way to increase a radiator's efficiency?
2. Explain why a pressure-relief valve is needed in an automotive oil pump.

3. List five problems that can be caused by engine overheating.
4. Describe the procedure for using air bleed valves to purge air out of a cooling system.
5. Describe the simple test used to determine whether the water pump is providing good circulation.

True or False

1. *True or False?* The presence of air in the cooling system indicates the head gasket is faulty.
2. *True or False?* Oil pressure is determined by whether the pump is a gear type or rotor type and by oil clearances, the pump's pressure regulator valve, and oil viscosity.
3. *True or False?* To eliminate the drain of engine power during times when cooling fan operation is not needed, many of today's belt-driven fans have a fan clutch that prevents the operation of the fan when the engine and radiator are heated up.

Multiple Choice

1. Which of the following is a function of the engine's lubrication system?
   a. Holds an adequate supply of oil
   b. Removes contaminants from the oil
   c. Delivers oil to all necessary areas of the engine
   d. All of the above
2. For every pound of pressure put on engine coolant, the boiling point of the coolant is raised about ___.
   a. 2 °F (1.1 °C)
   b. 3 °F (1.6 °C)
   c. 4 °F (2.2 °C)
   d. 5 °F (2.7 °C)
3. Which is not a typical method of driving the water pump?
   a. Accessory drive belt
   b. Electric motor
   c. Hydraulic motor
   d. Timing belt
4. Which of the following is not an effective way to determine if an engine has an internal coolant leak?
   a. Performing a pressure test on the system
   b. Visually inspecting the exhaust, coolant, and engine oil
   c. Using a dye penetrant and black light
   d. Using a combustion leak tester
5. Cooling system hoses should be replaced when they are ___.
   a. hard (brittle)
   b. soft (spongy)
   c. swollen
   d. all of the above
6. Which of the following is not a true statement about thermostats?
   a. Faulty thermostats are often the cause of air pockets in the coolant passages.
   b. They can also cause an increase in fuel consumption and poor engine performance.
   c. If the thermostat is stuck open, the coolant may not reach the desired temperature because it is cooled before it gets hot.
   d. If a thermostat is stuck closed, coolant will not flow between the engine and radiator and the engine will quickly overheat.

ASE-STYLE REVIEW QUESTIONS

1. An engine overheats in traffic but is fine when driving: Technician A says a faulty thermostat may be the cause. Technician B says the fan clutch could be the cause. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. Technician A says that excessive engine-oil consumption can be caused by low oil levels. Technician B says that excessive oil consumption can be caused by worn valve guides. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. While checking for conditions that might cause coolant electrolysis: Technician A places the positive lead of a voltmeter into the coolant and connects the negative lead to a ground. Technician B checks for the presence of voltage in the coolant with the ignition off. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

4. When discussing oil consumption: Technician A says using one-quart of oil every 2,000 miles is acceptable. Technician B says oil consumption may increase depending on driving conditions. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Technician A says that if the PCV valve or connecting hoses become clogged, excessive pressure will develop in the crankcase and can cause oil leaks. Technician B says that if the PCV valve or connecting hoses become clogged, oil may be pushed into the air cleaner or cause it to be drawn into the intake manifold. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. While bleeding air from a cooling system: Technician A loosens a heater hose at its highest point. Technician B uses air bleed valves. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. While diagnosing an engine that overheats after frequent hard accelerations: Technician A checks for a collapsed lower radiator hose. Technician B checks the cooling fan electrical circuit. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. While performing a cooling system service on a hybrid vehicle: Technician A says it may be necessary to connect a scan tool to the vehicle. Technician B says it may be necessary to disable the high-voltage system before servicing the engine. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. While discussing the causes of low engine oil pressure: Technician A says that contaminated and old engine oil could be the cause. Technician B says that a stuck pressure relief valve could be the cause. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While diagnosing the cause of air bubbles in the coolant recovery tank: Technician A checks for a bad head gasket. Technician B checks the radiator cap. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

SECTION 3

ELECTRICITY

CHAPTER 15

BASICS OF ELECTRICAL SYSTEMS

There is often confusion concerning the terms *electrical* and *electronic*. In this book, electrical and electrical systems refer to wiring and electrical parts, such as motors, lights, and other basic components. **Electronics** means components that use solid state integrated circuits, such as computers and other modules. Electronic parts are characterized by the use of transistors, diodes, and circuits constructed of layers of conducting material in circuit boards. Electronic items are used to control engine and many other vehicle systems.

OBJECTIVES

- Explain the basic principles of electricity.
- Define the terms normally used to describe electricity.
- Use Ohm's law to determine voltage, current, and resistance.
- List the basic types of electrical circuits.
- Describe the differences between a series circuit and a parallel circuit.
- Name the various electrical components and their uses in electrical circuits.
- Describe the different kinds of automotive wiring.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2002	**Make:** Dodge	**Model:** Ram 1500	**Mileage:** 155,581	**RO:** 15078
Concern:	Customer installed a light bar. The lights do not look as bright as they should.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

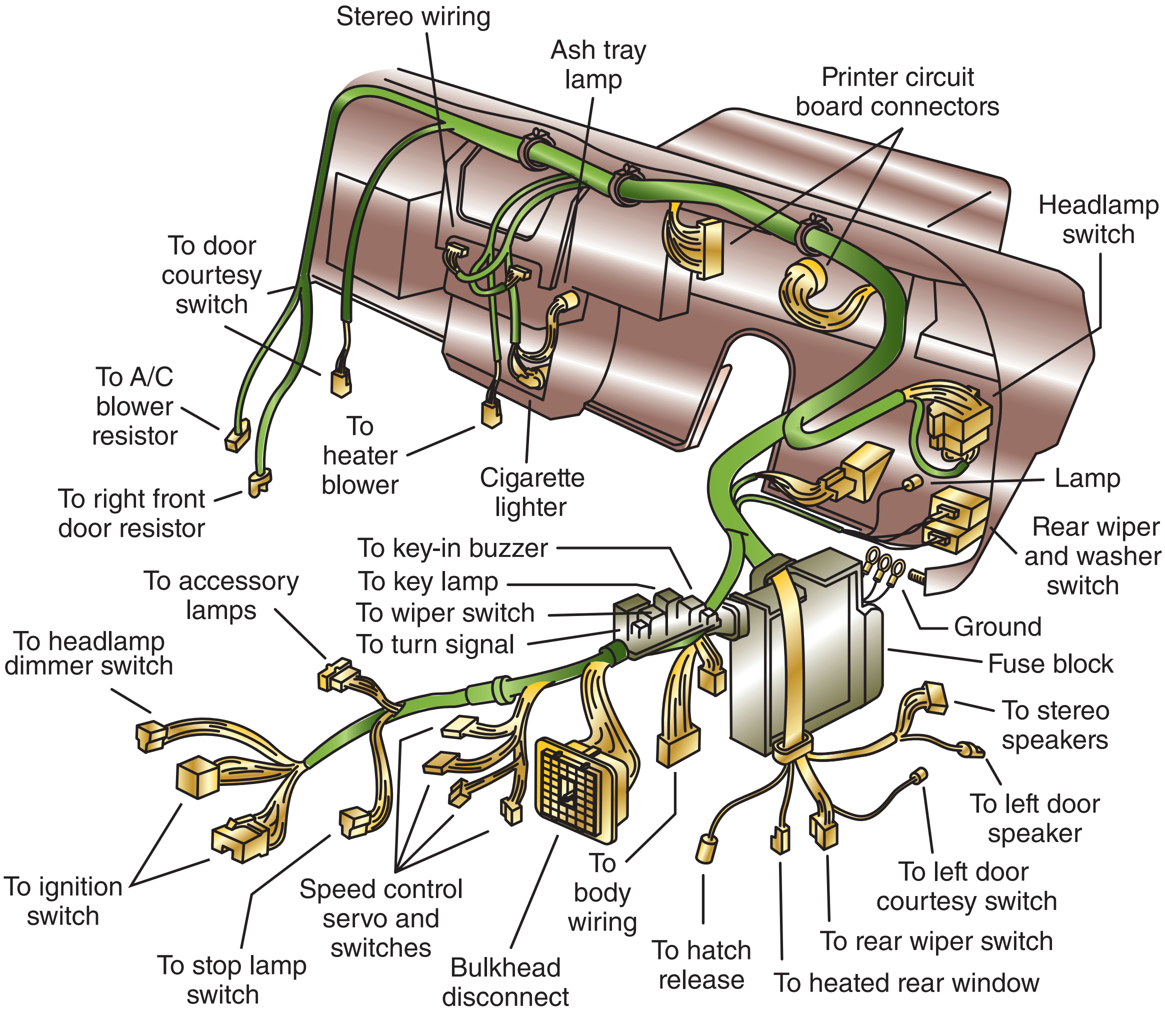


FIGURE 15–1 An example of common electrical components of their associated wiring.

Electronic systems involve many small parts that are assembled together and not serviced individually. Electrical circuits and parts can, typically, be serviced individually.

A good understanding of electrical principles is important for properly diagnosing any system that is monitored, controlled, or operated by electricity **(Figure 15–1)**.

Basics of Electricity

Perhaps the one reason it is difficult to understand electricity is that its action is not usually seen. By knowing what it is and what it is *not*, you can easily understand it. Electricity is not magic! It is something that takes place or can take place in everything you know. It not only provides power for lights, TVs, stereos, and refrigerators, it is also the basis for the communications between our brain and the rest of our bodies.

The effects of electricity can be seen, felt, heard, and smelled. One of the most common displays of electricity is a lightning bolt. Lightning is electricity—a large amount of electricity! The power of lightning is incredible. Other than lightning, electricity is not normally seen because it is the movement of extremely small objects that move at the speed of light (186,282.397 miles [299,792,458 meters] per second).

Flow of Electricity

Electricity is the result of the flow of electrons from one atom to another **(Figure 15–2)**. The release of energy as one electron leaves the orbit of one atom and jumps into the orbit of another is electrical energy. The key to creating electricity is to provide a reason for the electrons to move to another atom.

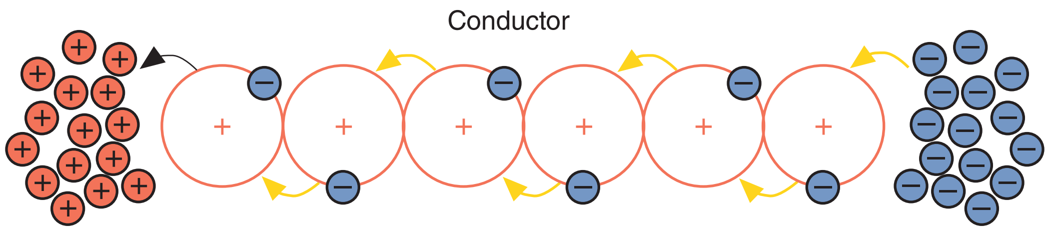


FIGURE 15-2 Electricity is the flow of electrons from one atom to another.

There is a natural attraction of electrons to protons. Electrons have a negative charge and are attracted to something with a positive charge. When an electron leaves the orbit of an atom, the atom then has a positive charge. This is caused by a hole left open by the exiting electron. An electron moves from one atom to another because the atom next to it appears to be more positive than the one it is orbiting around.

An electrical power source provides for a more positive charge and, to allow for a continuous flow of electricity, it supplies free electrons. To have a continuous flow of electricity, three things must be present: an excess of electrons in one place, a lack of electrons in another place, and a path between the two places.

Two power or energy sources are used in an automobile's electrical system. These are based on a chemical reaction and **magnetism**. Magnetism is produced by the controlled movement of electrons. Magnetism is used to generate electricity in many automotive systems.

A car's battery is a source of chemical energy **(Figure 15–3)**. The chemical reaction in a battery provides for an excess of electrons in one place and a lack of electrons in another. Batteries have two terminals, a positive and a negative. Basically, the negative terminal is the outlet for the electrons and the positive is the inlet for the electrons. The chemical reaction in a battery causes a lack of electrons at the positive (+) terminal and an excess at the negative (−) terminal. This creates an electrical imbalance, causing the electrons to flow from one terminal to the other through the path connecting the two terminals.

This chemical process continues to provide electrons until the chemicals become weak. At that time, either the battery has run out of electrons or all the protons are mated with an electron. When this happens, there is no longer a reason for the electrons to move to the positive side of the battery, as it no longer looks more positive. Fortunately, the vehicle's charging system restores the battery's supply of electrons. This allows the chemical reaction to continue indefinitely.

Electricity and magnetism are interrelated. One can be used to produce the other. Moving a wire (a conductor) through an already existing magnetic field (such as a permanent magnet) can produce electricity. This process of producing electricity through magnetism is called **induction**. The heart of a vehicle's charging system is the AC generator **(Figure 15–4)**.

FIGURE 15-3 An automotive battery.

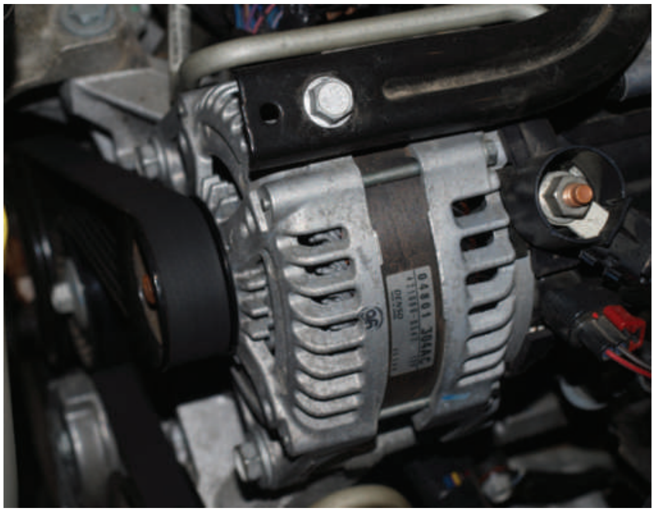


FIGURE 15-4 A late-model generator.

A magnetic field, driven by the crankshaft via a drive belt, rotates through a coil of wire, producing electricity.

Electricity is also produced by photoelectrical, thermoelectrical, and piezoelectrical reactions. These technologies are used by many of the sensors found in today's automobiles.

Electrical Terms

Electrical **current** describes the movement or flow of electricity. The greater the number of electrons flowing past a given point in a given amount of time, the more current the circuit has. The unit for measuring electrical current is the **ampere**, usually called an amp. The term *ampere* is used to honor André Ampère, who studied the relationship between electricity and magnetism. The instrument used to measure current in a circuit is called an ammeter.

When electricity flows, millions of electrons are moving past any given point at the speed of light. The electrical charge of any one electron is extremely small. It takes millions of electrons to make a charge that can be measured.

There are two types of current: **direct current (DC)** and **alternating current (AC)**. In direct current, the electrons flow in one direction only. In AC, the electrons change direction at a fixed rate. Most automotive systems rely on DC current and the current used in homes and buildings is AC. However, some automotive parts generate or use AC.

For the purposes of this book and for your own understanding of electricity, current flow **(Figure 15–5)**, regardless of whether it is AC or DC, is described as moving from a point of higher potential (voltage) to a point of lower potential (voltage).

When an electrically positive substance is separated, but close to, an electrically negative substance, a field of attraction is present between the two substances. The resulting force of this attraction is called electrical pressure or tension. This attraction field is an electrostatic field. The strength of the field depends on the distance separating the two substances and the difference of the electrical potential of the substances.

Voltage is the potential difference between the two points and best described as electrical pressure **(Figure 15–6)**. It is the force developed by the attraction of the electrons to protons. The stronger the attraction or the greater the potential difference, the higher the pressure or voltage. Voltage may also be called **electromotive force (EMF)** and is measured in units called volts. These units of measure for electrical pressure are named to

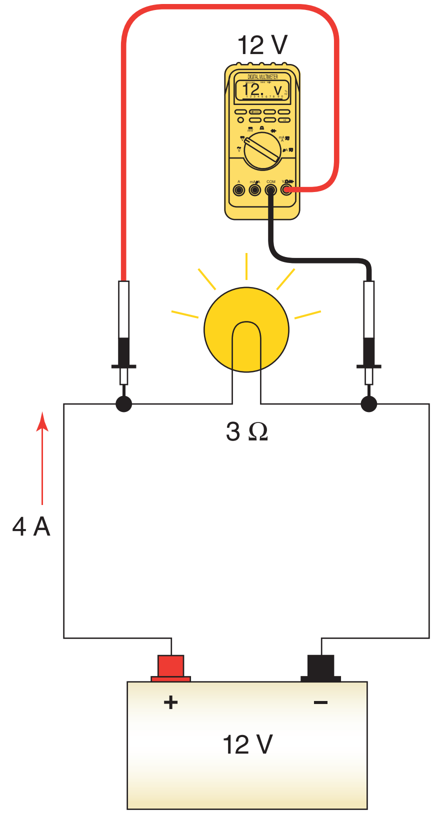


FIGURE 15-5 Current moves from a point of higher potential to a point of lower potential and remains constant in a series circuit.

SHOP TALK

Current flow may be expressed in coulombs. One coulomb represents the amount of electric charge moved by 1 ampere of current in 1 second. One ampere represents 6.25×10^{18} electrons passing through a point in one second.

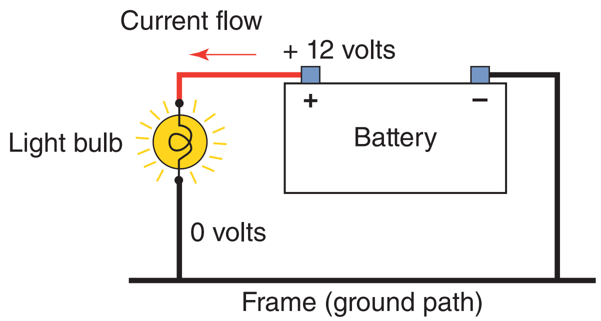


FIGURE 15-6 Voltage is electrical pressure.

FIGURE 15–7 Common symbol for an ohm.

honor Alessandro Volta, who, in 1800, made the first electrical battery.

When any substance flows, it meets **resistance**. The resistance to electrical flow can be measured. The resistance to current flow produces heat. This heat can be measured to determine the amount of resistance. A unit of measured resistance is called an **ohm**. The common symbol for an ohm is shown in **Figure 15–7**. Resistance can be measured by an instrument called an ohmmeter.

To visualize electricity as something we are familiar with, many people use water as an analogy. Water pressure, supplied by the city water system or by a pump, is similar in concept to voltage. Electron flow or amperage is similar to the amount of water that flows from a hose or faucet. The size of a water hose or faucet opening is similar to electrical resistance. Turning a faucet on slightly allows only a little bit of water to flow through, which has the effect of resistance to flow. Opening the faucet further is like reducing the resistance in a circuit and allowing more current to flow.

Alternating Current

The value of the voltage in an AC circuit constantly changes, as does the direction of the current. If a graph is used to represent the amount of DC voltage available from a battery during a fixed period, the line on the graph will be flat, which represents a constant voltage. If AC voltage is shown on a graph, it will appear as a **sine wave (Figure 15–8)**. The sine wave shows AC changing in amplitude (strength) and direction. The highest positive voltage equals the highest negative voltage. The movement of the AC from its peak at the positive side of the graph to the negative side and then back to the positive peak is commonly referred to as “peak-to-peak” value. This value represents the amount of voltage available at a point. During each complete cycle of AC, there are always two maximum or peak values, one for the positive half-cycle and the other for the negative half-cycle. The difference between the peak positive value and the peak negative value is used to measure AC voltages **(Figure 15–9)**.

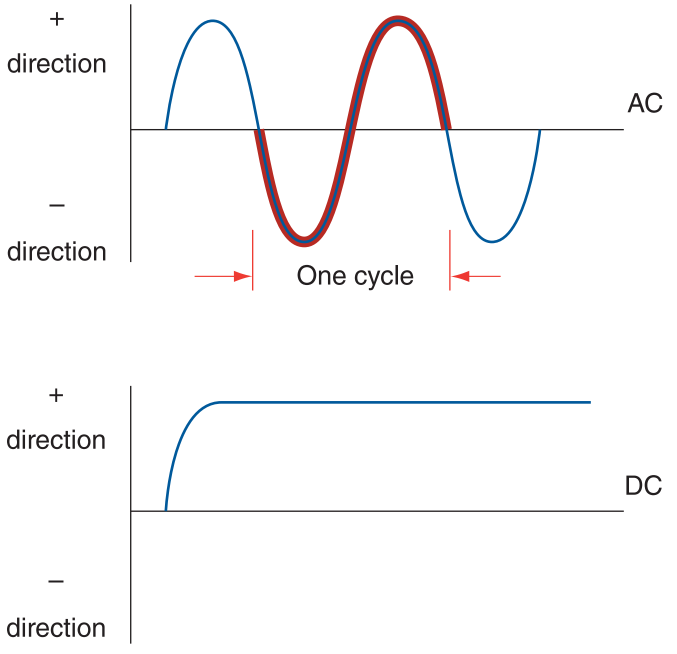


FIGURE 15–8 The difference between DC and AC.

AC does not have a constant value; therefore, as it passes through a resistance, nearly 29 percent less heat is produced when compared to DC. This is one reason that AC is preferred over DC when powering motors and other electrical devices.

AC has an effective value of 1 ampere when it produces heat in a given resistance at the same rate as does 1 ampere of DC. The effective value of alternating current is equal to 0.707 times its maximum or peak current value. Because the current is caused by an alternating voltage, the ratio of the effective voltage to the maximum voltage is the same as the ratio of the effective current to the maximum current, or 0.707 times the maximum value. AC voltage measurements are often expressed in terms of root mean square (RMS) values.

When AC is applied to a resistance, as the voltage changes in value and direction, so does the current. In fact, the change of current is in phase with the change in voltage. An “in-phase” condition exists when the sine waves of voltage and current are precisely in step with one another. The two sine waves go through their maximum and minimum points at the same time and in the same direction. In some circuits, several sine waves can be in phase with each other.

If a circuit has two or more voltage pulses but each has its own sine wave that begins and ends its cycle at a different time, the waves are “out of phase.” If two sine waves are 180 degrees out of

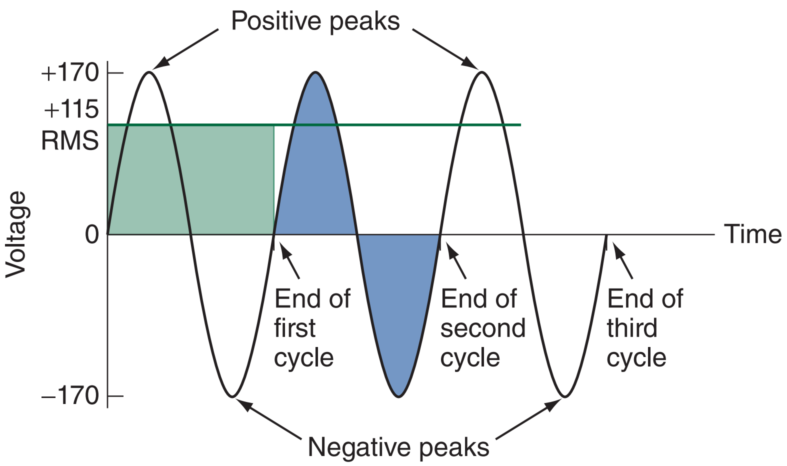


FIGURE 15–9 The action and measurement of alternating current.

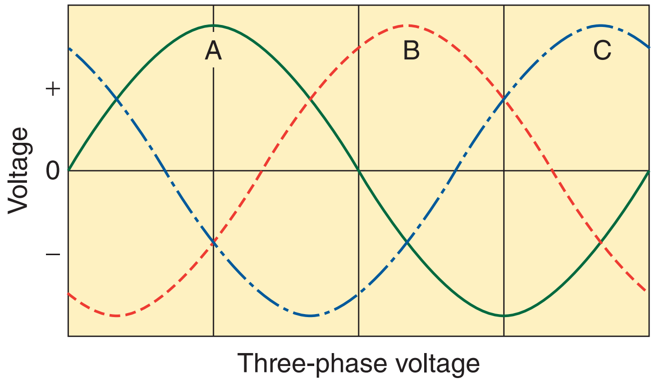


FIGURE 15–10 The sine waves of three-phase AC.

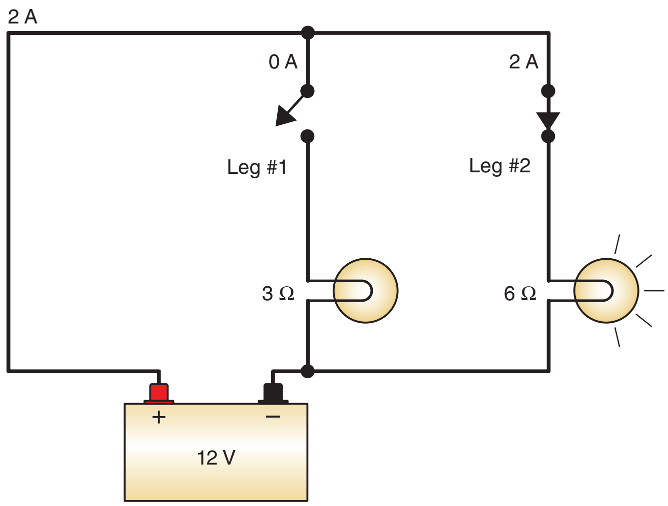


FIGURE 15–11 Conductors are drawn as lines from one point to another.

phase, they will cancel each other out if they have the same voltage and current. If two or more sine waves are out of phase but do not cancel each other, the effective voltage and current are determined by the position and direction of the sine wave at a given point within the circuit **(Figure 15–10)**.

Circuit Terminology

An electrical circuit is considered complete when there is a path that connects the positive and negative terminals of the electrical power source. A completed circuit is called a **closed circuit**, whereas an incomplete circuit is called an **open circuit**. When a circuit is complete, there is **continuity**. This means that there is a continuous or complete path between two points for current to flow through. Conductors are drawn in electrical diagrams as a line connecting two points, as shown in **Figure 15–11**.

In a complete circuit, the flow of electricity can be controlled and applied to do work, such as light a headlamp or run a motor. Components that use electrical power control the current in the circuit and convert electrical energy into another form of energy. These components are referred to as electrical loads. Loads are drawn in electrical diagrams as a symbol representing the part or as a resistor. The typical drawing of a resistor is shown in **Figure 15–12**.

The total resistance in a circuit determines how much current will flow through it. If voltage remains constant, as circuit resistance goes up, current goes down. Conversely, if resistance goes down, current will go up. The energy used to allow current to flow through the load is measured in volts and is called voltage drop.

FIGURE 15–12 Symbol for a resistor.

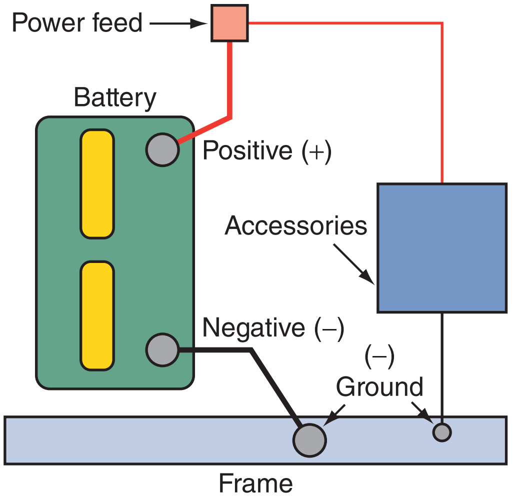


FIGURE 15–13 Most automotive electrical circuits use the chassis as the conductor for the negative side of the battery.

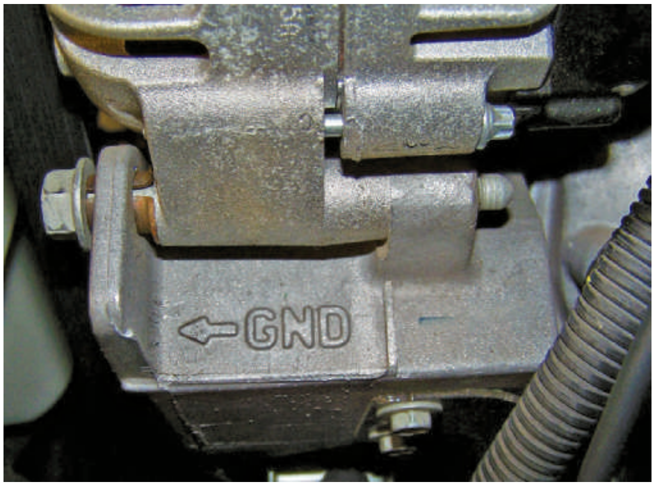


FIGURE 15–14 Many electrical parts are grounded through their mounting to the engine, transmission, or frame.

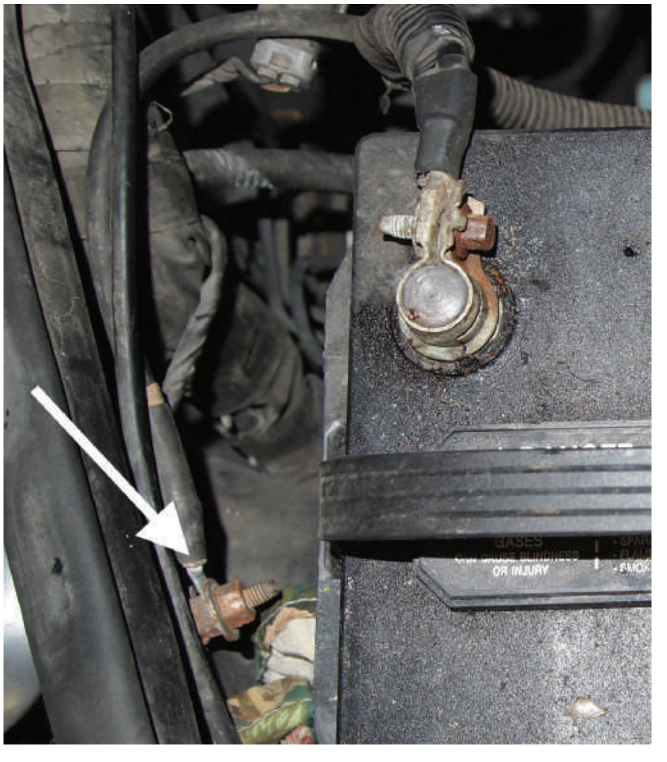


FIGURE 15–15 Chassis ground connections for a very dirty battery.

In a circuit, amperage stays constant but the voltage drops as it moves through a load. Measuring voltage drop tells how much energy is being used by the load or any other component or connection in the circuit.

Power is the rate of doing electrical work and it is expressed in watts. One watt is equal to 1 volt multiplied by 1 ampere. The formula for determining the power output of a load is the amount of current through the load multiplied by the voltage used by the load.

Grounding the Load Most automotive electrical circuits use the chassis as a conductor for the negative side of the battery, as shown in **Figure 15–13.** Current passes from the battery, through the load, through the metal frame, and back to the battery. Using the frame as a return path or ground eliminates the need for a separate ground wire at each component. Without grounding parts to the frame, hundreds of additional wires would be needed to complete the individual circuits.

Major components, such as the engine block and transmission case, also have a grounding wire connected to the frame. This provides a ground circuit for parts that are mounted directly to the block **(Figure 15–14)** or transmission. Other parts have a separate ground wire that connects them to the frame, engine, or transmission. These connections are called **chassis ground** connections. The wire that serves as the contact to the chassis is commonly called the **ground wire** or lead **(Figure 15–15)**.

In wiring diagrams, chassis ground connections are drawn to show the type of ground connection for that part. When the ground is made through the mounting of the component, the connection is represented in the drawing A **(Figure 15–16A).** When the ground is made by a wire that connects to the chassis, the connection is shown as B **(Figure 15–16B)**.

Some circuits, particularly computer sensor circuits, often use floating or isolated grounds **(Figure 15–16C).** These ground circuits are typically shown as reference low in wiring diagrams. In these

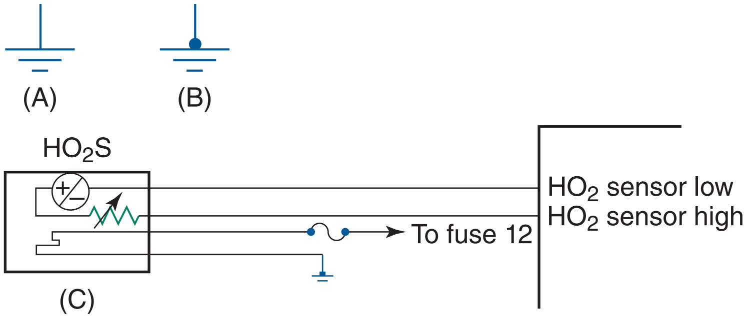


FIGURE 15–16 Symbols for grounds: (A) made through the component's mounting, (B) made by a remote wire, and (C) is an example of a component's circuit with a remote ground.

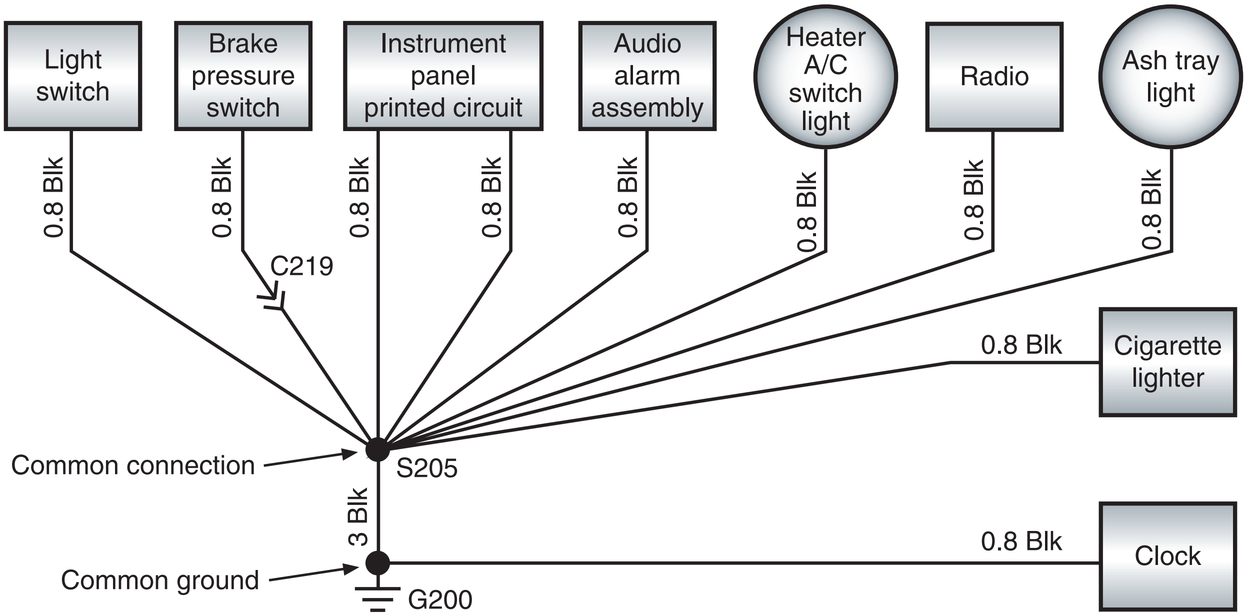


FIGURE 15–17 Common connections and splices are used to reduce the number of wires and connectors.

circuits, the ground is not directly attached to chassis ground. Instead, inside of the computer, the reference low circuit floats above chassis ground by passing through a fixed resistance. This allows the computer to use a fixed ground reference voltage that is not affected by noise generated by other, often high-current circuits. For example, inside of the computer, the reference low circuit "ground" voltage may be 0.75V (75 mV) above chassis ground voltage. The computer can then compare the sensor signal high, which may be a 5 to 12V signal, to the 0.75V low reference.

The increased use of plastics and other nonmetallic materials has made electrical grounding more difficult. To ensure good grounding, some manufacturers use a network of common grounding terminals and wires **(Figure 15–17)**.

Ohm's Law

In 1827, a German mathematics professor, Georg Ohm, published a book that included his explanation of the behavior of electricity. His thoughts have become the basis for the understanding of electricity. He found it takes 1 volt of electrical pressure to push 1 ampere of electrical current through 1 ohm of resistance. This statement is the basic law of electricity and is known as **Ohm's law**.

A simple electrical circuit is a load connected to a voltage source by conductors. The resistor could be a fog light, the voltage source could be a battery, and the conductor could be a copper wire **(Figure 15–18)**.

In any electrical circuit, current (*I*), resistance (*R*), and voltage (*E*) are mathematically related. This relationship is expressed in a mathematical statement of

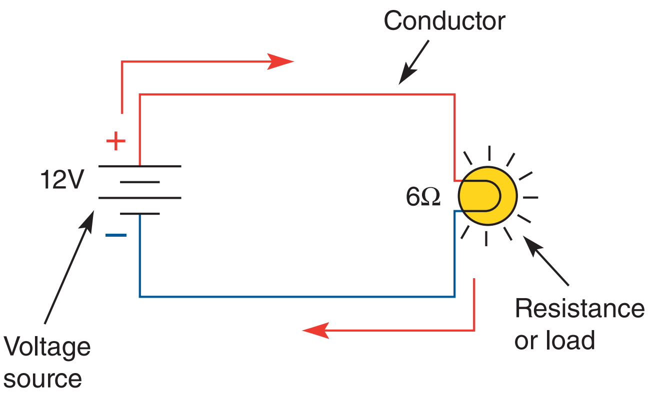


FIGURE 15–18 A simple circuit consists of a voltage source, conductors, and a resistance or load.

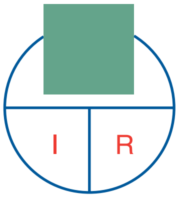


FIGURE 15–20 To find voltage, cover the *E* and use the exposed formula.

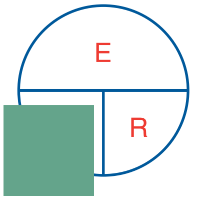


FIGURE 15–21 To find current, cover the *I* and use the exposed formula.

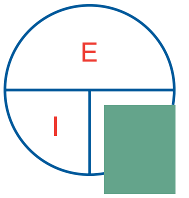


FIGURE 15–22 To find resistance, cover the *R* and use the exposed formula.

Ohm's law. Ohm's law can be applied to the entire circuit or to any part of a circuit. When any two factors are known, the third factor can be found. Using the circle shown in **Figure 15–19**, you can find the formula for calculating the unknown value. By covering the value you need to find, the necessary formula is shown in the circle.

- To find voltage, cover the *E* **(Figure 15–20)**. The voltage (*E*) in a circuit is equal to the current (*I*) in amperes multiplied by the resistance (*R*) in ohms.
- To find current, cover the *I* **(Figure 15–21)**. The current in a circuit equals the voltage divided by the resistance.
- To find resistance, cover the *R* **(Figure 15–22)**. The resistance equals the voltage divided by the current.

It is very important to understand Ohm's law. This includes understanding the relationships between volts, amps, and resistance. For example, when working with resistances in a series circuit, Ohm's law allows for adding the resistances together to determine total circuit resistance. Resistances can be added together because they are like terms. This means that voltages also can be added together, just as amperages can be added together. Because volts and amps are not like terms they cannot be

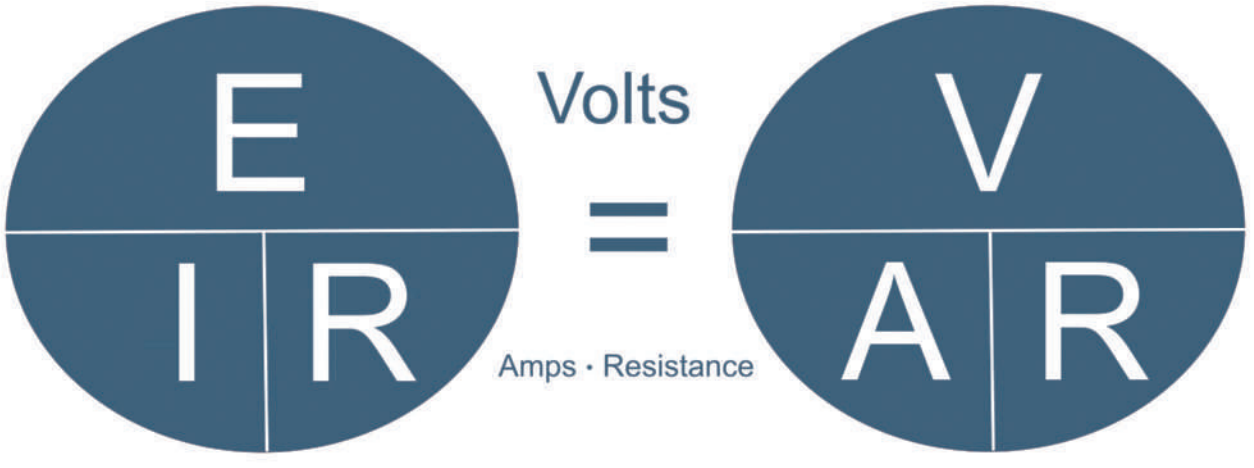


FIGURE 15–19 Ohm's law.

added together. Understanding these aspects of Ohm's law will help you understand how to apply it, not just to electrical circuits on paper, but also in practice on a vehicle. It also explains how an increase or decrease in voltage, resistance, or current affects a circuit. For example, if the fog light in Figure 15–18 has a 6-ohm resistance, determine the current in the circuit. Since cars have a 12-volt battery, you know two of the values in the fog light circuit and calculating the third value is quite simple:

$$I\text{ (unknown)} = \frac{E\text{ (12 volts)}}{R\text{ (6 ohms)}}$$

$$I = \frac{12}{6}$$

$$I = 2\text{ amperes}$$

In a clean, well-wired circuit, the fog lights will draw 2 amperes of current. What would happen if resistance in the circuit increases due to corroded or damaged wires or connections? If bad connections add 2 ohms of resistance to the circuit, the total resistance is 8 ohms **(Figure 15–23)**. Therefore, the amount of current through the circuit decreases.

$$I = \frac{12}{6+2} = \frac{12}{8}$$

$$I = 1.5\text{ amperes}$$

If the lights are designed to operate at 2 amperes, this decrease to 1.5 amperes causes them to burn dimly. Removing the corrosion or installing new wires and connectors will eliminate the unwanted resistance. Now the correct amount of current will flow through the circuit, allowing the lamp to burn as brightly as it should.

Voltage Drops

Voltage drop is the amount of voltage required to cause current flow through a load. For there to be voltage dropped, the circuit must be complete **(Figure 15–24A)**. An open circuit **(Figure 15–24B)** does not have any voltage drop since there is no current flow. The voltage is dropped as a result of the change in electrical energy (voltage) into another form of energy, such as the heat generated from a light bulb. This conversion uses the voltage supply and current flow to produce work. Because a complete path is necessary for the circuit to operate, the electrons moving through the circuit (amps) are not consumed, but the force pushing on the electrons is reduced (voltage drop) as work is performed. As electrical energy is changed to another form of energy as it flows through a load, the amount of voltage leaving the load is lower than it was when it entered. The amount of voltage dropped by a load depends on the circuit's current and the resistance of the load. Voltage drop can be calculated by using Ohm's law. If the resistance of the load and the circuit's current is known, the voltage drop is the product of the two. If there is only one load in the circuit, the voltage drop will equal the source voltage.

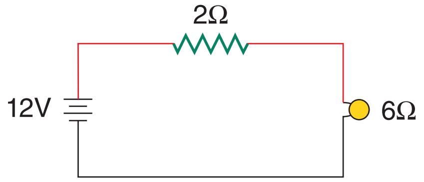


FIGURE 15–23 Same circuit as shown in Figure 15–18 but this one has a corroded wire, represented by the additional resistor.

When there is more than one load, the voltage drop will vary with the values of the loads. For example, if a 12-volt circuit has a 3-ohm load and a 9-ohm load, the total current will be 1 ampere and the total resistance will be 12 ohms. The voltage drop across the 3-ohm load will be 1×3, which equals 3 volts. The drop across the other load will be 1×9, or 9 volts **(Figure 15–25)**.

All of the available voltage in a circuit is dropped by the loads; therefore, 0 volts is present at the negative connection of the power source.

AC Circuits In AC circuits, the total opposition to current flow is called its **impedance**. Electrical impedance, like resistance, is measured in ohms and represents the resistance of the load plus the opposition to AC current flow that results from its interaction with magnetic fields within the conductor. Voltage drop in an AC circuit is the product of the current and the impedance (Z) of the circuit or load. It is expressed by the formula $E = I \times Z$.

Power and Watt's Law

Watt's law refers to a formula used to calculate the electrical power (P) used by a load. The law is mathematically expressed by $P = I \times E$. In other words, power equals current multiplied by voltage. Electric power is expressed in **watts** and represents the rate at which electrical energy is converted to another form of energy. Electrical energy can be converted into sound, heat, light, or motion.

If two loads have the same available voltage, the load with the lowest resistance will use the most power. For example, a 40-W household light bulb has a higher resistance than a 100-W bulb.

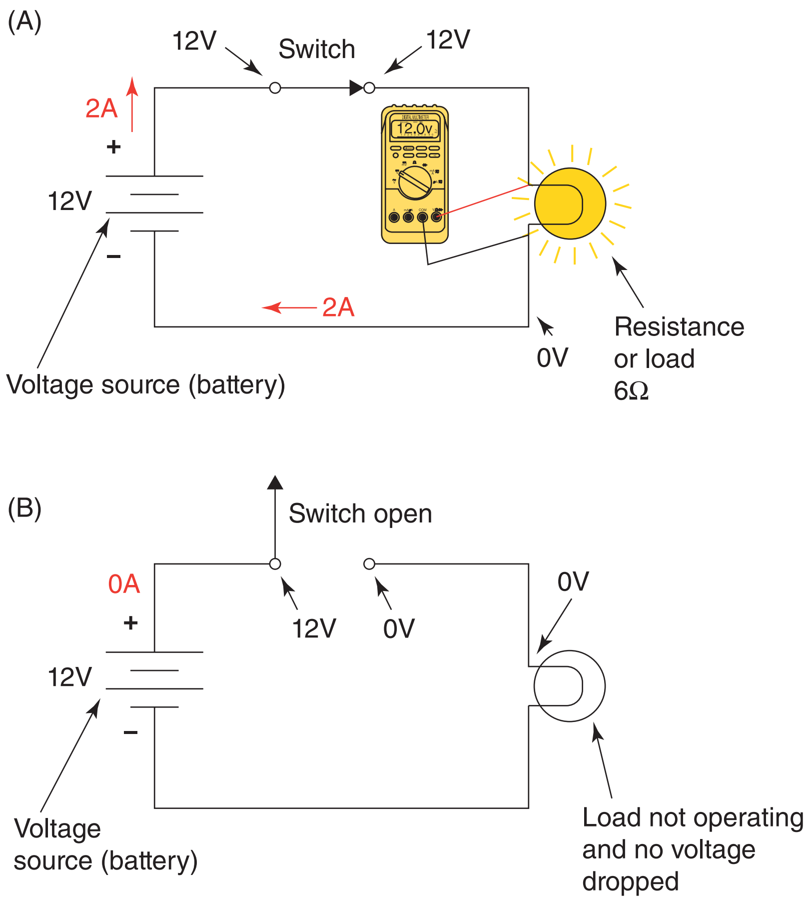


FIGURE 15–24 In Figure A, the circuit is complete and all of the source voltage is dropped within the circuit. In Figure B, the circuit is open and no voltage drops take place.

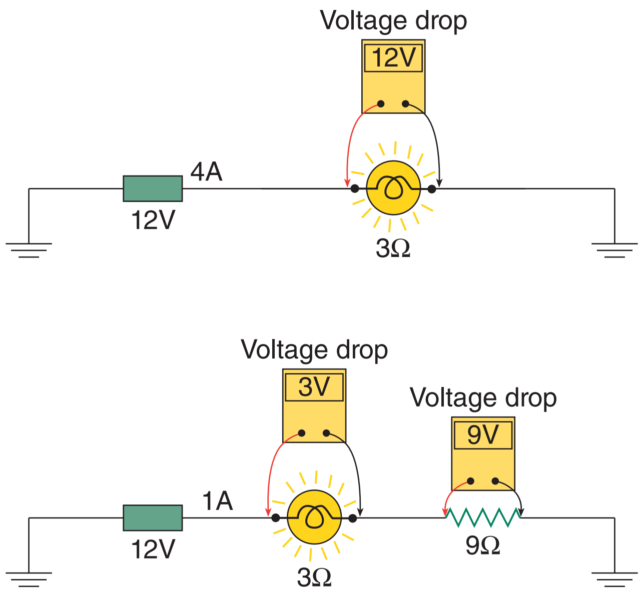


FIGURE 15–25 All of the available voltage is dropped by the loads in the circuit. The amount of drop depends on the resistance of the load.

Although power measurements are rarely needed in automotive service, knowing the power requirements of light bulbs, electric motors, and other components is sometimes useful when troubleshooting electrical systems. Looking back at the example of the fog light circuit, the amount of power used by the fog light can be calculated **(Figure 15–26)**.

$$P = 12 \text{ volts} \times 2 \text{ amperes}$$

$$P = 24 \text{ watts}$$

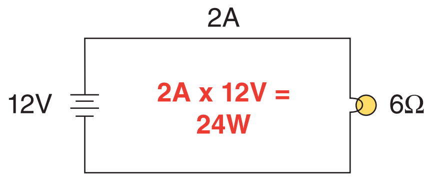


FIGURE 15–26 Electrical power is calculated by multiplying voltage by current.

The normal fog light uses 24 watts of power, whereas the corroded fog light circuit results in the following:

$$P = 12 \text{ volts} \times 1.5 \text{ amperes}$$

$$P = 18 \text{ watts}$$

This reduction in power explains the decrease in bulb brightness.

Circuits

Most automotive circuits contain five basic parts.

1. Power sources, such as a battery or generator, that provide the energy needed to cause electron flow
2. Conductors, such as copper wires, that provide a path for current flow
3. Loads, which are devices that use electricity to perform work, such as light bulbs, electric motors, or resistors
4. Controllers, such as switches or relays, that control or direct the flow of electrons
5. Circuit protection devices, such as fuses, circuit breakers, and fusible links

Three basic types of circuits are used in automotive electrical systems: series circuits, parallel circuits, and series-parallel circuits. Each type has its own characteristics regarding amperage, voltage, and resistance.

Series Circuits

A **series circuit** consists of one or more loads connected to a voltage source with only one path for electron flow. For example, a simple series circuit consists of a resistor (2 ohms in this example) connected to a 12-volt battery **(Figure 15–27A)**. The current can be determined by applying Ohm's law.

$$I = \frac{E}{R} = \frac{12}{2} = 6 \text{ amperes}$$

Another series circuit may contain a 2-ohm resistor and a 4-ohm resistor connected to a 12-volt battery **(Figure 15–27B)**. The word *series* is given to a circuit in which the same amount of current is present throughout the circuit. This means that the current that flows through one point in the circuit is the same amount of current that flows through all parts of the circuit. As that amount of current leaves the battery, it flows through the conductor to the first resistor. At the resistor, some electrical energy or voltage is consumed as the current flows through it and heat is generated **(Figure 15–27C)**. The decreased amount of voltage is then applied to the next resistor as current flows to it. By the time the current is flowing in the conductor leading back to the battery, all voltage has been dropped.

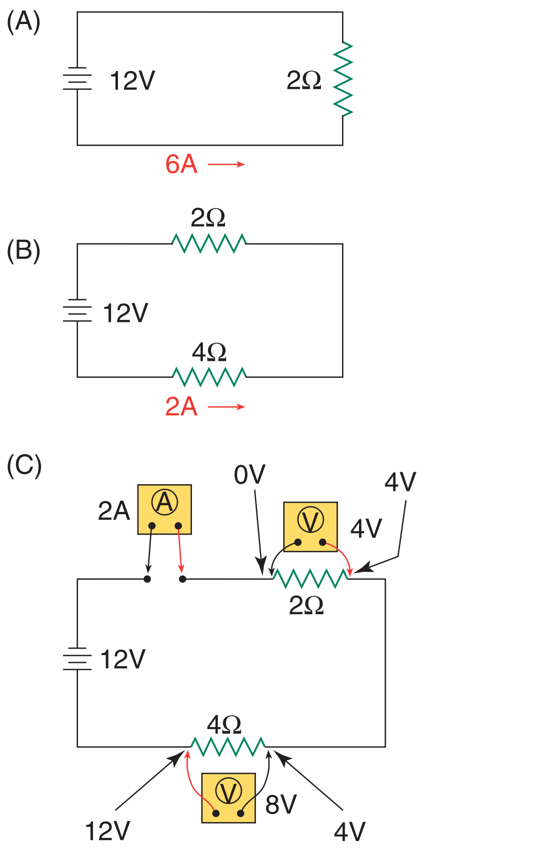


FIGURE 15–27 Figure A shows a simple series circuit with one load. Figure B shows a series circuit with two loads. Figure C is the same circuit as Figure B but shows the voltage drops and ampere readings within the circuit.

In a series circuit, the total amount of resistance in the circuit is equal to the sum of the individual resistances. In the circuit in **Figure 15–27B**, the total circuit resistance is 4 + 2 = 6 ohms. Based on Ohm's law, current is $I = E/R = {}^{12}/_{6} = 2$ amperes. In a series circuit, current is constant throughout the circuit. Therefore, 2 amps flow through the conductors and both resistors.

Ohm's law can be used to determine the voltage drop across parts of the circuit. For the 2-ohm resistor, $E = IR = 2 \times 2 = 4$ volts. For the 4-ohm resistor, $E = 2 \times 4 = 8$ volts. The sum of all voltage drops in a series circuit must equal the source voltage, or $4 + 8 = 12$ volts.

An ammeter connected anywhere in this circuit will read 2 amperes, and a voltmeter connected across each of the resistors will read 4 volts and 8 volts, as shown in **Figure 15–28**.

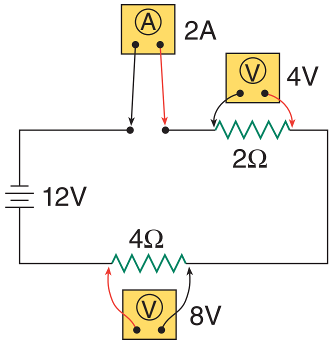


FIGURE 15–28 Measuring the current and voltage drops in the circuit.

All calculations for a series circuit work in the same way no matter how many resistances there are in series. Consider the circuit in **Figure 15–29**. This circuit has four resistors in series with each other. The total resistance is 12 ohms (5 ohms + 2 ohms + 4 ohms + 1 ohm). Using Ohm's law, we can see that the circuit current is 1 amp ($I = E/R = 12/12 =$ 1 amp). We can also use Ohm's law to determine the voltage drop across each resistor in the circuit. For example, since the circuit current is 1 amp, 4 volts are dropped by the 4-ohm resistor ($E = I \times R = 1$ amp $\times$ 4 ohms = 4 volts).

A series circuit is characterized by the following facts:

1. The circuit's current is determined by the total resistance in the circuit and is constant throughout the circuit.
2. The voltage drops across each resistor are different if the resistance values are different.
3. The sum of the voltage drops equals the source voltage.
4. The total resistance is equal to the sum of all resistances in the circuit.

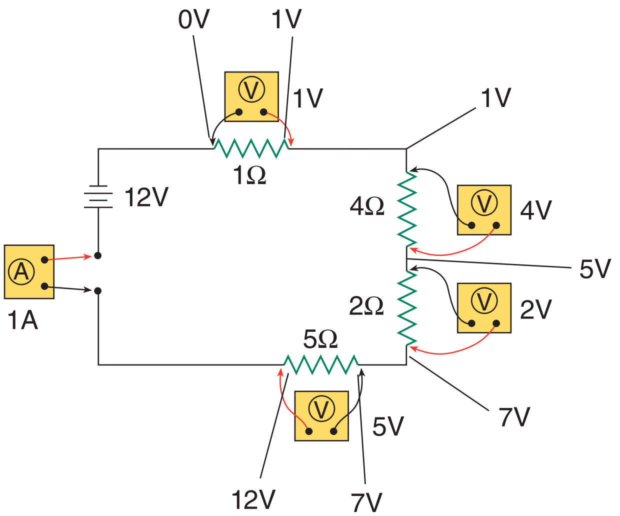


FIGURE 15–29 Values in the series circuit.

Parallel Circuits

A **parallel circuit** provides two or more different paths for current flow. Each path has separate loads and can operate independently of the other paths. The different paths for current are commonly called the legs of a parallel circuit.

A parallel circuit is characterized by the following:

1. Total circuit resistance is always lower than the resistance of the leg with the lowest total resistance.
2. The current through each leg will be different if the resistance values are different.
3. The sum of the current on each leg equals the total circuit current.
4. The voltage applied to each leg of the circuit will be dropped across the legs if there are no loads in series with the parallel circuit.

Consider the circuit shown in **Figure 15–30**. Two 3-ohm resistors are connected to a 12-volt battery. The resistors are in parallel with each other, since the battery voltage (12 volts) is applied to each resistor and they have a common negative lead. The current through each resistor or leg can be determined by applying Ohm's law. For the 3-ohm resistors, $I = E/R = 12/3 = 4$ amperes. Therefore, the total circuit current supplied by the battery is 4 + 4 = 8 amperes. Using Ohm's law, we find that 12 volts are dropped by both resistors **(Figure 15–31)**.

Resistances are not added up to calculate the total resistance in a parallel circuit. Rather, total resistance is determined by dividing the product of their ohm values by the sum of their ohm values. This formula works when the circuit has two parallel legs.

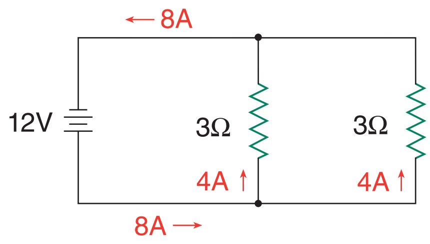


FIGURE 15–30 A simple parallel circuit.

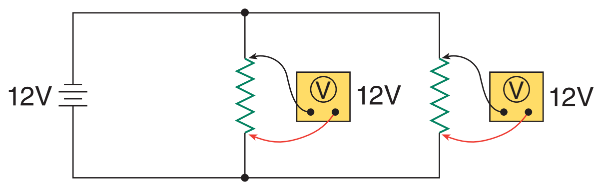


FIGURE 15–31 A parallel circuit with voltage drops shown.

The formula is written as $Rt = \frac{R_1 \cdot R_2}{R_1 + R_2}$. For this circuit, the resistance total is 1.5 ohms.

$$\frac{3 \text{ ohms} \times 3 \text{ ohms}}{3 \text{ ohms} + 3 \text{ ohms}} = \frac{9}{6} = 1.5 \text{ ohms}$$

Total resistance can also be calculated by using Ohm's law if you know the total circuit current and the voltage ($R = E/I = 12/8 = 1.5$ ohms).

Consider another parallel circuit, **Figure 15–32A**. In this circuit there are two legs and four resistors. Each leg has two resistors in series. One leg has a 4-ohm and a 2-ohm resistor. The total resistance on that leg is 6 ohms. The other leg has a 1-ohm and a 2-ohm resistor. The total resistance of that leg is 3 ohms. Therefore, we have 6 ohms in parallel with 3 ohms, shown in **Figure 15–32B**.

Current flow through the circuit can be calculated by different methods. Using Ohm's law, we know that $I = E/R$. If we take the total resistance of each leg and divide it into the voltage, we then know the current through that leg. Since total circuit current is equal to the sum of the current flows through each leg, we simply add the current across each leg together. This will give us total circuit current.

Leg 1: $I = E/R = 12/6 = 2$ amps
Leg 2: $I = E/R = 12/3 = 4$ amps

2 amps + 4 amps = 6 amps which is the total circuit current

Circuit current can also be determined by finding the total resistance of the circuit. To do this, the product-over-sum formula is used. By dividing this total into the voltage, total circuit current is known.

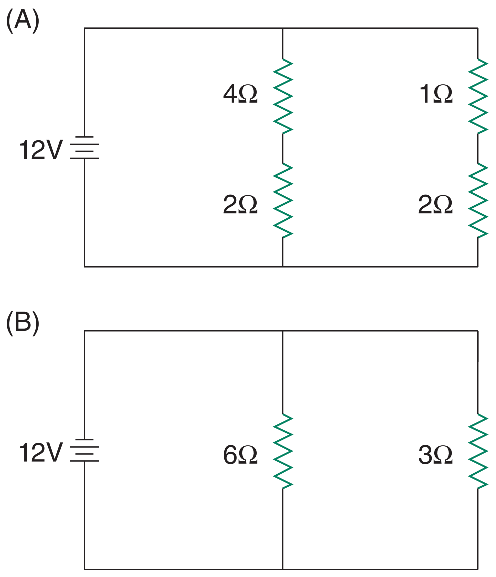


FIGURE 15-32 Figure A shows two series circuits within a parallel circuit. The total resistance in each series circuit is the sum of the resistances, as shown in Figure B.

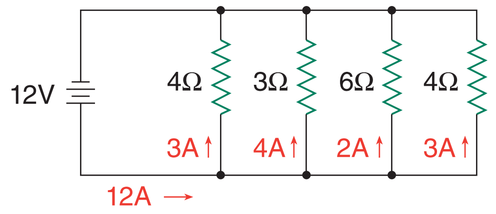


FIGURE 15-33 A parallel circuit with four legs.

$$\frac{\text{Leg 1} \times \text{Leg 2}}{\text{Leg 1} + \text{Leg 2}} = \frac{6 \times 3}{6 + 3} = \frac{18}{9} = 2 \text{ ohms}$$

since $I = E/R$, $I = 12/2$, $I = 6$ amps (total circuit current)

When a circuit has more than two legs, the reciprocal formula should be used to determine total circuit resistance. The formula follows:

$$\frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_n}}$$

To demonstrate how to use this formula, consider the circuit in **Figure 15–33**. Here is a parallel circuit with four legs. The resistances across each leg are 4 ohms, 3 ohms, 6 ohms, and 4 ohms. Using the reciprocal formula, we will find that the total resistance of the circuit is 1 ohm. (Note that the total resistance is lower than the leg with the lowest resistance.)

$$\frac{1}{\frac{1}{4} + \frac{1}{3} + \frac{1}{6} + \frac{1}{4}} =$$

$$\frac{1}{\frac{3}{12} + \frac{4}{12} + \frac{2}{12} + \frac{3}{12}} = \frac{1}{\frac{12}{12}} = \frac{1}{1} = 1$$

The total of this circuit could also have been found by calculating the current across each leg then adding them together to get the total circuit current. Using Ohm's law, if you divide the voltage by the total circuit current, you will get total resistance.

Leg 1: $I = E/R = 12/4 = 3$ amps
Leg 2: $I = E/R = 12/3 = 4$ amps
Leg 3: $I = E/R = 12/6 = 2$ amps
Leg 4: $I = E/R = 12/4 = 3$ amps

Total circuit current = 3 + 4 + 2 + 3 + 3 amps; then,

$$R = E/R = 12/12 = 1 \text{ ohm}$$

Series-Parallel Circuits

In a **series-parallel circuit**, both series and parallel combinations exist in the same circuit. If you are

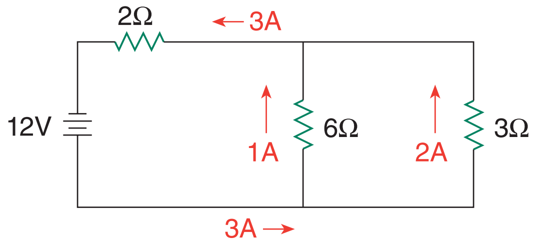


FIGURE 15-34 In a series-parallel circuit, the sum of the currents through the legs must equal the current through the series part of the circuit.

faced with the task of calculating the values in a series-parallel circuit, determine all values of the parallel circuit(s) first. By looking carefully at a series-parallel circuit, you will find that it is nothing more than one or more parallel circuits in series with each other or in series with some other resistance.

A series-parallel circuit is illustrated in **Figure 15–34**. The 6- and 3-ohm resistors are in parallel with each other and together are in series with the 2-ohm resistor.

The total current in this circuit is equal to the voltage divided by the total resistance. The total resistance can be determined as follows. The 6- and 3-ohm parallel resistors in **Figure 15–35** are equivalent to a 2-ohm resistor, since $(6 \times 3)/(6 + 3) = 2$. This equivalent 2-ohm resistor is in series with the other 2-ohm resistor. To find the total resistance, add the two resistance values together. This gives a total circuit resistance of 4 ohms ($2 + 2 = 4$ ohms). The voltage drop of each resistor is 6 volts. Even though there are two resistances in parallel, they act as one resistance when in series with another resistance. The total current, therefore, is $I = {}^{12}/_{4} = 3$ amperes. This means that 3 amps of current are flowing through the 2-ohm resistor in series and 3 amps are divided between the resistors in parallel. In series-parallel circuits, the sum of the currents, flowing in the parallel legs, must equal that of the series resistors' current.

To find the current through each of the resistors in parallel, find the voltage drop across those resistors first. With 3 amperes flowing through the 2-ohm resistor, the voltage drop across this resistor is $E = IR = 3 \times 2 = 6$ volts, leaving 6 volts across the 6- and 3-ohm resistors. The current through the 6-ohm resistor is $I = {}^{6}/_{3} = 2$ ampere, and through the 3-ohm resistor $I = E/R = {}^{6}/_{6} = 1$ amperes. The sum of these two current values must equal the total circuit current, and it does, $1 + 2 = 3$ amperes (see **Figure 15–35**). The sum of the voltage drops across the parallel part of the circuit and the series part must also equal source voltage.

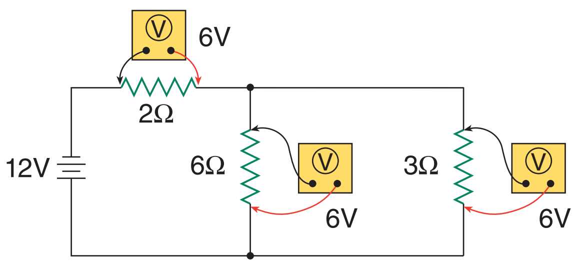


FIGURE 15-35 The circuit in Figure 15–34 with voltage drops shown.

Kirchhoff's Law

In the 1840s, German physicist Gustav Kirchhoff described two laws on the behavior of electricity. Both of these laws relate to Ohm's law and help define the characteristics of series and parallel circuits.

Kirchhoff's "voltage law" basically states that the sum of the voltage drops in a closed circuit equals the voltage applied to that circuit. This directly describes the behavior of a series circuit. This law also describes the characteristics of more complex circuits in which there are positive and negative voltages. These are not discussed here.

Kirchhoff's "current law" explains the behavior of current in a parallel circuit. This law can be safely stated as: "At any junction point in a circuit, the current arriving to that point is equal to the current leaving." If 10 amperes of current arrives at the point in a circuit where a parallel leg is added to the circuit, the 10 amps will be divided according to the resistance of each leg, but a total of 10 amps will be present at the junction that ties the legs together again. In other words, the sum of the branch currents is equal to the total current entering the branches as well as the total current leaving the branches.

Circuit Components

Automotive electrical circuits contain a number of different electrical devices. The more common components are outlined in the following sections.

Power Sources

Most of today's vehicles operate with basically 12-volt electrical systems. The word *basically* is used because the battery is rated at 12 volts but stores 12.6 volts, and the charging system puts out about 14 volts while the engine is running. Because the charging system is the primary source of electrical power, it is fair to say that an automobile's electrical system is a 14-volt system.

For hybrid and electric vehicles, a high-voltage battery and high-voltage system is used to power the electric motors and air-conditioning system. All other systems, such as lighting, wipers, and others are powered by a low-voltage, 12-volt system.

In 1954, General Motors equipped its Cadillac with a 12-volt system. Prior to 1954, vehicles had 6-volt systems. The electrical demands of accessories, such as power windows and seats, put a severe strain on the 6-volt battery and charging system. With a 12-volt system, the charging system had to work less hard and there was plenty of electrical power for the electric accessories.

The increase in voltage also allowed wire sizes to decrease because the amperage required to power things was reduced. To explain this, consider an accessory that required 20 amps to operate in a 6-volt system (120 watts). When the voltage was increased to 12 volts, the system only drew 10 amperes. This is illustrated in **Figure 15–36**. As voltage increases, the amperage requirement is reduced due to the greater pressure supplied by the voltage. Increasing system voltage allows wire gauge to decrease as the current-carrying capacity of the wire is reduced. One should expect to see manufacturers move to 48-volt systems to keep pace with increased electrical demand while reducing the size of the wiring needed to supply to many accessories.

Today we are faced with the same situation. The use of computers and the need to keep their memories fresh has put a drain on the battery even when the engine is not running. The number of electrical accessories also has and will continue to grow.

Today's vehicles are very sensitive to voltage change. In fact, their overall efficiency depends on a constant voltage. The demands of new technology make it difficult to maintain a constant voltage, and engineers have determined that system voltage must be increased to meet those demands. As vehicles evolve, emissions, fuel economy, comfort, convenience, and safety features will put more of a drain on the electrical system. This increased demand results from converting purely mechanical systems into electromechanical systems, such as steering, suspension, and braking systems, as well as new safety and communication systems. It has been estimated that in a few years the demand for continuous electrical power will be 3,000 to 7,000W. Current 14-volt systems are rated at 800 to 1,500W.

To meet these demands there are two possible solutions: increase the amperage capacity of the battery and charging system or increase system voltage.

Higher-amperage batteries and generators are only a Band-Aid solution. Because the generator is driven by engine power, more power from the engine will be required to keep the higher-capacity battery charged. Therefore, overall efficiency will decrease.

By moving to a higher system voltage, the battery will need to be larger and heavier. However, because system amperage will be lower, wire size will be smaller and perhaps the weight gain at the battery will be offset by the decreased weight of the wiring.

Loads

Electrical loads can be thought of as energy conversion devices. Examples of appropriate loads are motors, such as the power window and door lock, interior fan, and starter motors. Other loads include the horn, lights, rear-window defroster, stereo, and

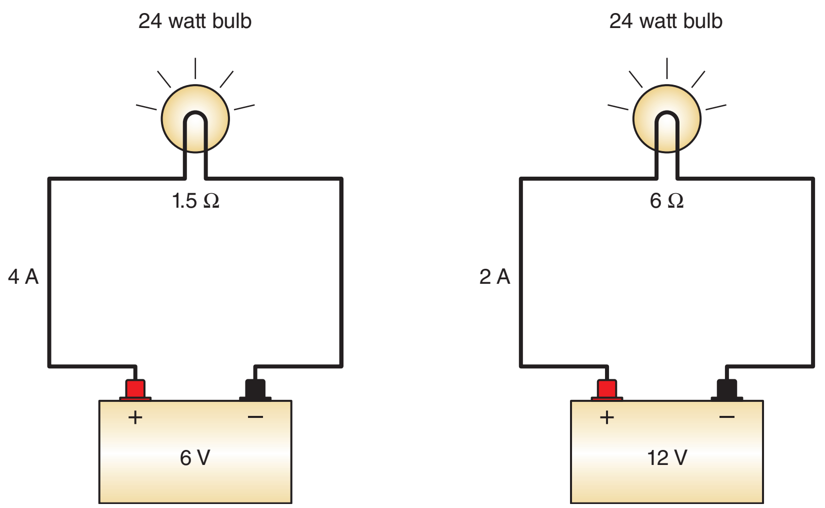


FIGURE 15–36 By doubling the voltage, the same amount of work can be performed at half the amperage.

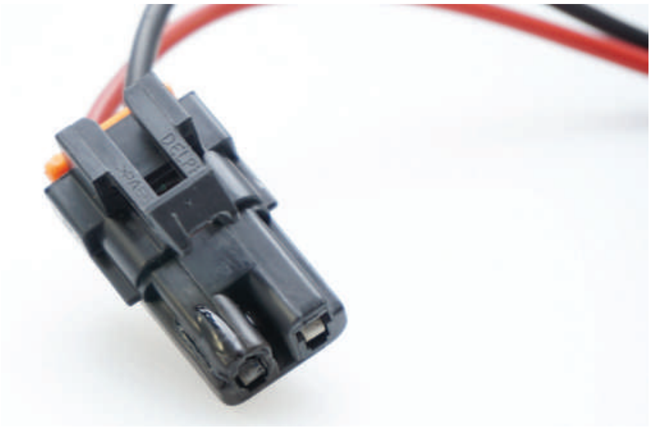


FIGURE 15–37 A connector damaged by a voltage drop across the terminal inside.

speakers. Each of these components receives voltage and amperage and converts them into movement, light and heat, or sound.

Loads can also be unwanted, such as from a poor electrical connection between a wire and a load. The poor connection becomes a voltage drop and a load, using power that generates heat, sometimes causing damage to the components **(Figure 15–37)**.

Resistors

As shown in the explanation of simple circuit design, resistors are used to limit current flow (and thereby voltage) in circuits where full current flow and voltage are not needed or desired. Resistors are devices specially constructed to add a specific amount of resistance to a circuit. Also, other components use resistance to produce heat and even light. An electric window defroster is a specialized type of resistor that produces heat. Incandescent lamps are resistors that get so hot they produce light.

Automotive circuits can contain these types of resistors: fixed value, stepped or tapped, and variable.

Fixed value resistors are designed to have only one rating, which should not change. These resistors decrease the amount of voltage applied to a component, such as an ignition coil. Often manufacturers use a special wire, called resistor wire, to limit current flow and voltage in a circuit. This wire looks much like normal wire but is not a good conductor and is marked as a resistor.

Tapped or **stepped resistors** are designed to have two or more fixed values available by connecting wires to the several taps of the resistor. Heater motor resistor packs, which provide for different fan speeds, are an example of this type of resistor **(Figure 15–38)**.

Variable resistors are designed to have a range of resistances available through two or more taps and a control. Two examples of this type of resistor are **rheostats** and **potentiometers**. Rheostats **(Figure 15–39)** have two connections, one to the fixed end of a resistor and one to a sliding contact with the resistor. Moving the control moves the sliding contact away from or toward the fixed end tap, increasing or decreasing the resistance. Potentiometers **(Figure 15–40)** have three connections, one at each end of the resistance and one connected to a sliding contact with the resistor. Moving the control moves the sliding contact away from one end of the resistance but toward the other end. These are called potentiometers because different amounts of potential or voltage can be sent to another circuit. As the sliding contact moves, it picks up a voltage equal to the source voltage minus the amount dropped by the resistor so far **(Figure 15–41)**.

Another type of variable resistor is the **thermistor**. This resistor is designed to change its resistance value as its temperature changes. Most resistors are carefully constructed to maintain their rating within a few ohms through a range of temperatures, but a thermistor is not. Thermistors are used to provide compensating voltage for components or to determine temperature. As a temperature sensor, the

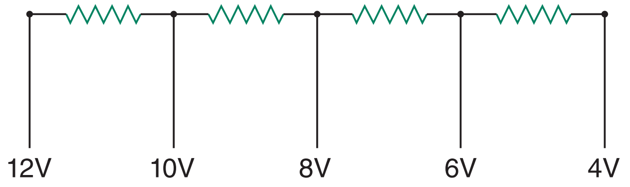


FIGURE 15–38 A stepped resistor.

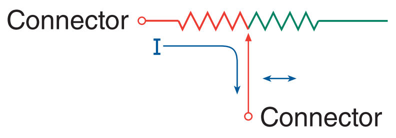


FIGURE 15–39 A rheostat.

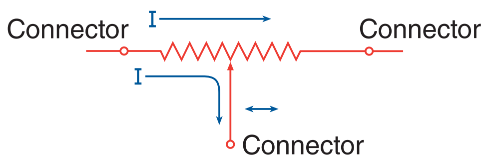


FIGURE 15–40 A potentiometer.

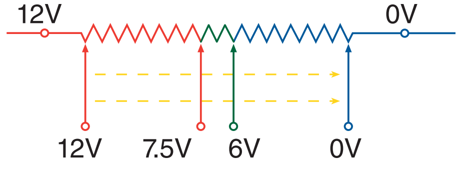


FIGURE 15–41 Voltage across a potentiometer.

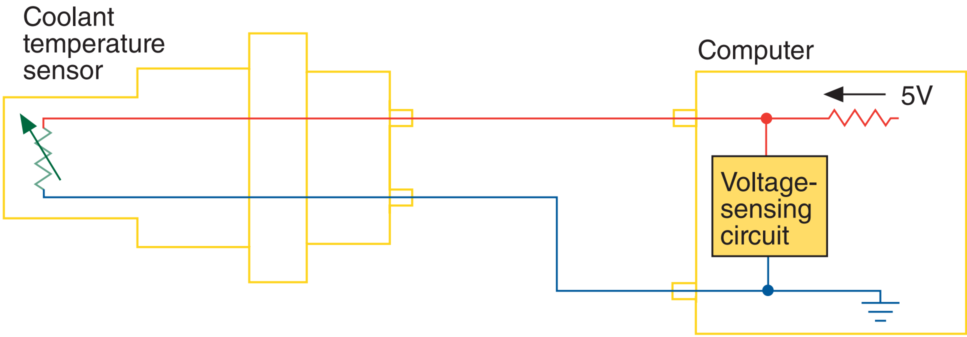


FIGURE 15-42 A thermistor is used to measure temperature. The sensing unit measures the change in resistance and translates this into a temperature value.

thermistor is connected to a voltmeter calibrated in degrees. As the temperature rises or falls, the resistance of the thermistor changes, which causes a change in the circuit's voltage. These changes can be read on the temperature gauge. Thermistors are also used to sense temperature and send a signal back to a control unit **(Figure 15–42)**.

Circuit Protective Devices

When overloads or shorts in a circuit cause too much current to flow, the wiring in the circuit heats up, the insulation melts, and a fire can result, unless the circuit has some kind of protective device. Fuses, fuse links, maxi-fuses, and circuit breakers are designed to provide protection from high current. They may be used singly or in combination. Typical symbols for protection devices are shown in **Figure 15–43**.

Warning! Fuses and other protection devices normally do not wear out. They go bad because something went wrong. Never replace a fuse or fusible link, or reset a circuit breaker, without finding out why it went bad.

SHOP TALK

There are two basic types of thermistors: negative temperature coefficient (NTC) and positive temperature coefficient (PTC). The resistance of a NTC thermistor decreases with an increase in temperature, whereas the resistance of a PTC thermistor increases with an increase in temperature.

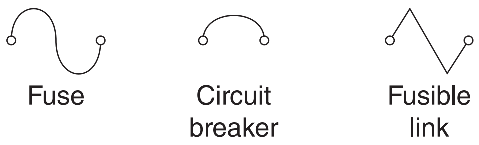


FIGURE 15-43 Electrical symbols for common circuit protection devices.

Fuses

Automotive fuses are normally rated for circuits no higher than 24 volts DC, but some may be rated for 42-volt systems. There are three basic types of fuses used in automobiles: cartridge, ceramic, and blade **(Figure 15–44)**.

A cartridge fuse, or glass tube fuse, was commonly used in older domestic vehicles and a few imports. It has a strip of low temperature melting metal enclosed in a transparent glass or plastic tube. These fuses are available in many different sizes and amperage ratings. All glass fuses have the same diameter, but the length varies with the current rating.

The ceramic fuse, at times referred to as the Bosch-type fuse, was used on many older European imports. The core is a ceramic insulator with a conductive metal strip along one side. These fuses are available in two sizes, code GBF (small) and the more common code GBC (large). The amperage rating is also embossed on the insulator.

Nearly all late-model domestic vehicles and imports use blade or spade fuses. Blade fuses have a plastic body and two prongs that fit into sockets. These fuses can be mounted in fuse blocks **(Figure 15–45)**, in-line fuse holders, or fuse clips. The fuse panels are normally located under the dashboard, behind a panel in the foot well, or in the engine compartment.

Blade fuses are available in several different physical dimensions: low-profile mini, mini, micro, regular, multi-terminal, and maxi heavy-duty. The low-profile mini fuse is sometimes called "micro"

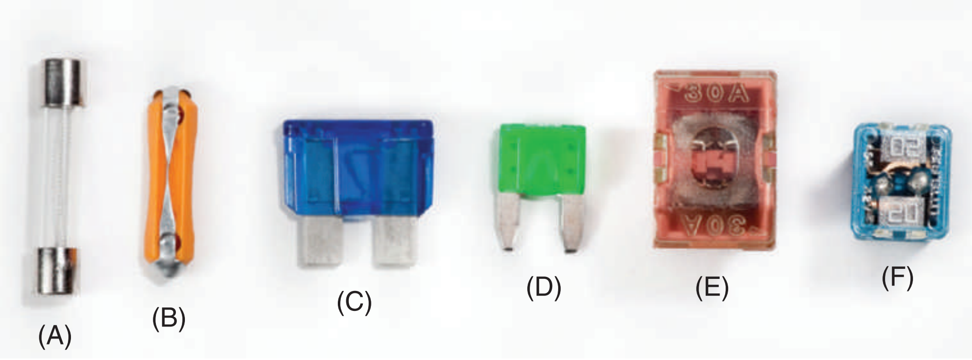


FIGURE 15–44 Common fuses (A) glass cartridge, (B) ceramic, (C) blade, (D) mini, (E) cartridge, and (F) low profile cartridge.

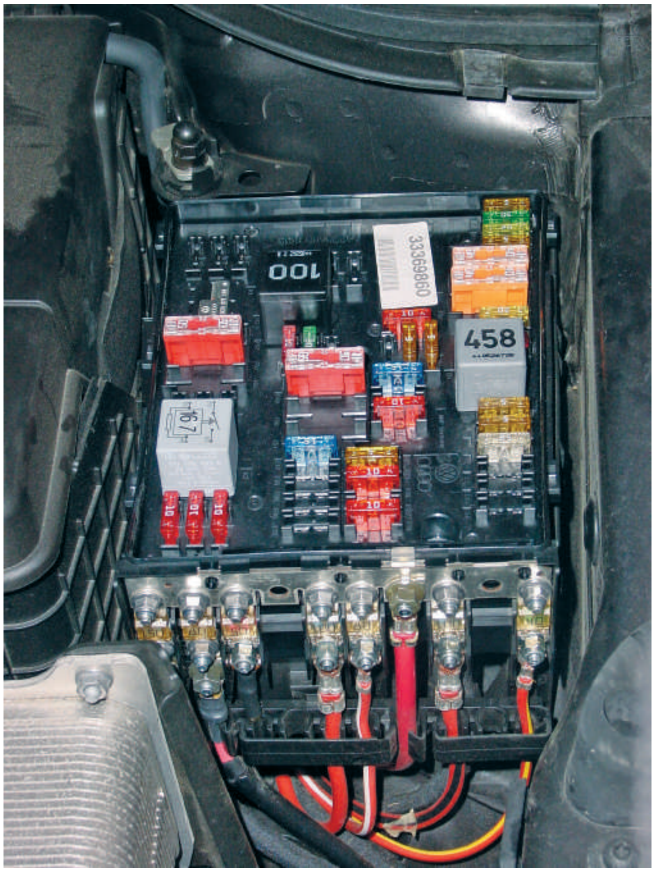


FIGURE 15–45 Typical fuse box or panel.

since the term means smaller than mini. However, micro fuses are external blade fuses that are narrower, approximately 9 mm wide, compared to mini fuses that are about 11 mm wide. The mini fuse is the most commonly used circuit protection device. Regular blade-type fuses are also known as standard fuses. The **maxi-fuse** is a serviceable replacement for a fusible link cable and is used in circuits that have high operating current.

Maxi-fuses also allow the vehicle's electrical system to be broken down into smaller circuits, which makes it easier to diagnose and repair a circuit. For example, if a single fusible link protects one-half or more of all circuitry and it burns out, many electrical systems are lost. By replacing this single fusible link with several maxi-fuses, the number of systems lost due to a problem in one circuit is drastically reduced. This makes it easy to pinpoint the source of trouble.

Each fuse has a current rating marked on the top of the fuse. Also, a three-letter code is used to indicate the types and sizes of fuses. The codes indicate the length and diameter of the fuse **(Figure 15–46)**. Fuse lengths in each of the series are the same, but the current rating can vary. The code and the current rating are usually stamped on the end cap. The current rating for blade fuses is also indicated by the color of its plastic case **(Table 15–1)**.

Fuse Links Fuse or **fusible links** were used in circuits where limiting the maximum current is critical. They were normally found in the engine compartment near the battery or on the battery connection at the starter solenoid. Fusible links were also used when it would be awkward to run wiring from the battery to the fuse panel and back to the load.

BLADE TYPE	BLADE SERIES	DIMENSIONS L x W x H
Low-profile Mini	APS, ATT	0.43 x 0.15 x 0.34 in. (*10.9 x 3.81 x 8.73 mm*)
Mini	APM, ATM	0.43 x 0.014 x 0.64 in. (*10.9 x 3.6 x 16.3 mm*)
Standard	APR, ATC, ATO	0.75 x 0.2 x 0.73 in. (*19.1 x 5.1 x 18.5 mm*)
Maxi	APX	0.15 x 0.33 x 1.35 in. (*29.2 x 8.5 x 34.3 mm*)

FIGURE 15–46 Description of the commonly used blade fuses.

TABLE 15-1 TYPICAL COLOR CODING OF BLADE-TYPE FUSES

Color	Amp Rating	Micro	Mini	Standard	Maxi
Dark blue	0.5	–	–	–	–
Black	1	–	–	X	–
Gray	2	X	X	X	–
Violet	3	–	X	X	–
Pink	4	–	X	X	–
Tan	5	X	X	X	–
Brown	7.5	X	X	X	–
Red	10	X	X	X	–
Blue	15	X	X	X	–
Yellow	20	X	X	X	X
Clear	25	X	X	X	Gray
Green	30	X	X	X	X
Blue/Green	35	–	–	X	Brown
Orange	40	–	–	X	X
Red	50	–	–	–	X
Blue	60	–	–	–	X
Amber/Tan	70	–	–	–	X
Clear	80	–	–	–	X
Violet	100	–	–	–	X
Purple	120	–	–	–	X

A fuse link **(Figure 15–47)** is a short length of small-gauge wire installed in a conductor. Because the fuse link is a lighter gauge of wire than the main conductor, it melts and opens the circuit before damage can occur in the rest of the circuit **(Table 15–2)**. Fuse link wire is covered with a special insulation that bubbles when it overheats, indicating that the link has melted.

Mega Fuses Rather than use a fusible link to protect high-amperage circuits, many new vehicles have mega fuses. These fuses may be rated for 100, 125, 150, 175, 200, 225, or 250 amps.

Circuit Breakers Some circuits are protected by **circuit breakers** (abbreviated c.b. in most fuse

> Caution! Always disconnect the battery ground cable prior to servicing any fuse link.

FIGURE 15–47 A typical fuse link.

TABLE 15-2 DESCRIPTION OF FUSIBLE LINKS ACCORDING TO COLOR

Color	Size	Protects
Gray	12 gauge	8 gauge or heavier
Green	14 gauge	10 gauge or heavier
Black or Orange	16 gauge	12 gauge or heavier
Brown or Red	18 gauge	14 gauge or heavier
Blue	20 gauge	16 gauge or heavier

charts and wiring diagrams). They can be fuse panel mounted or inline. Like fuses, they are rated in amperes.

In a circuit breaker, current flows through an arm made of two different metals bonded together. If the arm starts to carry too much current, it heats up. As one metal expands faster than the other, the arm bends, opening the contacts. This opens the circuit and the path for current flow is broken. A circuit breaker can be cycling **(Figure 15–48)** or must be manually reset.

In the cycling type, the bimetal arm begins to cool once the current stops. Once it returns to its original shape, the contacts are closed and power is restored. If the current is still too high, the cycle of breaking the circuit is repeated.

Two types of noncycling or resettable circuit breakers are used. One is reset by removing the power from the circuit. In this type, there is a coil wrapped around a bimetal arm **(Figure 15–49A)**. When there is excessive current and the contacts open, a small current passes through the coil. This current is not enough to operate a load, but it does heat up both the coil and the bimetal arm. This keeps the arm in the open position until power is removed.

The other type is reset by depressing a button. A spring pushes the bimetal arm down and holds the

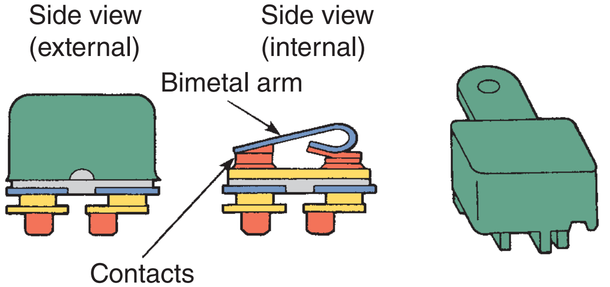


FIGURE 15-48 Cycling circuit breaker.

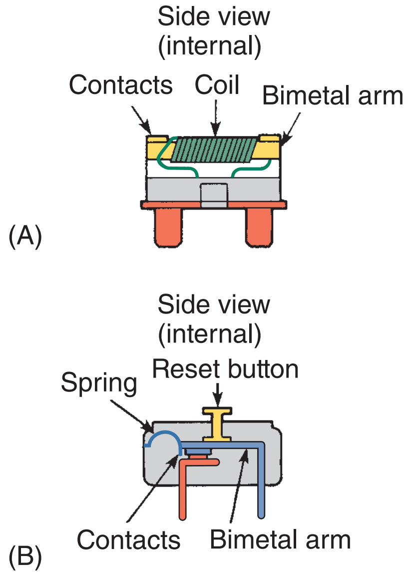


FIGURE 15-49 Resetting noncycling circuit breakers by (A) removing power from the circuit and (B) depressing a reset button.

contacts together **(Figure 15–49B)**. When an overcurrent condition exists and the bimetal arm heats up, the bimetal arm bends enough to overcome the spring and the contacts snap open. The contacts stay open until the reset button is pushed, which snaps the contacts together again.

Some vehicles have automatically resetting circuit breakers. These are solid state devices, meaning that they have no moving parts. In their normal state, they allow current to flow by having a conductive path through the carbon particles. When excessive current flows through the device, the particles heat and expand, opening the circuit **(Figure 15–50)**. Once the carbon particles cool, they contract and the circuit will operate. This type of circuit breaker is often used on power window and power door lock circuits.

High-Voltage Systems HV systems require special circuit protection devices. A special high-voltage service disconnect plug is used to isolate the high-voltage battery from the rest of the electrical system. Inside of the service plug is a fuse, often rated for over 100 amps, that is used to protect the service plug connection.

High-voltage systems use a variety of electrical and electronic devices to protect the electrical circuits. Most have temperature sensors and sensors that constantly monitor system current. If the temperature rises above the limit or if the current is higher than normal, the HV system automatically shuts down.

Voltage Limiter Some information gauges are protected against voltage fluctuations that could damage

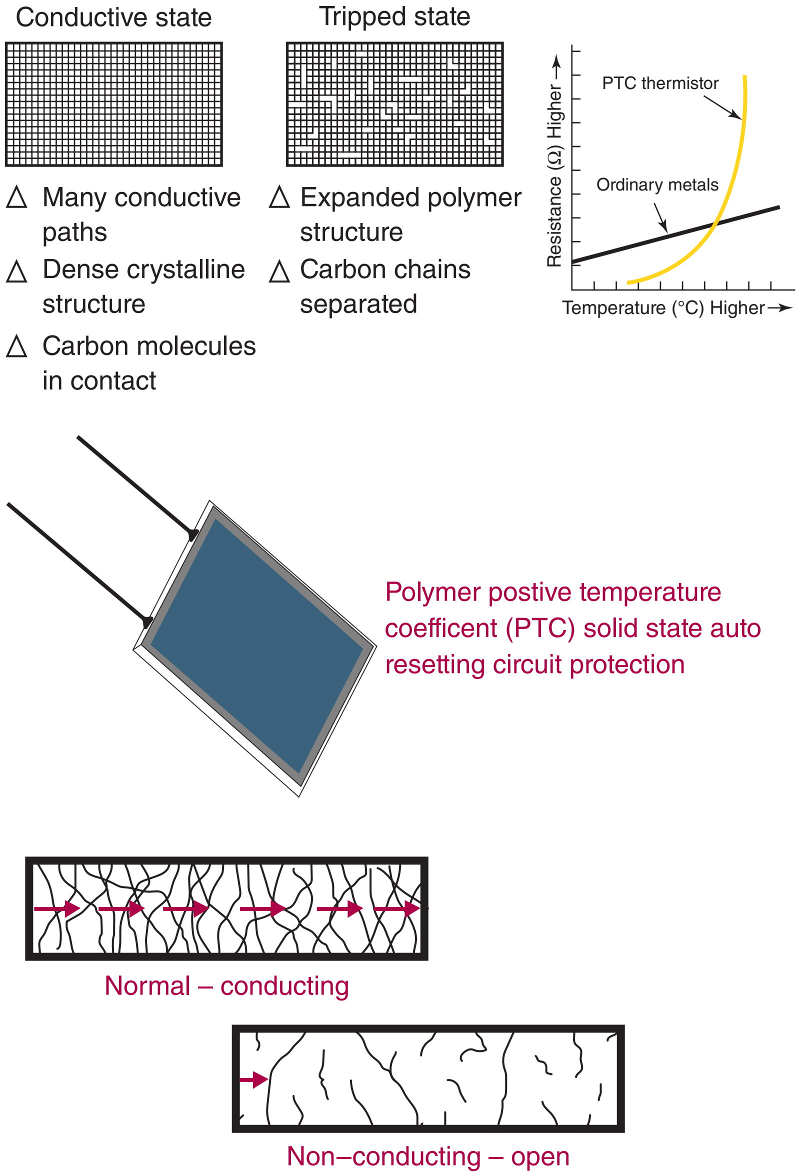


FIGURE 15–50 A PTC self-resetting circuit breaker.

the gauges or give erroneous readings. A voltage limiter restricts the voltage to the gauges. The limiter contains a heating coil, a bimetal arm, and a set of contacts. When the ignition is in the on or accessory position, the heating coil heats the bimetal arm, causing it to bend and open the contacts. When the arm cools down to close the contacts, the cycle is repeated.

Switches

Electrical circuits are usually controlled by some type of switch **(Figure 15–51)**. Switches do two things: turn the circuit on or off, or direct the flow of current in a circuit. Switches can be controlled by the driver or can be self-operating through the condition of the circuit, the vehicle, or the environment.

FIGURE 15–51 Examples of the various switches used in automobiles.

A switch is defined by the job they do or the sequence in which they work. A hinged-pawl switch **(Figure 15–52)** is the simplest type of switch. It either

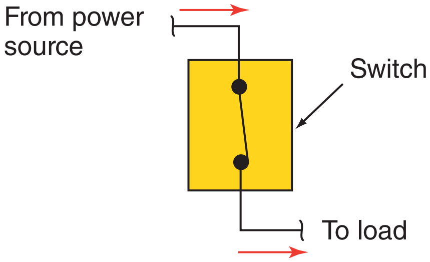


FIGURE 15–52 SPST hinged-pawl switch diagram.

makes (allows for) or breaks (opens) current flow in a single conductor or circuit. This type of switch is a single-pole, single-throw (SPST) switch. The **throw** refers to the number of output circuits, and the **pole** refers to the number of input circuits made by the switch.

Another type of SPST switch is a momentary contact switch **(Figure 15–53)**. A spring-loaded contact keeps the switch from closing the circuit except when pressure is applied to the button. A horn button is this type of switch. Because a spring holds the contacts open, the switch is called a normally open switch. When the contacts are held closed except when the button is pressed, the switch is called a normally closed switch. A normally closed momentary contact switch is used to turn on the courtesy lights when one of the vehicle's doors is opened.

Single-pole, double-throw (SPDT) switches have one wire in and two wires out. **Figure 15–54** shows an SPDT hinged-pawl switch that feeds either the high-beam or low-beam headlight circuit. The dotted lines in the symbol show movement of the switch pawl from one contact to the other.

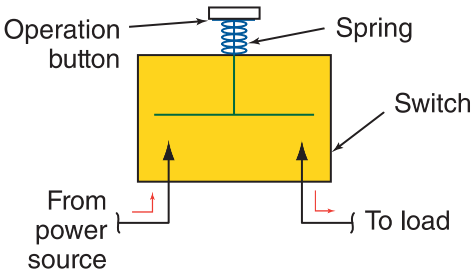


FIGURE 15–53 SPST momentary contact switch diagram.

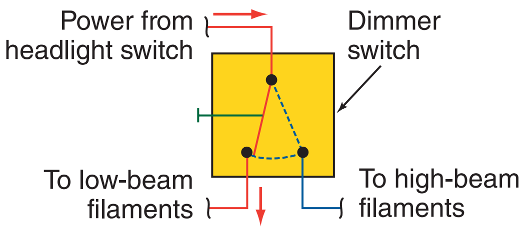


FIGURE 15–54 SPDT headlight dimmer switch.

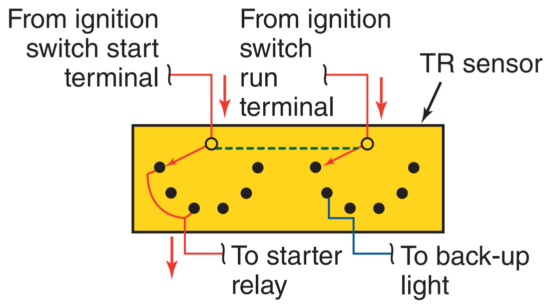


FIGURE 15–55 MPMT neutral start safety switch.

Switches can have a great number of poles and throws. The transmission neutral start switch shown in **Figure 15–55**, has two poles and six throws and is referred to as a **multiple-pole, multiple-throw (MPMT)** switch. It has two movable wipers that move in unison across two sets of terminals. The dotted line shows that the wipers are mechanically linked, or **ganged**. It is important to realize that current flows only through the circuits that are mechanically connected by the switch.

Most switches are combinations of hinged-pawl and push-pull switches, with different numbers of poles and throws. A mercury switch is sometimes used to detect motion in a component, such as the one used in the engine compartment to turn on the compartment light.

Mercury is a very good conductor of electricity. In the mercury switch, a capsule is partially filled with mercury **(Figure 15–56)** and at one end of the capsule are two electrical contacts. The switch is attached to the hood or luggage compartment lid. When the lid is opened, the mercury flows to the contact end and provides a circuit between the electrical contacts.

A temperature-sensitive switch normally contains a bimetallic element heated electrically or by a component. In the latter case, the switch is called a **sensor**. When the engine coolant is below or at normal operating temperature, the coolant temperature sensor remains in its normally open condition. If the coolant exceeds the temperature limit, the bimetallic element bends the two contacts together and the switch closes.

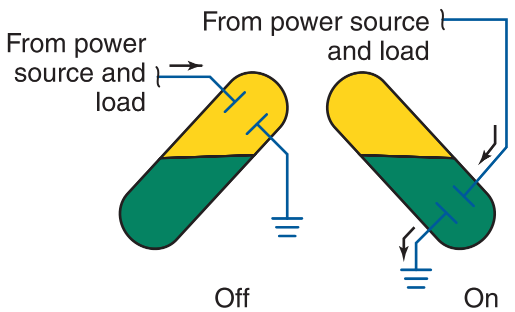


FIGURE 15–56 A typical mercury switch.

Relays

A **relay** is an electric switch that allows a small amount of current to control a high-current circuit **(Figure 15–57)**. When the control circuit switch is open, no current flows to the coil of the relay, so the windings are de-energized. When the switch is closed, the coil is energized, turning the iron core into an electromagnet and drawing the armature down. This closes the power circuit contacts, connecting power to the load circuit **(Figure 15–58)**. When the control switch is opened, current stops flowing and the electromagnetic field disappears. This releases the armature, which breaks the power circuit contacts.

The terminals of nearly all ISO relays have the same identification number and the general purpose of each terminal is also the same **(Figure 15–59)**.

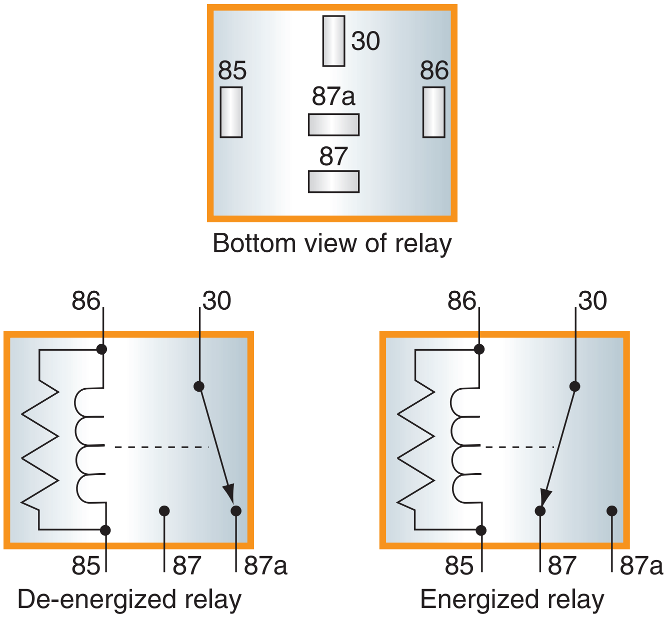


FIGURE 15-58 Action of an ISO relay.

TERMINAL	GENERAL PURPOSE
30	Normally connected to battery voltage
85	Ground for the electromagnet (coil)
86	Voltage supply for the electromagnet (coil)
87	Connects with terminal 30 when the relay is energized
87A	Connects with terminal 30 when the relay is energized

FIGURE 15-59 ISO relay terminal identification and their purpose.

Solenoids

Solenoids are also electromagnets with movable cores used to change electrical current flow into mechanical movement **(Figure 15–60)**. They are used in a wide variety of systems and can also close contacts, acting as a relay at the same time they mechanically cause something to happen.

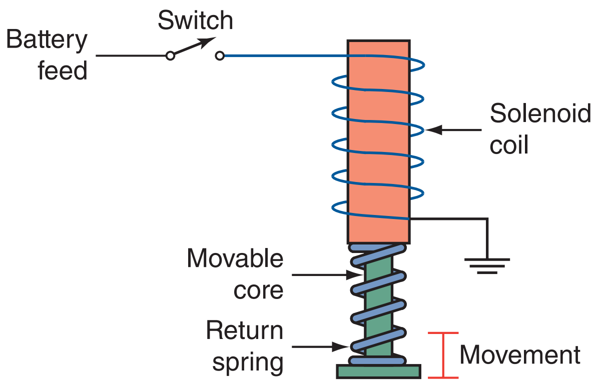


FIGURE 15-60 A solenoid is a device that has a movable electromagnetic core.

Conductors and Insulators

Controlling and routing the flow of electricity requires the use of materials known as conductors and insulators **(Figure 15–61)**.

Conductors are materials that have low resistance to current flow. If the number of electrons in the outer shell or ring of an atom is less than 4, the force holding them in place is weak. The voltage needed to move these electrons and create current flow is relatively small. These materials, such as copper, silver, and aluminum, are good conductors.

When the number of electrons in the outer ring is greater than 4, the force holding them in orbit is very strong, and very high voltages are needed to

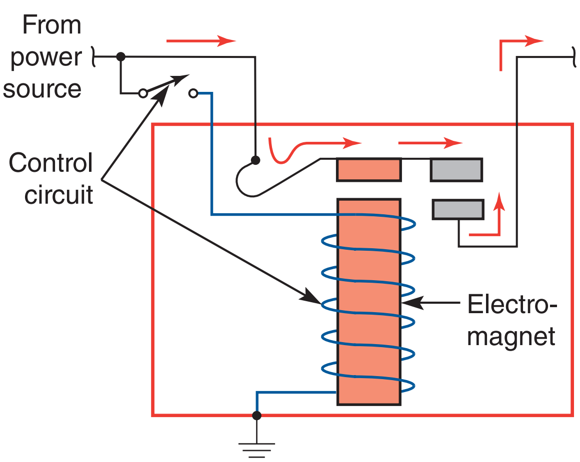


FIGURE 15-57 The basic way a relay works.

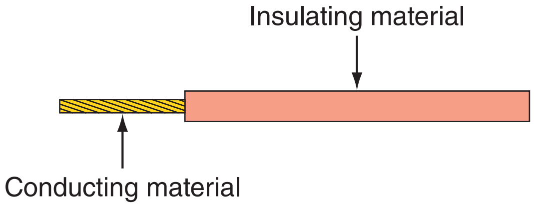


FIGURE 15-61 Basic construction of a wire.

move them. These materials are known as **insulators**. They resist the flow of current. Thermal plastics are the most common electrical insulators used today. They can resist heat, moisture, and corrosion without breaking down. Wire wound inside electrical units, such as relays and generators, usually has a very thin baked-on insulating coating.

> **Warning!** Your body is a good conductor of electricity. Remember this when working on a vehicle's electrical system. Always observe all electrical safety rules.

Copper wire is by far the most popular conductor. The resistance of a uniform, circular copper wire depends on the length, the diameter, and the temperature of the wire. If the length is doubled, the resistance between the wire ends is doubled. The longer the wire, the greater the resistance. If the diameter of a wire is doubled, the resistance for any given length is cut in half. The larger the wire's diameter, the lower the resistance.

Another important factor affecting the resistance of a wire is temperature. As the temperature increases, the resistance increases. Heat is developed in any wire-carrying current because of the resistance in the wire. If the heat becomes excessive, the insulation will be damaged. Resistance occurs when electrons collide as current flows through the conductor. These collisions cause friction, which in turn generates heat.

Wires

Two basic types of wires are used: solid and stranded. Solid wires are single-strand conductors. Stranded wires are the most common and are made up of a number of small solid wires twisted together to form a single conductor **(Figure 15–62)**.

Wire size standards were established by the Society of Automotive Engineers (SAE). These standards are called the **American wire gauge (AWG)** system. Sizes are identified by a numbering system ranging from gauge size 0 to 40, with number 0 being the largest and number 40 the smallest

FIGURE 15-62 A stranded wire.

in a cross-sectional area. Most automotive wiring range from number 10 to 24, with battery cables normally 4 gauge or lower. Battery cables must be large gauge wires because of the heavy current they must carry.

Some manufacturers list wire size in metric sizes. Metric wiring sizes are based on the cross-sectional area of the wire. The stated gauge size of a metric wire goes up as the wire's diameter increases. This is the opposite of the AWG system. **Table 15–3** gives the closest equivalent size cross-references between metric and AWG wire sizes.

Automotive wiring can also be classified as primary or secondary. Primary wiring carries low voltage

TABLE 15-3 AWG WIRE GAUGE SIZE WITH METRIC EQUIVALENT

AWG Gauge #	Diameter in inches	Diameter in mm	Approx. Metric Equivalent Size
4	0.2043	5.189	19.0
6	0.1620	4.115	13.0
8	0.1285	3.264	8.0
10	0.1019	2.588	5.0
12	0.08081	2.053	3.0
14	0.06408	1.628	2.0
16	0.05082	1.291	1.0
18	0.04030	1.024	0.8
20	0.03196	0.8118	0.5
22	0.02535	0.6439	0.36
24	0.02010	0.5105	0.22

to all the electrical systems of a vehicle except to the secondary circuit of the ignition system. Secondary wires, also called high-tension cables, have extra thick insulation to carry high voltage from the ignition coil to the spark plugs. The conductor itself is designed for low currents.

Wires are commonly grouped together in harnesses. Harnesses and harness connectors help organize the electrical system and provide a convenient starting point for tracking and testing many circuits. Most major wiring harness connectors are located in the dash or fire wall area **(Figure 15–63)**.

Flat Wiring As the number of installed electrical and electronic devices increases, so does the need for more wiring. This leads to more weight and more potential problems. The size and number of wiring harnesses also increases and the spots to carefully tuck them away are limited. For example, a large wiring harness has a difficult time fitting between the roof and the headliner of the vehicle. A common way to reduce the bulk of many standard wiring harnesses is to use flat wiring.

Flat wiring reduces the bulge or thickness of a harness. The copper conductors are flattened and are no longer round in appearance. Several flat wires are laid out next to each other and are covered with a plastic insulating material. The plastic offers protection and isolation to the conductors and keeps the harness flat and flexible. In the future, flat wiring may also have electronic components embedded in it. With this design, the wiring harness is not only easier to hide in body panels but also serves as a flexible printed circuit able to be located nearly anywhere in the vehicle.

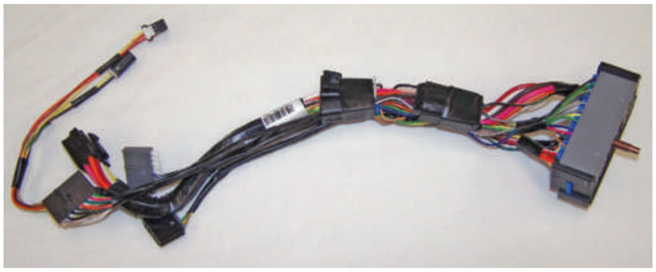


FIGURE 15–63 A typical partial wiring harness that connects to a connector on the fire wall.

Printed Circuits Many vehicles use flexible printed circuits **(Figure 15–64)** and printed circuit boards. Both types of printed circuits allow for complete circuits without the need to run dozens of wires. Printed circuit boards are typically contained in a housing, such as the engine control module. These boards are not serviceable and in some cases not visible. When these boards fail, the entire unit is replaced.

A flexible printed circuit saves weight and space. It is made of thin sheets of nonconductive plastic onto which conductive metal, such as copper, has been deposited. Parts of the metal are then etched or eaten away by acid. The remaining metal lines form the conductors for the various circuits on the board. The printed circuit is normally connected to the power supply or ground wiring through the use of plug-in connectors mounted on the circuit sheet.

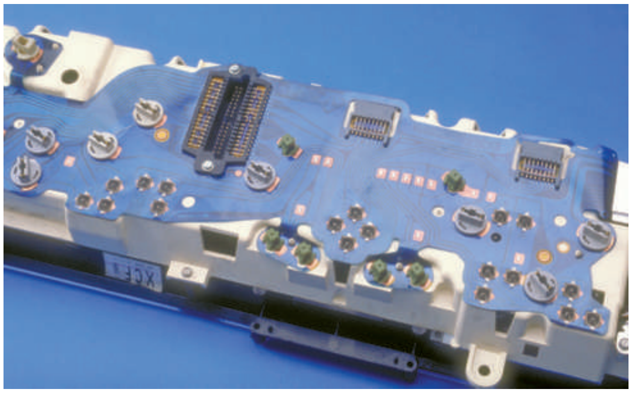


FIGURE 15–64 A typical printed circuit board.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2002	**Make:** Dodge	**Model:** Ram 1500	**Mileage:** 155,581	**RO:** 15078
Concern:	Customer installed light bar. The lights do not look as bright as they should.			
The technician confirms that the lights do not appear very bright. When checking voltage to the lights, she measures 12.4 volts on the positive side and 4.4 volts on the ground side..				
Cause:	Checked wiring between the lights and ground bolt. Found excessive voltage drop on the ground circuits. Lights were bolted to roll bar.			
Correction:	Inspection of the wiring determined that the ground connection at the roll bar was not adequate. Ran a new ground to a clean body ground. Lights worked properly and were bright.			

KEY TERMS

Alternating current (AC)
American wire gauge (AWG)
Ampere
Chassis ground
Circuit breaker
Closed circuit
Conductor
Continuity
Current
Direct current (DC)
Electromotive force (EMF)
Electronics
Fusible link
Ganged
Ground wire
Impedance
Induction
Insulator
Magnetism
Maxi-fuse
Multiple-pole, multiple throw (MPMT)
Ohm
Ohm's law
Open circuit
Parallel circuit
Pole
Potentiometer
Relay
Resistance
Rheostat
Sensor
Series circuit
Series-parallel circuit
Sine wave
Stepped resistor
Tapped resistor
Thermistor
Throw
Variable resistor
Voltage
Voltage drop
Watt

SUMMARY

- Electricity results from the flow of electrons from one atom to another.
- The greater the number of electrons flowing past a given point in a given amount of time, the more current the circuit has. The unit for measuring electrical current is the ampere.
- There are two types of current: direct current (DC) and alternating current (AC). In direct current, the electrons flow in one direction only. In alternating current, the electrons change direction at a fixed rate.
- Voltage is electrical pressure or the force developed by the attraction of the electrons to protons.
- Resistance is measured in ohms, which is a measurement of the amount of the resistance something has to current flow.
- A completed electrical circuit is called a closed circuit, whereas an incomplete circuit is called an open circuit. When a circuit is complete, it is said to have continuity.
- The amount of electricity consumed by a load is normally called electrical power usage or watts.
- The mathematical relationship between current, resistance, and voltage is expressed in Ohm's law, $E = IR$.
- Voltage drop is the amount of voltage required to cause current flow through a load.
- Most automotive circuits contain five basic parts: power sources, conductors, loads, controllers, and circuit protection devices.
- There are three basic types of automotive electrical circuits: series circuits, parallel circuits, and series-parallel circuits.
- A series circuit consists of one or more resistors connected to a voltage source with only one path for electron flow.
- A parallel circuit provides two or more different paths for the current to flow through.
- In a series-parallel circuit, both series and parallel combinations exist in the same circuit.
- Resistors limit current flow.
- Fuses, fuse links, maxi-fuses, and circuit breakers protect circuits against overloads.
- Switches control on/off and direct current flow in a circuit.
- A relay is an electric switch.
- A solenoid is an electromagnet that translates current flow into mechanical movement.
- Controlling and routing the flow of electricity requires the use of materials known as conductors and insulators.
- Two basic types of wires are used: solid and stranded. Solid wires are single-strand conductors. Stranded wires are the most common and are made up of a number of small solid wires twisted together to form a single conductor.

REVIEW QUESTIONS

Short Answer

1. What is represented by the E, I, and R in the formula $E = IR$?
2. What are the two types of wires and which is the most commonly used in automobiles?
3. Define voltage drop.
4. Define circuit protection.
5. What happens in an electrical circuit when the resistance increases?
6. What is the difference between voltage and current?
7. What is an SPST switch?

8. Solve the parallel circuit for total circuit resistance, total circuit amperage, and the amperage through each leg **(Figure 15–65)**.

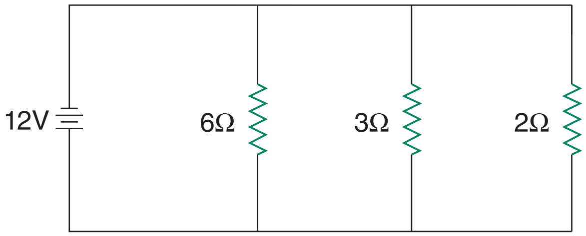


FIGURE 15-65

True or False

1. *True or False?* In a parallel circuit, circuit current is the same throughout all parts of the circuit.
2. *True or False?* An open switch is one that can flow current through it.

Multiple Choice

1. Which type of resistor is commonly used in automotive circuits?
   a. Fixed value
   b. Stepped
   c. Variable
   d. All of the above
2. Which of the following is *not* a characteristic of parallel circuits?
   a. Total circuit resistance is always less than the resistance of the leg with the lowest total resistance.
   b. The current through each leg will be different if the resistance values are different.
   c. The sum of the resistance in each leg equals the total circuit resistance.
   d. Source voltage will be dropped across each leg of the parallel circuit.
3. Which of the following states that the sum of the voltage drops in a closed circuit equals the voltage applied to the circuit?
   a. Ohm's law
   b. Watt's law
   c. Kirchhoff's law
   d. Power law
4. Which of the following is *not* a true statement about blade fuses?
   a. They are available in several different sizes.
   b. They are color coded according to their voltage capacity.
   c. They are normally in an underhood fuse block.
   d. They allow the vehicle's electrical system to be broken down into small circuits.
5. Which of the following is commonly used as a transmission neutral start switch?
   a. Mercury
   b. Momentary
   c. MPMT
   d. SPST

ASE-STYLE REVIEW QUESTIONS

1. While discussing resistance: Technician A says that current will decrease with a decrease in resistance. Technician B says that current will decrease with an increase in resistance. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. Technician A says that a 12-volt light bulb that draws 12 amps has a power output of 1 watt. Technician B says that a motor that has 1 ohm of resistance has a power rating of 144 watts if it is connected to a 12-volt battery. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. While discussing the circuit shown in **Figure 15–66**: Technician A says that the total resistance of the circuit is 1 ohm. Technician B says that the current flow through the 6-ohms of resistance is 12 amps. Who is correct?

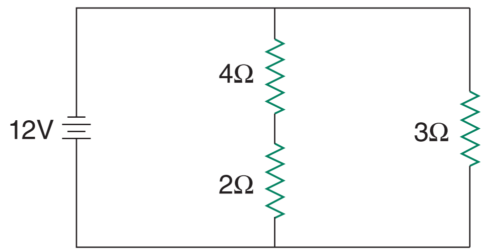


FIGURE 15-66

   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

4. While discussing electrical grounds: Technician A says that a component may be grounded through its mounting to a major metal part. Technician B says that some components must be grounded by connecting its positive terminal to a metal section of the frame. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. While discussing voltage drop: Technician A says voltage drops in a closed circuit must equal source voltage. Technician B says that voltage drops can be calculated by multiplying circuit voltage times the load's resistance. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. While discussing electrical relays: Technician A says that the relay's coil is energized when the circuit's control switch is open. This action connects power to the load circuit. Technician B says that a relay is an electric switch that allows a large amount of current to control a low-current circuit. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. While discussing copper wire: Technician A says that if the length of wire is doubled, the resistance between the wire ends is doubled. Technician B says that if the diameter of a wire is doubled, the resistance between the wire ends is doubled. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. While discussing current flow: Technician A says that current results from electrons being attracted to protons. Technician B says that for practical purposes, it is best to remember that current flows from a point of higher potential to a point of lower potential. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. While discussing voltage: Technician A says that voltage is the force developed by the attraction of the electrons to protons. Technician B says that the force developed by the attraction of electrons to protons is called electromotive force and it is measured in volts. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While discussing the AWG system: Technician A says that most automotive wiring range from 0 to 4 gauge. Technician B says that the higher the gauge number, the larger the diameter of the wire. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

GENERAL ELECTRICAL SYSTEM DIAGNOSTICS AND SERVICE

CHAPTER 16

OBJECTIVES

- Describe the different possible types of electrical problems.
- Read electrical diagrams.
- Perform troubleshooting procedures using meters, testlights, and jumper wires.
- Describe how each of the major types of electrical test equipment are connected and interpreted.
- Explain how to use a DMM for diagnosing electrical and electronic systems.
- Explain how to use an oscilloscope for diagnosing electrical and electronic systems.
- Test common electrical components.
- Use wiring diagrams to identify circuits and circuit problems.
- Diagnose common electrical problems.

Diagnosing nearly every system of a vehicle involves electrical and electronic systems. An understanding of how electrical/electronic systems work **(Figure 16–1)** and the knowledge of how to use the various types of test equipment are the keys to efficient diagnosis.

Electrical Problems

All electrical problems can be classified into one of three categories: opens, shorts, or unwanted or high-resistance problems. Identifying the type of problem allows technicians to identify the correct tests to perform when diagnosing an electrical problem. An explanation of the different types of electrical problems follows.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2010	**Make:** Mazda	**Model:** RX-8	**Mileage:** 118,551	**RO:** 15875
Concern:	Customer states stop lights do not work. When he replaced the fuse, it blew as soon as the brake pedal was pressed.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

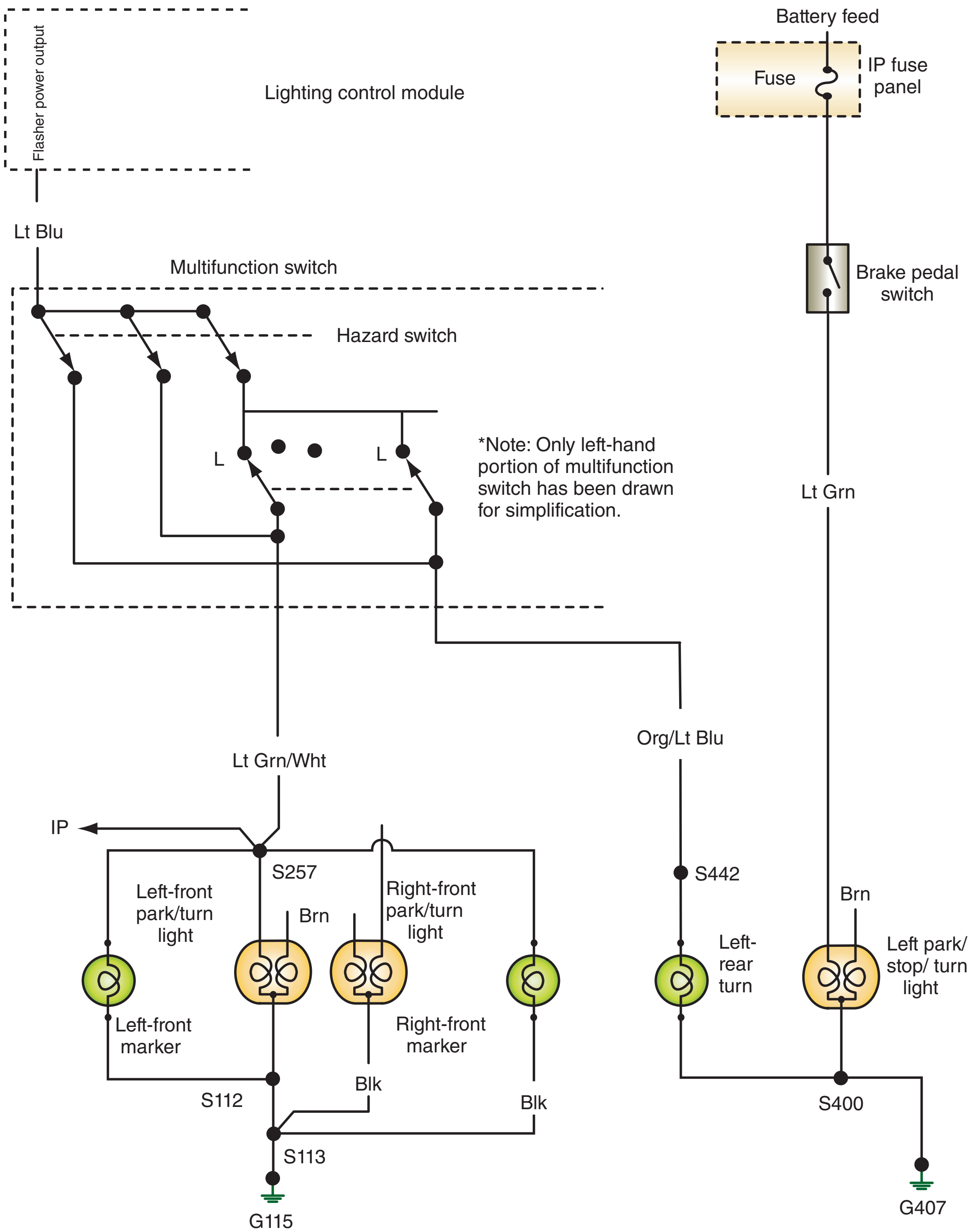


FIGURE 16–1 Repairing electrical systems requires understanding how they work.

Open Circuits

An open occurs when a circuit is incomplete. Without a completed path, current cannot flow **(Figure 16–2)**, voltage is not dropped, and the load or component will not work. An open circuit can be caused by a disconnected wire or connector, a broken wire, or a switch in the off position. When a circuit is off, it is open. When the circuit is on, it is closed. Switches open and close circuits, but at times a fault, such as worn or burned contacts in the switch will cause an open. Opening a circuit stops current flow through the circuit. Voltage is still applied up to the open point, but because there is no current flow no voltage is dropped by the load. Without current flow, there are no voltage drops across the various loads.

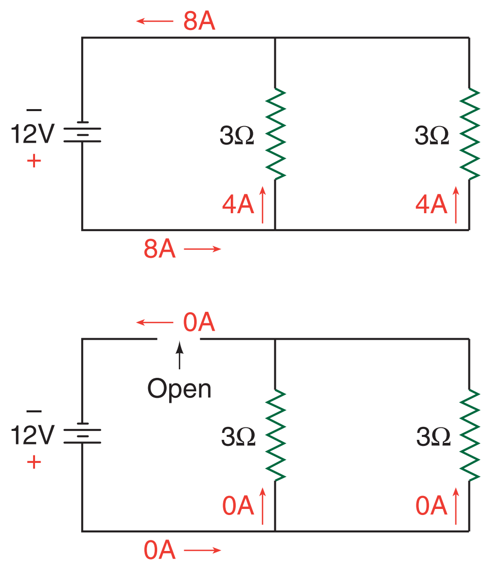


FIGURE 16–2 In an open circuit, there is no current flow in the circuit due to the open.

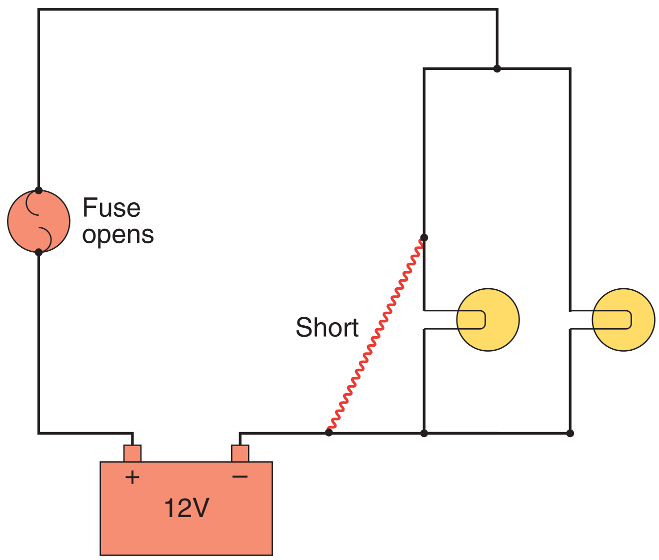


FIGURE 16–3 A short to ground.

Shorted Circuits

When a circuit has an unwanted path for current to follow, it has a **short**. Shorts can be either to power or to ground. A short circuit is sometimes referred to as a low-resistance circuit. When an energized wire accidentally contacts the frame or body of the car or another wire, circuit current can travel in unintended directions through the wires. This can cause uncontrollable circuits and high current through the circuits. Shorts are caused by damaged wire insulation, loose wires or connections, damaged connections, improper wiring, or careless installation of accessories.

A short creates an unwanted parallel leg or path in a circuit. If the short is to ground, circuit resistance decreases and current increases. The amount that the current will increase depends on the resistance of the short. The increased current flow can burn wires or components. Preventing this is the purpose of circuit protection devices. When a circuit protection device opens due to higher than normal current, a short is the likely cause. Also, if a connector or group of wires shows signs of burning or insulation melting, high current is the cause.

A short can be caused by a number of things and can be evident in a number of ways. The short is often in parallel to a load and provides a low-resistance path to ground. Look at **Figure 16–3**; this short is caused by bad insulation that allows the power feed for the lamp to touch the ground for the same lamp. This creates a parallel circuit. **Figure 16–4** represents Figure 16–3 but is drawn to show the short as a parallel leg with very low resistance. The resistance assigned to the short may be more or less than an actual short, but

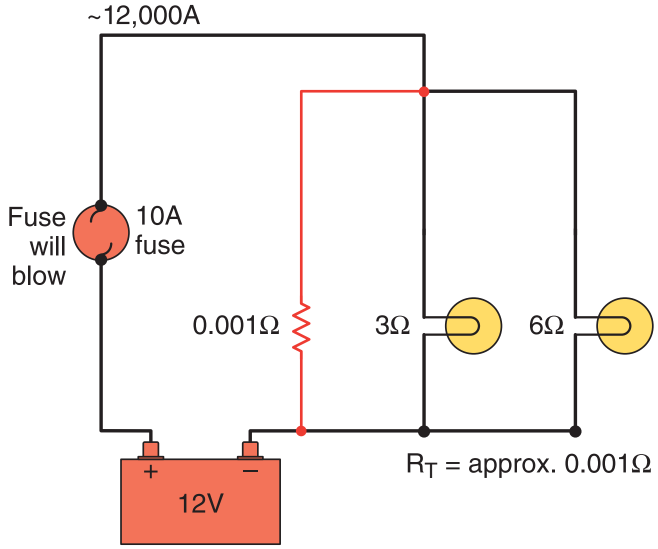


FIGURE 16–4 Ohm's law applied to Figure 16–3. Notice the rise in circuit amperage.

the value 0.001 ohm is given to illustrate what happens. With the short, the circuit has three loads in parallel: 0.001, 3, and 6 ohms. The total resistance of this parallel circuit is less than the lowest resistance or 0.001 ohm. Therefore the circuit's current is more than 12,000 amps, which is much more than the fuse can handle. The high current will burn the fuse and the circuit will not work. Some call this problem a "grounded circuit" or a "copper-to-iron" short.

Sometimes two separate circuits become shorted together. When this happens, each circuit is controlled by the other. This may result in strange happenings, such as the horn sounding every time the brake pedal is depressed **(Figure 16–5)**, or vice

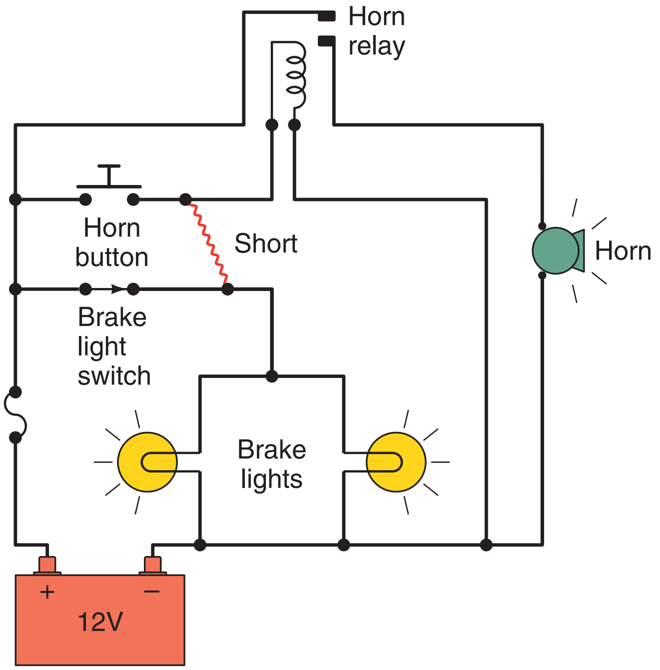


FIGURE 16–5 A wire-to-wire short.

versa. In this case, the brake light circuit is shorted to the horn circuit. This is often called a "copper-to-copper" or a "wire-to-wire" short.

Unwanted or High-Resistance Circuits

Resistance problems occur when there is unwanted resistance in the circuit. The higher than normal resistance causes the current flow to be lower and the components in the circuit cannot operate properly. A common cause of this problem is corrosion at a connector. The corrosion becomes an additional load in the circuit **(Figure 16–6)**. This load uses some of the circuit's voltage, which prevents full voltage to the circuit's normal loads. Because the resistance becomes a voltage drop, electrical energy is used and converted into another form of energy, typically heat. This can cause wiring and connectors to overheat and melt. So in addition to the intended load not operating correctly, the unwanted resistance can also cause damage to wiring and connectors.

Many sensors are fed a 5-volt reference signal. The signal or voltage from the sensor is less than 5 volts depending on the condition it is measuring. A poor ground in the reference voltage circuit can cause higher than normal readings back to the computer. This seems to be contradictory to other high-resistance problems. However, if you look at a typical voltage divider circuit used to supply the reference voltage, you will understand what is happening. In **Figure 16–7**, there are two resistors in series with a voltage reference tap between them. Because the total resistance in the circuit is 12 ohms, the circuit current is 1 amp. Therefore, the voltage drop across the 7-ohm resistor is 7 volts, leaving 5 volts at the tap.

Figure 16–8 is the same circuit, but a bad ground of 1 ohm was added. This resistance could be caused by corrosion at the connection. With the bad ground, the total resistance is now 13 ohms. This decreases our circuit current to approximately 0.92 amp.

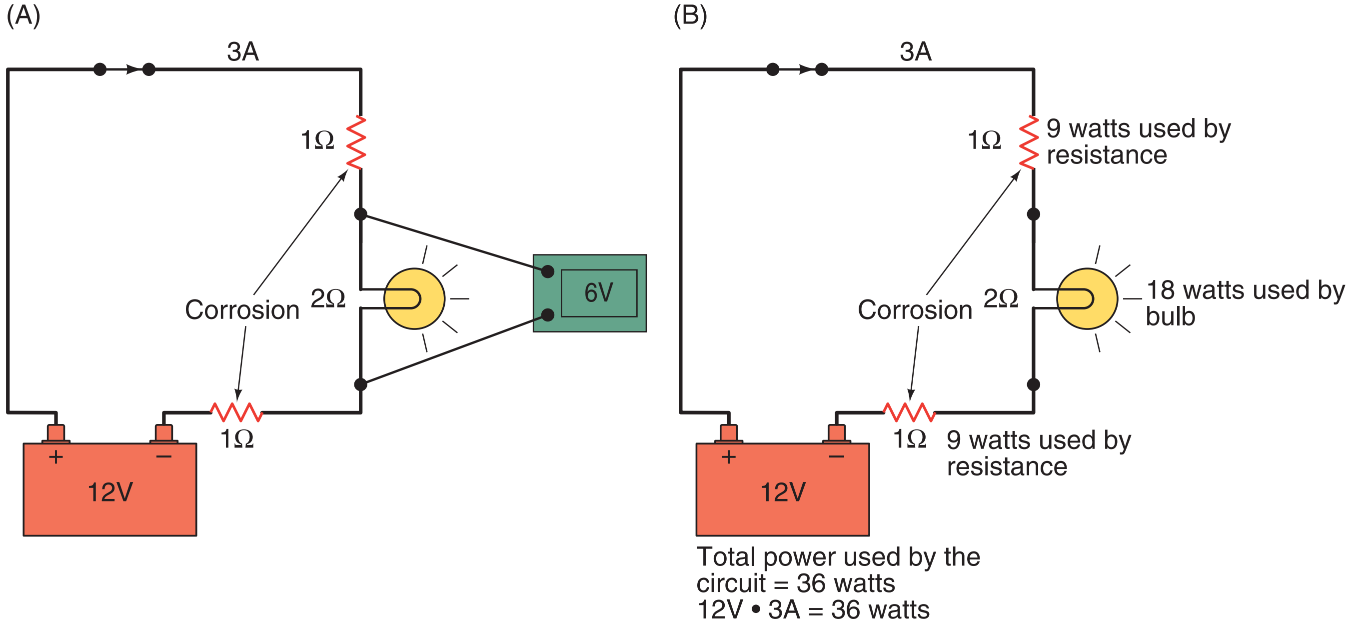


FIGURE 16–6 (A) A simple light circuit with unwanted resistance. (B) The amount of power (watts) consumed by each resistance.

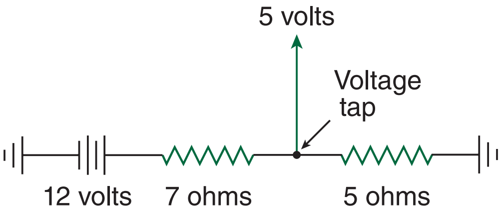


FIGURE 16–7 A voltage divider circuit.

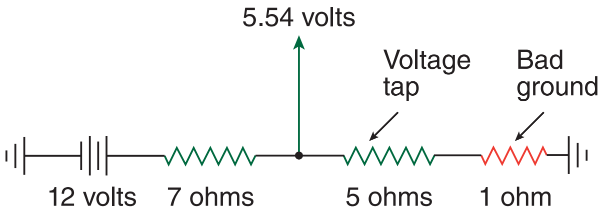


FIGURE 16–8 A voltage divider circuit with a bad ground.

With this lower amperage, the voltage drop across the 7-ohm resistor is now about 6.46 volts, leaving 5.54 volts at the voltage tap. This means the reference voltage would be more than one-half volt higher than it should be. Depending on the sensor and the operating conditions of the vehicle, this could be critical.

Electrical Wiring Diagrams

Wiring diagrams, sometimes called **schematics**, show how circuits are constructed. These diagrams are used to diagnose and repair a vehicle's electrical system. They identify the wires and connectors in every circuit of a vehicle. While doing this, they show where and how the components of a circuit are connected.

A wiring diagram does not show the actual location of the parts or their appearance, nor does it indicate the length of the wire that runs between components. It does show the color of the wire's insulation **(Figure 16–9)** and sometimes the wire gauge size. Typically the wire insulation is color coded as shown in **Table 16–1**. The first letter or set of letters usually indicates the base color of the insulation. The second set refers to the color of the stripe, hash marks, or dots on the wire, if there are any. Circuits are traced through a vehicle by identifying the beginning and end of a particular colored wire.

Many different symbols are used to represent components such as resistors, batteries, switches, transistors, and many other items. Some of these symbols have already been shown in earlier discussions. Other common symbols are shown in **Figure 16–10**.

Wiring diagrams can become quite complex. To avoid this, most diagrams usually illustrate one distinct system, such as the back-up light circuit, oil pressure indicator circuit, or wiper motor circuit. In more complex ignition, electronic fuel injection, and computer-controlled systems, a diagram may only illustrate a part of the entire circuit.

Connectors, splices, grounds, and other details are also given in a wiring diagram; a sample of these is shown in **Figure 16–11**.

Connector and Terminals

An electrical terminal is a copper, brass, or steel end crimped or soldered to a wire. When mated to another terminal, an electrical connection is made. These terminals are housed in plastic connectors. A connector slips into or over another connector, depending on the connection; a connector is either a male or female. As the connectors are snapped together, the internal terminals connect **(Figure 16–12)**. How the terminals are retained in a connector, depends on the type of connector. Here is a list of the common types of connectors.

- *Molded connector*—This type normally has one to four wires and terminals molded into a single unit.
- *Multiple-wire hard-shell connector*—This connector has a hard plastic shell that holds the terminals.
- *Bulkhead connector*—This connector is used when several wires must pass through the fire wall. Bulkhead connections often use a retaining bolt to prevent the connector from coming loose.
- *Weather-pack connector*—This connector is used when the terminals may be exposed to the environment. It has rubber seals to protect the terminals.

USING SERVICE INFORMATION

Electrical symbols are not standardized throughout the automotive industry. Different manufacturers may have different methods of representing certain components, particularly the less common ones. Always refer to the symbol reference charts, wire color code charts, and abbreviation tables listed in the service information to avoid confusion.

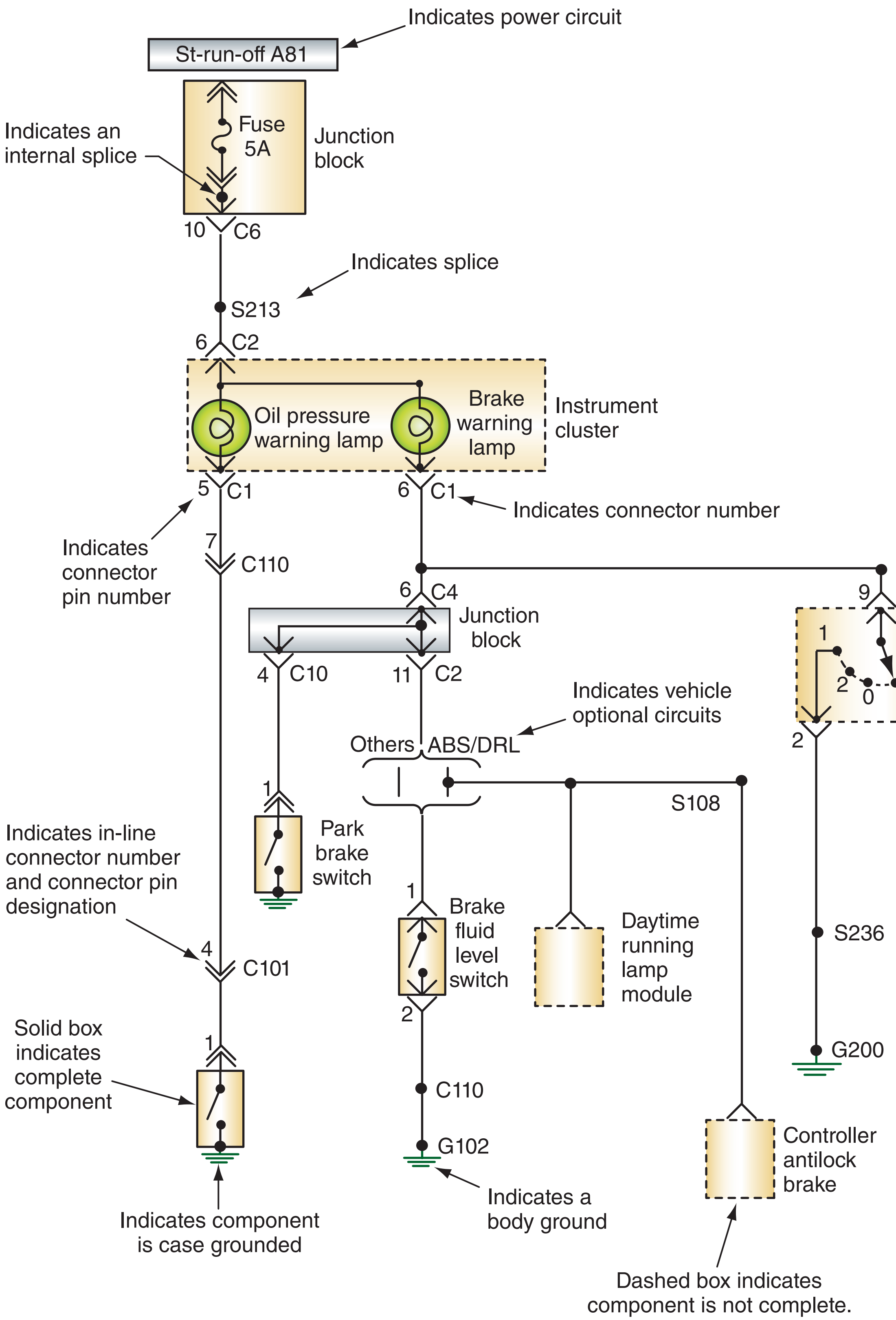


FIGURE 16–9 A wiring diagram for part of an instrument panel.

TABLE 16–1 STANDARD WIRE COLOR CODES

Color	Abbreviations		
Black	BLK	BK	B
Blue	BL	BLU	L
Dark Blue	BLU DK	DB	DK BLU
Light Blue	BLU LT	LB	LT BLU
Brown	BRN	BR	BN
Glazed	GLZ	GL	
Gray	GRA	GR	G
Green	GN	GRN	G
Dark Green	GRN DK	DG	DK GRN
Light Green	GRN LT	LG	LT GRN
Maroon	MAR	M	
Orange	ORN	O	ORG
Pink	PNK	PK	P
Purple	PPL	PR	
Red	RED	R	RD
Tan	TAN	T	TN
Violet	VLT	V	
White	WHT	W	WH
Yellow	YEL	Y	YL

- *Metri-pack connector*—Similar to a weather-pack connector without the seal.
- *Heat shrink covered butt connector*—A connector that serves as a single wire connection and is protected by shrink wrap. This type connection is normally found in air bag circuits.

Electrical Testing Tools

Several meters are used to test and diagnose electrical systems. These are the voltmeter, ohmmeter, ammeter, and volt/amp meter. These should be used along with jumper wires, testlights, and variable resistors (piles).

Multimeter

A multimeter is one of the most important tools for troubleshooting electrical and electronic systems. A basic multimeter measures DC and AC voltage, current, and resistance. Because most of today's multimeters have a digital display, they are commonly referred to as a digital multimeter or DMM **(Figure 16–13)**. Most DMMs also check engine speed, signal frequency, duty cycle, pulse width, diodes, and temperature. The desired test is selected by turning a control knob or depressing keys on the meter. These meters can be used to test simple electrical circuits, ignition systems, input sensors, fuel injectors, batteries, and starting and charging systems.

New DMMs A DMM with a wireless remote display is currently available. This meter has a detachable display that slides out of the body of the meter. The display can be placed where it can be easily seen, up to 10 meters away. This also allows for placing the meter at the best spot for taking measurements. The removable display has a magnetic back and flat bottom, which allows it to be placed or mounted on any flat surface. When the display assembly is in the meter's body, the meter will operate as a normal DMM.

Lab Scopes

Lab scopes are fast reacting meters that measure and display voltages within a specific period of time. The voltage readings appear as a waveform or trace on the scope's screen **(Figure 16–14)**. An upward movement of the trace indicates an increase in voltage, and a decrease in voltage results in a downward movement. These are especially valuable when watching the action of a circuit. The waveform displays what is happening and any problems can be observed when they happen. This gives the technician a chance to observe what caused the change.

Lab scopes are often used with pressure transducers and current clamps, sometimes called current probes. These devices convert a measurement, such as pressure, vacuum, or amperage into a voltage reading that is then displayed on the scope.

Scan Tools

A scan tool may be used as part of diagnosing an electrical issue because many of the systems on modern vehicles are computer controlled or monitored. A scan tool can retrieve fault codes from a computer's memory and digitally display these codes **(Figure 16–15)**. A scan tool may also perform other diagnostic functions depending on the year and make of the vehicle.

Trouble codes are typically set when a voltage signal is entirely out of its normal range. The codes help technicians identify the cause of the problem. If a signal is within its normal range but is still not

SYMBOLS USED IN WIRING DIAGRAMS			
+	Positive		Temperature switch
—	Negative		Diode
	Ground		Zener diode
	Fuse		Motor
	Circuit breaker	C101	Connector 101
	Condenser	→	Male connector
	Ohms		Female connector
	Fixed value resistor		Splice
	Variable resistor	S101	Splice number
	Rheostat		Thermal element
	Coil		Multiple connectors
	Open contacts	88:88	Digital readout
	Closed contacts		Single filament bulb
	Closed switch		Dual filament bulb
	Open switch		Light-emitting diode
	Ganged switch (N.O.)		Thermistor
	Single pole double throw switch		PNP bipolar transistor
	Momentary contact switch		NPN bipolar transistor
	Pressure switch		Gauge

FIGURE 16–10 Common electrical symbols used on wiring diagrams.

correct, the computer may or may not display a trouble code. However, a problem will still exist. As an aid to identify this type of problem, most manufacturers recommend that the signals to and from the computer be carefully looked at. This is done by observing the serial data stream or through the use of a breakout box **(Figure 16–16)**.

Other Test Equipment

Other electrical test equipment may be needed to diagnose an electrical circuit.

Circuit Testers

Circuit testers (testlights) are used to identify shorted and open circuits in electrical circuits. Low-voltage testers are used to troubleshoot 6- to 12-volt circuits. High-voltage circuit testers diagnose higher voltage systems, such as the secondary ignition circuit. High-impedance testlights are available for diagnosing electronic systems. However, most manufacturers do not recommend their use.

Nonpowered testlights are used to check for available voltage. With the wire lead connected to a good ground and the tester's probe at a point of voltage, the light turns on with the presence of voltage **(Figure 16–17)**. The amount of voltage determines the brightness of the light. By connecting the wire lead to power, the testlight can be used to check for ground. By inserting the testlight in place of a component, such as a light or motor that is not working, the light can indicate if current is flowing through the circuit when the circuit is turned on.

A self-powered testlight is used to check for continuity. Hooked across a circuit or component, the light turns on if the circuit is complete. A powered testlight should only be used if the power for the circuit or component has been disconnected.

Jumper Wires Jumper wires are used to bypass individual wires, connectors, or components. Basically a jumper wire is a wire about 18 inches long with an alligator clip on each end of the wire. Bypassing a

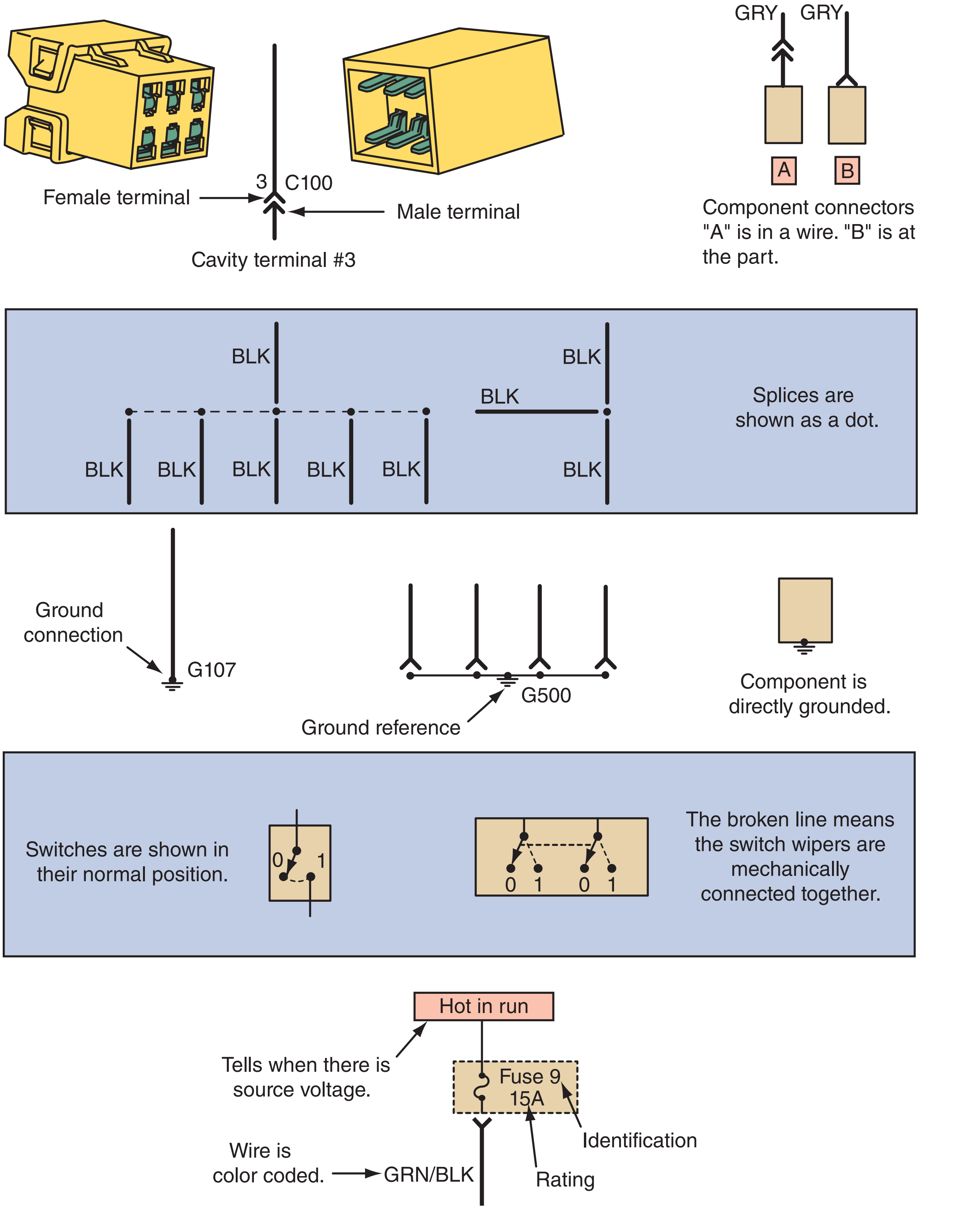


FIGURE 16–11 Examples of the information contained in a typical wiring diagram.

component or wire helps to determine if that part is faulty **(Figure 16–18)**. If the symptom is no longer evident after the jumper wire is installed, the part bypassed is faulty. It is always recommended to only use a fused jumper wire. These jumper wires have a circuit breaker or fuse between the two ends. The purpose of these is to protect the tested circuit from excessive current.

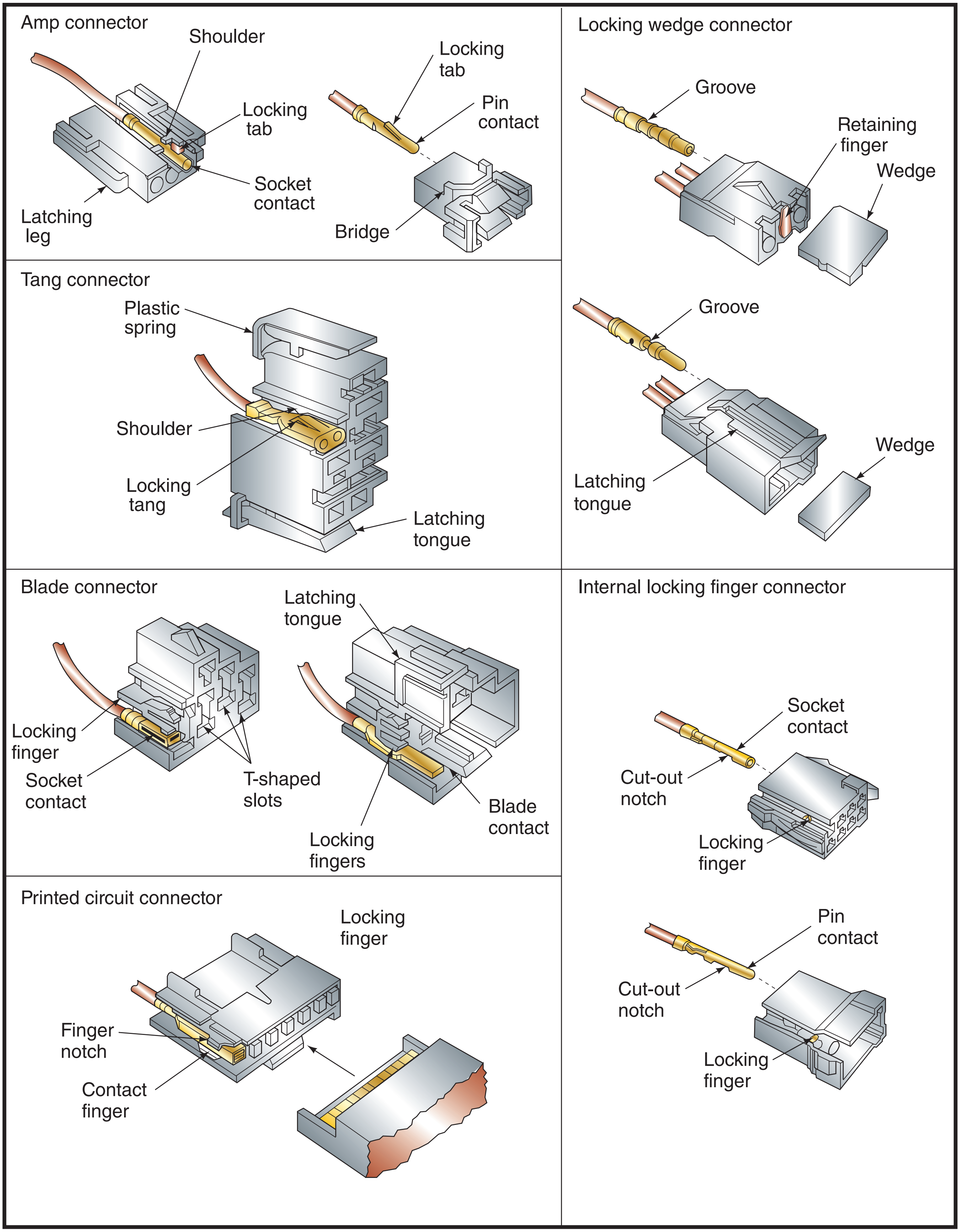


FIGURE 16-12 Various multiple wire hard shell connectors.

FIGURE 16–13 A DMM.

FIGURE 16–15 A typical scan tool.

Computer Memory Saver Whenever a vehicle's battery needs to be disconnected, connect a memory saver to the vehicle. This tool is designed to maintain the memory of the electronic systems when the power source is disconnected. Use of this tool prevents loss of drivability codes, diagnostic codes, anti-theft radio codes, keyless entry codes, radio presets, cellular phone settings, comfort settings, and other memory-related functions.

Memory savers that plug into the OBD II DLC connect only to the positive and ground pins at the connector. Therefore, they will not affect any stored fault codes or other diagnostic information. The OBD II connector is attached to a long cord, which allows for connection to a remote power source. Some also include an adapter for the cigarette lighter receptacle. All power leads have a built-in fuse or resettable circuit breaker to protect the circuits. Others are contained in a protective carrier and contain a sealed automotive battery with a state-of-charge indicator.

Some memory savers are part of a multi-functional assembly. These may also be used as a 12-volt source for jump starting an engine, a long-term source of 12-volt power, and the source of power for emergency lights and cordless tools. They are equipped with a maintenance-free, sealed battery or a gel battery and may have an LED display that shows the internal battery's state-of charge.

If you connect the memory saver under the hood, use care if you connect it to the battery cable clamps **(Figure 16–19)**. Removing and reinstalling the battery may dislodge the memory saver's alligator clips and make it useless. Instead, you can connect the saver's negative (–) lead to a good engine ground and the positive (+) lead to a point that is hot at all

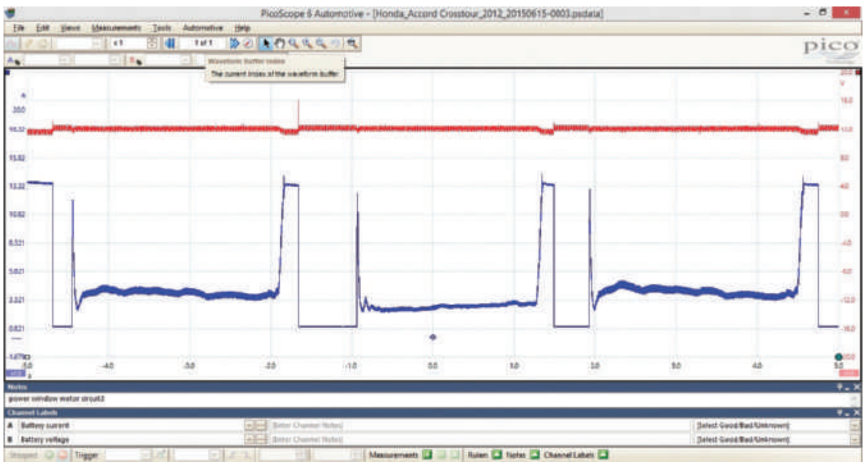


FIGURE 16–14 Voltage and current flow in a power window motor circuit.

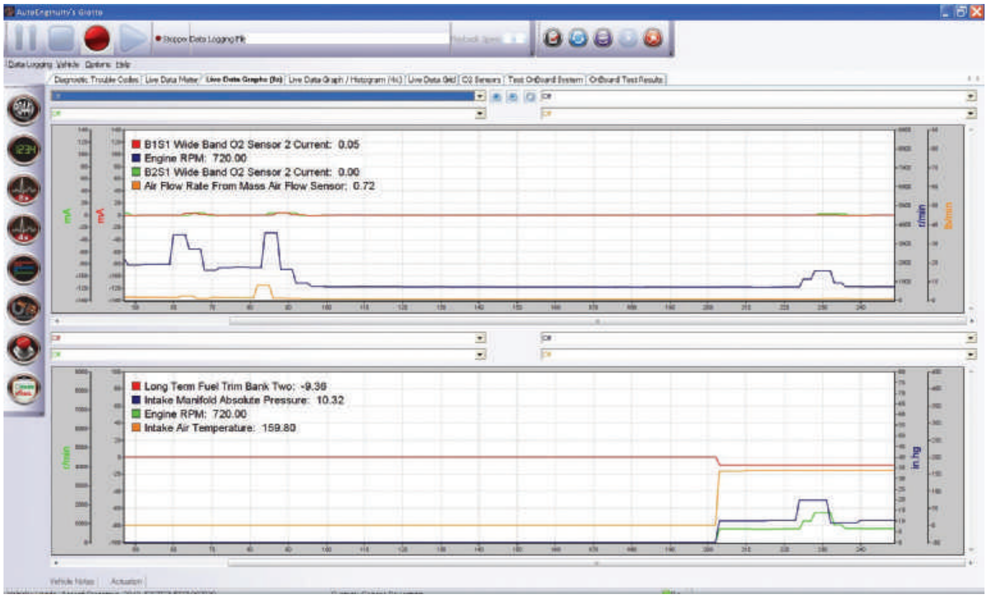


FIGURE 16–16 An example of the data graphed on a scan tool.

FIGURE 16–17 A testlight will illuminate when the probe is touched to a part of the circuit that is powered.

FIGURE 16–19 Using an external power source as a memory saver.

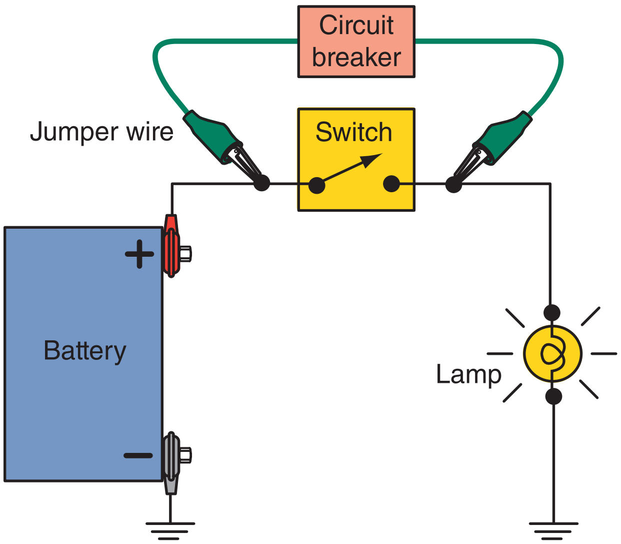


FIGURE 16–18 A jumper wire can be used to bypass a switch.

times, such as the battery connection at the generator or junction box.

Backprobing Tools Often testing electrical circuits requires a technician to backprobe a connector to allow a test lead to contact a terminal inside the connector. To do this, a backprobing tool **(Figure 16–20)** is slid into the backside of the connector. Once the tool contacts the terminal of the desired wire, the lead of a meter can be connected to the metal portion of the probe that extends out of the connector **(Figure 16–21)**. The proper use of these tools will prevent damage to the connector and its seals. Attempting to force a backprobe tool or meter lead into a female terminal can damage the terminal and expand its opening. This can create an open or intermittent connection once the connector is reattached.

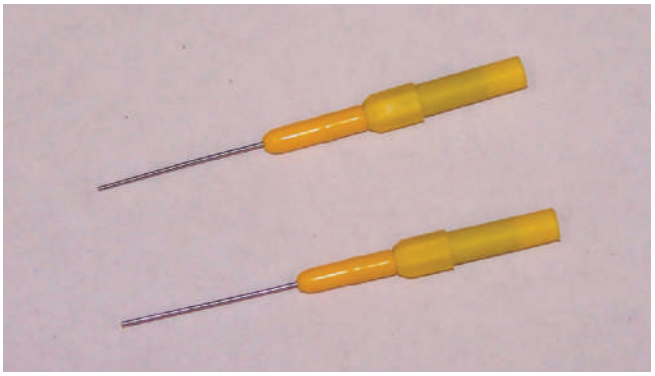


FIGURE 16–20 Backprobing tools.

FIGURE 16–21 A backprobing tool properly inserted into the back of a connector.

Using Multimeters

Multimeters are available with either analog or digital displays. Analog meters use a needle to point to a value on a scale and are seldom used on today's vehicles. Analog meters should not be used to test electronic parts. They have low internal resistance (input impedance). The low input impedance allows too much current to flow through circuits and can damage delicate electronic devices.

A digital meter shows the value in numbers or digits. The most commonly used meter is DMM, sometimes called a digital volt/ohm meter (DVOM). DMMs have high input impedance, 1 megohm (million ohms) to 10 megohms or more **(Figure 16–22)**. And, the metered voltage for resistance tests is below 5 volts, reducing the risk of damage to delicate electronic components and circuits.

The front of a DMM is normally comprised of four sections: the display area, range selectors, mode selector, and jacks for the test leads **(Figure 16–23)**. In the center of the display are large digits that represent

FIGURE 16–22 Two meters showing internal resistance (left) and the voltage output when measuring resistance (right).

SHOP TALK

The DMM used on high-voltage systems in hybrids should be classified as a category III or category IV meter. There are basically four categories for electrical meters, each built for specific purposes and to meet certain standards. The categories define how safe a meter is when measuring certain circuits. The standards for the various categories are defined by the American National Standards Institute, the International Electrotechnical Commission, and the Canadian Standards Association. A CAT III or CAT IV meter is required for testing hybrid vehicles because of the high voltages, three-phase current, and the potential for high transient voltages. Transient voltages are voltage surges or spikes that occur in AC circuits. To be safe, you should have either a CAT III or IV 1,000-volt meter and CAT III or IV rated meter leads. Within a particular category, meters have different voltage ratings that reflect the ability to withstand transient voltages. Therefore, a CAT III 1,000-volt meter offers much more protection than a CAT III meter rated at 600 volts (Figure 16–23).

FIGURE 16–23 The front of a DMM normally has four distinct sections: the display area, range selectors, mode selector, and jacks for the test leads.

the measured value. Normally there are four to five digits with a decimal point. To the right of the number, the units of measurement are displayed (V, A, or Ω). These units may be further defined by a symbol to denote a value of more or less than one **(Figure 16–24)** and the type of voltage **(Figure 16–25)**.

Setting the range on a DMM is important. The range on some DMMs is manually set. If the measured value is beyond the set range, the meter will display an infinite reading of "OL" or over limit. In the meter shown in **Figure 16–26A**, to measure battery voltage, the meter must be set to the 40 V scale. Even though the 4 V setting is closer to battery voltage, this

Symbol	Name	Value
mV	millivolts	volts × 0.001
kV	kilovolts	volts × 1,000
mA	milliamps	amps × 0.001
µA*	microamps	amps × 0.000001
KΩ	kilo-ohms	ohms × 1,000
MΩ	megohms	ohms × 1,000,000

*Automotive technicians seldom use readings at the microamp level.

FIGURE 16–24 Symbols used to define the value of a measurement on a DMM.

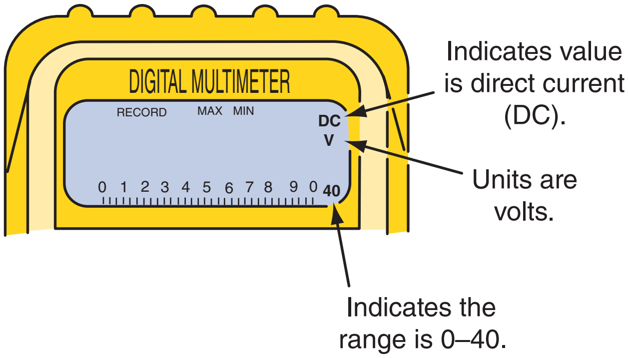


FIGURE 16–25 The measurement display also shows other important information. Some of this defines the measured value, the type of voltage—AC or DC—and the range selected on the meter.

setting only reads up to 4 volts, making it useless for trying to measure most automotive circuits. Other meters have an "auto range" feature, in which the appropriate scale is automatically selected by the meter **(Figure 16–26B)**. Auto ranging is helpful when you do not know what value to expect. When using a meter with auto range, make sure you note the range being used by the meter. There is a big difference between 10 ohms and 10,000,000 (10 M) ohms.

Warning! Many DMMs with auto range display the measurement with a decimal point. Make sure you observe the decimal and the range being used by the meter as shown in Figure 16–27 **(Figure 16–27)**. A reading of 0.972 kilo ohm equals 972 ohms. If you ignore the decimal point, you will interpret the reading as 972,000 ohms or as 0.972 ohms.

(A) (B)

FIGURE 16–26 (A) A DMM that requires setting measurement ranges. (B) An auto-ranging DMM.

0.345 KΩ = 345 Ω

1025 mAmps = 1.025 Amps

FIGURE 16–27 Placement of decimal point and the scale should be noticed when measuring with a meter with auto range.

The mode selector defines what the meter will be measuring. The number of available modes varies with meter design, but nearly all have the settings shown in **Figure 16–28**.

Most DMMs have two test leads and four input jacks. The black test lead always plugs into the COM input jack and the red lead plugs into one of the other input jacks, depending on what is being measured. Often technicians have multiple sets of test leads, each for specific purposes. For example, a lead set with small tips is ideal for probing in hard-to-reach or tight spaces. Other test leads may be fitted with alligator clips to hold the lead at a point during testing.

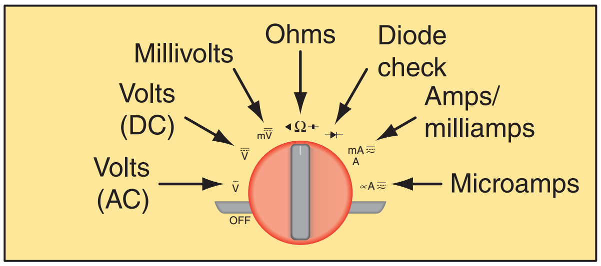


FIGURE 16–28 The mode selector defines what the meter will be measuring.

Typically, the three input jacks are:

- "A" for measuring up to 10 amps of current
- "A/mA" for measuring up to 400 mA of current
- "V/Ω/diode" for measuring voltage, resistance, conductance, capacitance, and checking diodes

Once the controls of the DMM are set correctly, the meter can be used as an ammeter, voltmeter, or ohmmeter **(Figure 16–29)**. It is important that the meter be properly connected to the circuit.

Warning! Improper setup and use of the meter, meaning selecting the wrong mode, placing the leads into the wrong jacks, or connecting the meter incorrectly to a circuit can cause personal injury and damage to the meter.

Measuring Voltage

A DMM can measure source voltage, available voltage **(Figure 16–30)**, and voltage drops. Voltage is measured by placing the meter in parallel to the component or circuit being tested.

In step three in the procedure to measure voltage, it states to connect the black meter lead to a good ground. You will often see references to connect something to a "good ground" but what does that mean? With the key on engine off (KOEO) the most negative point on the vehicle is the battery negative

PROCEDURE

To measure DC voltage follow these steps:

1. Set the mode selector switch to Volts DC.
2. Select the auto range function, or manually set the range to match the anticipated value. Normally, the range is set closer to and higher than 12 volts.
3. Connect the test leads in parallel to the circuit or component being tested. The red lead should be connected first to the most positive side (side closest to the battery). The black lead is connected to a good ground.
4. Read the measurement on the display. If the reading is negative, it is likely that the leads are reversed.

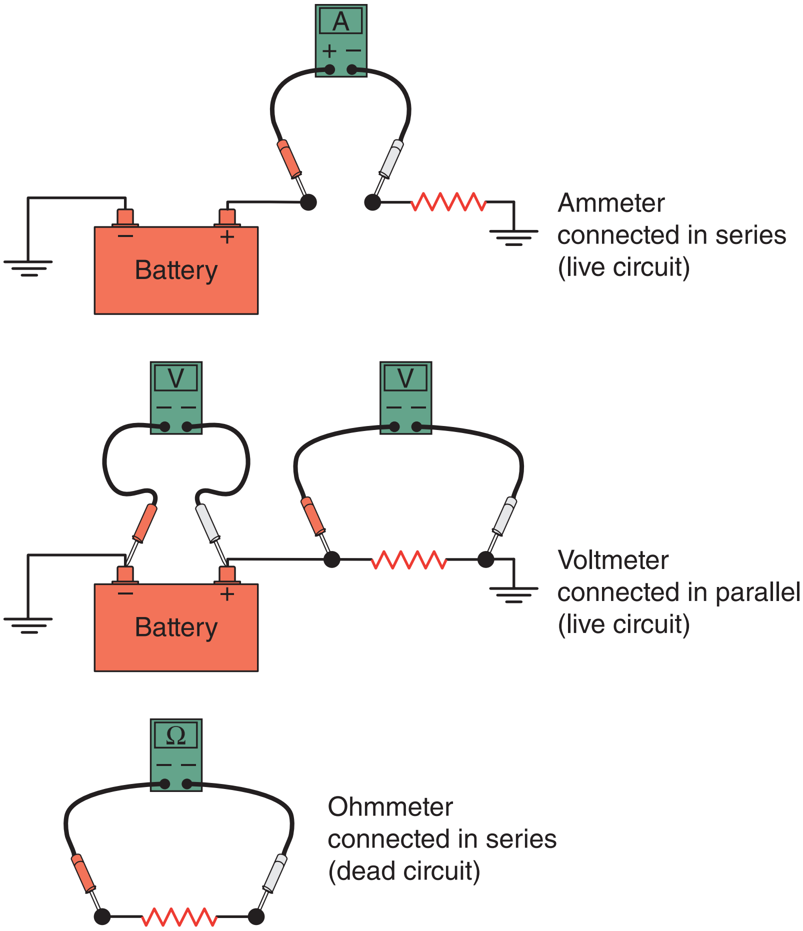


FIGURE 16-29 Correctly connected to a circuit, a DMM can be used as an ammeter, voltmeter, or ohmmeter.

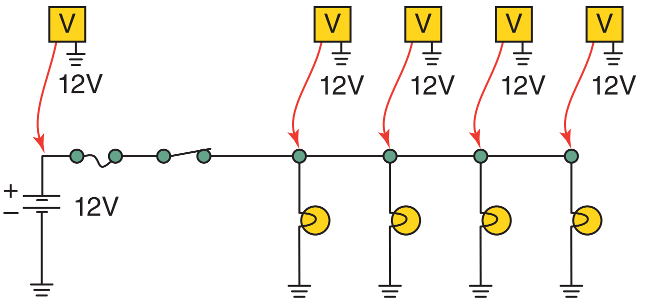


FIGURE 16-30 Checking available voltage at points within a circuit with a voltmeter.

terminal, which is a "good ground." However, once the engine is running, the generator case becomes the most negative point. The remainder of the vehicle's electrical system connects back to the battery negative through common grounds: the frame, body, and negative battery cable connections. If there is a problem, such as a loose or resistive connection between the engine or body and the negative cable, this will affect the ground circuit to which you attach your meter lead for a "good ground." To eliminate this issue, many technicians use the battery negative terminal as their grounding point when performing voltage tests. If testing a component that grounds to the engine and you are testing with the engine running, you should ground to the generator case or the engine block.

Warning! **Hybrid vehicles have much higher voltage; always follow all safety precautions and service procedures when working with high-voltage circuits.**

Voltage Drop Test Measuring voltage drop is a very important test. The test can be performed between any two points in a circuit and across any component, such as wires, switches, relay contacts and coils, and connectors. Photo Sequence 13 shows the basic steps for conducting a voltage drop test.

The test can find excessive resistance in a circuit that may not be detected by using an ohmmeter. An ohmmeter passes a small amount of current through

FIGURE 16–31 Measuring the voltage drop across the battery post and cable. It is easy to see why the voltage drop is high!

the component while it is isolated from the circuit. A voltage drop test is conducted with the circuit operating with normal amounts of current.

One of the common symptoms that require a voltage drop test is low battery voltage to the starter, generator, and other circuit **(Figure 16–31)**. Voltage drops should not exceed:

- 200 mV across a wire or connector
- 100 mV across a switch or relay contacts
- 100 mV at a ground connection
- 0 mV to < 50 mV across all sensor connections

To understand the true purpose of a voltage drop test, consider a simple circuit. If 12 volts are available at the battery and the switch is closed, there should be 12 volts available at each light. If, for example, less than 12 volts are measured, that means some additional resistance is somewhere else in the circuit. The lights may light but not as brightly as they should.

Figure 16–32 illustrates two headlights (2 ohms each) connected to a 12-volt battery using two wires. Each wire has an unwanted resistance of 0.05 ohm. The two headlights are wired parallel, and total resistance of the headlights is:

$$\frac{2 \text{ ohms} + 2 \text{ ohms}}{2 \text{ ohms} + 2 \text{ ohms}} = 1 \text{ ohm}$$

The total circuit resistance (including the unwanted resistance) is:

$$1 \text{ ohm} + 0.05 \text{ ohm} + 0.05 \text{ ohm} = 1.1 \text{ ohms}$$

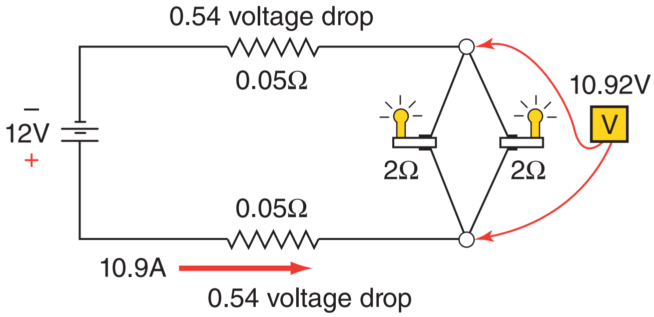


FIGURE 16–32 Wire resistance results in a slight voltage drop in the circuit.

Therefore, the current in the circuit is

$$I = \frac{E}{R} = \frac{12}{1.1} = 10.9 \text{ amperes}$$

The voltage drop across each wire is:

$$E = I \div R$$
$$E = 10.9 \div 0.05 = 0.54 \text{ V}$$

This means there is a total of 1.08 volts dropped across the wires. When the voltage drop of the wires is subtracted from the 12-volt source voltage, 10.92 volts remain for the headlights.

Without the resistance in the wires, the headlights receive 12 amperes. With the resistance, current flow was reduced to 10.9 amperes. The decreased current and voltage drop means the lights will not be as bright as normal. It is important to remember that voltage drops will be present in the electrical system and that less than battery voltage is commonly measured at components because of this. Each section of wire and connection drops a slight amount of voltage. It is when the voltage drops become excessive that problems occur.

Checking Circuit Grounds A DMM can be used to check for proper circuit grounding. For example, if the voltmeter shows battery voltage at a lamp but no lighting is seen, the bulb or socket could be bad or the ground connection is faulty. An easy way to check for a defective bulb is to replace it with one known to be good. You can also use an ohmmeter to check for continuity through the bulb. A dim bulb can be caused by excessive resistance in the ground circuit. Voltage drop testing can identify that problem.

If the bulb is not defective, the light socket or ground wires are bad. With the bulb installed in the connector, connect the voltmeter to the bulb's ground wire and a good ground as shown in **Figure 16–33**. If 0 volts is measured, move the positive meter lead to the power terminal for the bulb. If 0 volts is measured

PHOTO SEQUENCE 13

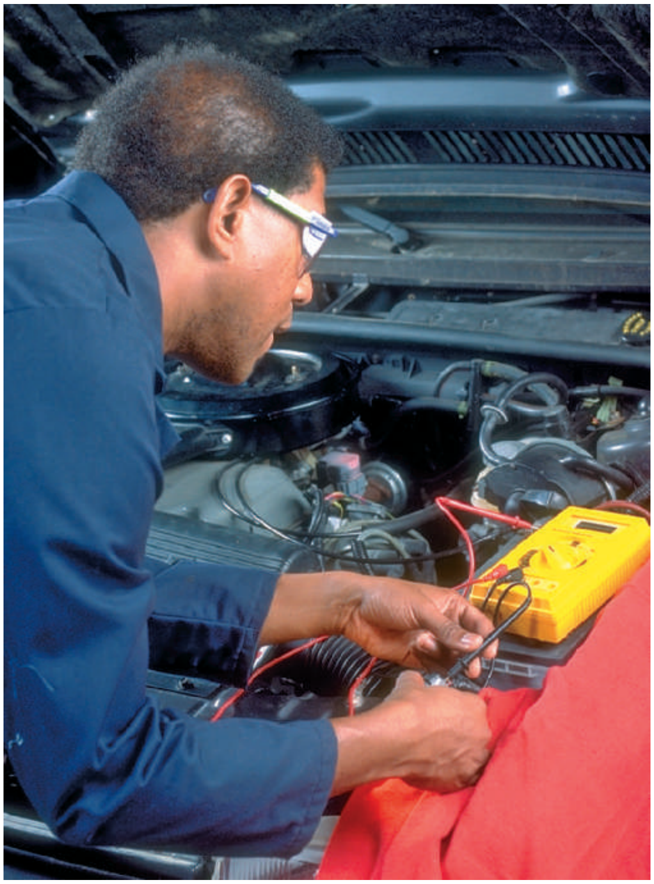
Performing a Voltage Drop Test

P13-1 The tools required to perform this task: a DMM, backprobing tool, and fender covers.

P13-2 Set the voltmeter on its lowest DC volt scale.

P13-3 To measure the voltage drop of the entire insulated part of the headlamp circuit, connect the positive test lead to the positive terminal at the battery, which is the most positive side of the circuit.

P13-4 Use the backprobing tool to connect the negative test lead into the low beam power terminal in the headlamp socket.



P13-5 Turn on the headlights (low beams) and observe the voltmeter's reading. This is the amount of voltage dropped across the circuit from the battery to the headlamp. Excessive voltage drops indicate excessive resistance (an unwanted load) in that portion of the circuit.

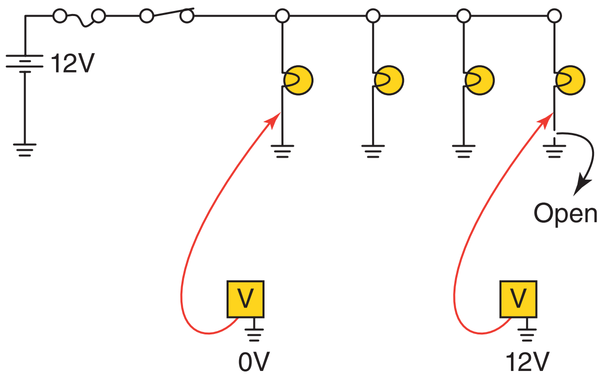


FIGURE 16-33 Using a voltmeter to check for open grounds.

there, the light socket or terminal is defective. In a normal light circuit, there should be close to 0 volts at the negative side of the bulb. If battery voltage is read on the bulb's ground terminal, there is an open in the ground circuit. If the socket is not defective and some voltage is measured at the ground, the ground circuit is faulty. The higher the voltage reading on the ground, the greater the voltage drop is in the ground circuit. This problem will cause the bulb to be dim or not light at all. Check the voltage drop of the circuit ground to the battery negative terminal. This reading will tell you how much voltage is being lost between the ground for the circuit and the battery. If the voltage drop is excessive, you will need to diagnose the ground circuit back to the battery to find the cause of the resistance.

Measuring AC Voltage A DMM may display AC voltage as peak-to-peak (Emax), **root mean square** (Erms) and **average responding** (Eavg). When an AC voltage signal is a true sine wave, these methods will display the same reading. Because most automotive sensors do not produce pure sine wave signals, it is important to know how the meter will display the AC voltage reading when comparing measured voltage to specifications. Peak-to-peak represents the span between the highest voltage and the lowest voltage peaks. For example, if the highest positive peak is 60 volts and the lowest negative peak is also 60 volts, there would be a peak-to-peak of 120 volts.

RMS meters convert the AC signal to a comparable DC voltage signal. Average responding meters display the average voltage peak. Both of these are based on peak voltages. Always check the voltage specification to see if the specification is for RMS voltage; if it is, use an RMS meter **(Figure 16–34)**.

Measuring Current

Measuring the current through a circuit gives a true picture of what is happening in the circuit. This is because the circuit is being tested under load. Low current indicates that the circuit has high resistance, and high current means the circuit has low resistance. Many technicians do not check current because few specifications list what should be normal. This should not be a problem because current can be calculated if you know the resistance and voltage in the circuit. Remember, to have current the circuit must be complete and there must be voltage applied to it.

The circuit in **Figure 16–35** normally draws 6 amps and is protected by a 10 amp fuse. If the circuit constantly blows the fuse, something has reduced circuit resistance and perhaps there is a short somewhere in the circuit. Mathematically, each light should draw 1.5 amperes ($6 \div 4 = 1.5$). To find the short, disconnect all lights by removing them from their sockets. Then, close the switch and read the ammeter. With the loads disconnected, the meter should read 0 ampere. If there is any reading, the wire between the fuse and the sockets is shorted to ground.

If 0 amp was measured, reconnect each light in sequence; the reading should increase 1.5 amperes with each bulb. If, when making any connection, the reading is higher than expected, the problem is in that part of the light circuit.

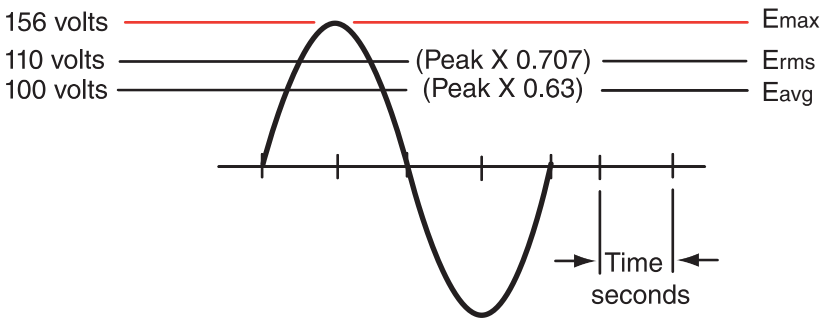


FIGURE 16-34 AC voltage: RMS.

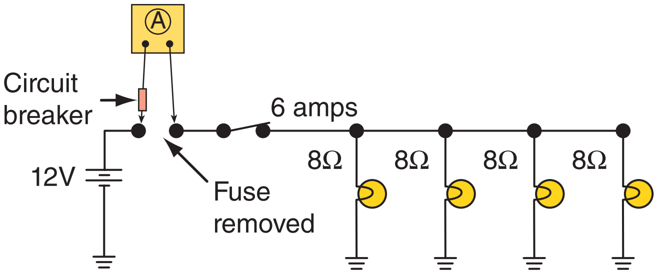


FIGURE 16–35 Checking a circuit using an ammeter.

> **Warning!** When testing for a short, never bypass the fuse with a wire and make sure a fuse is installed in the circuit. The fuse should be rated at no more than 50 percent higher capacity than specifications. This offers circuit protection and provides enough amperage for testing. After the problem is found and corrected, be sure to install a fuse with the specified rating.

PROCEDURE

To measure current follow these steps:

1. Turn off the circuit.
2. Connect the test leads to the correct input jacks on the DMM.
3. Set the mode selector to the correct current setting (normally amps or milliamps).
4. Select the auto range function, or manually select the range for the expected current.
5. Open the circuit at a point where the meter can be inserted.
6. Connect a fused jumper wire to one of the test leads.
7. Connect the red lead to the most positive side of the circuit and the black lead to the other side.
8. Turn on the circuit.
9. Read the display on the DMM.
10. Compare the reading to specifications or your calculations.

Before checking current, make sure the meter is capable of measuring the suspected amount. If you suspect that a measurement will have a current higher than the meter's maximum rating, use an inductive current probe.

An ammeter, without an amp probe, must be connected in series with the circuit; this allows circuit current to flow through the meter.

> **Warning!** Never place the leads of an ammeter across the battery or a load. This puts the meter in parallel with the circuit and will blow the fuse in the ammeter or possibly destroy the meter.

Inductive Current Probes Current probes eliminate the need to insert the ammeter into the circuit. These probes sense the magnetic field formed in a wire by current flow **(Figure 16–36)**. Normally, to use a current probe, the DMM's mode selector is set to read millivolts (mV). The probe is then connected to the meter and turned on. Some probes must be zeroed prior to taking a measurement. This is done before the probe is clamped around a wire. The DMM may have a zero adjust control, which is turned until zero reads on the meter's display. The clamp is placed around a wire in the circuit being tested. Make sure the arrow on the clamp is pointing in the direction of current flow. After the clamp is in place, the circuit is turned on and the voltage read on the display. The voltage reading is then converted to an amperage reading, such as −100 mV = 1 ampere.

Current Ramping A current probe is especially important when it is used with a lab scope. It is the fastest and least intrusive way to assess the operating condition of an electronic circuit. The probe converts an electromagnetic signal into a voltage signal that the scope can show on its screen **(Figure 16–37)**. Looking at the current as it flows to energize something and

FIGURE 16–36 An ammeter with an inductive pickup. The pickup eliminates the need to connect the meter in series.

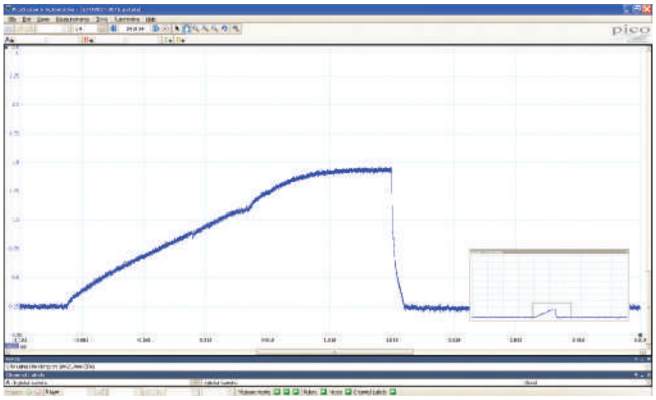


FIGURE 16–37 A waveform of current flow through a fuel injector.

after it has stopped is called observing the ramping of current and can be a very effective way to diagnose an electronic circuit.

Measuring Resistance

To test circuit continuity and resistance, the circuit or component must first be disconnected from its power source **(Figure 16–38)**. Connecting an ohmmeter to a live circuit will result in damage to the meter.

Checking the resistance can check the condition of a component **(Figure 16–39)** or circuit. Often specifications list a normal range of resistance values for specific parts. If the resistance is too high, check for an open circuit or a faulty component. Loose, damaged, or dirty connections are common causes of excessive resistance. If the resistance is too low, check for a shorted circuit or faulty component.

Ohmmeters also are used to check wires. Connect one probe of the ohmmeter to one end of the wire and touch the other probe to the other end of the wire. If low resistance is shown on the meter, the wire is intact. If no resistance is measured, the wire is open. This test does not confirm that the wire is actually good. This is because automotive wire is made of strands. For a given piece of wire, only one strand is necessary for the meter to provide a resistance reading. However, if only one strand is actually flowing current, the voltage drop will be significant. Because of this, it is important to remember that a resistance test can be used to confirm if something is faulty but should not be relied on to decide if something is good.

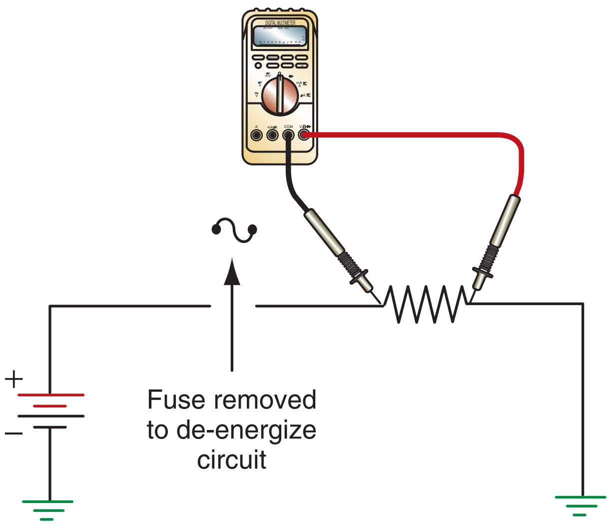


FIGURE 16–38 Measuring resistance with an ohmmeter. The meter should be connected in parallel to the component after the power is removed from the circuit.

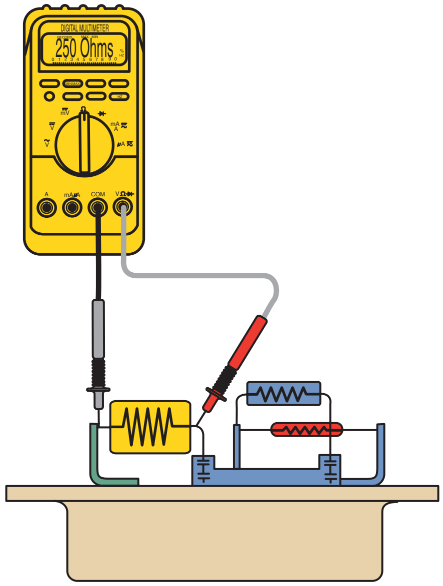


FIGURE 16–39 An ohmmeter can test the resistance of a component after it has been removed from the circuit.

Continuity Tests Many DMMs have a continuity test mode **(Figure 16–40)** that makes a beeping noise when there is continuity through the item being tested. This audible sound will continue as long as there is continuity, making it a quick, easy test for bulbs and switches. This feature is also handy for finding the cause of an intermittent problem. This test is performed by connecting the DMM across a circuit and wiggling sections of the wiring harness. When the beeping stops after a particular wire was moved, there is a problem with that wire.

Caution! To avoid possible damage to the meter or to the equipment under test, disconnect the circuit power and discharge all high-voltage capacitors before measuring resistance. Always follow the manufacturer's test procedures when testing air bags.

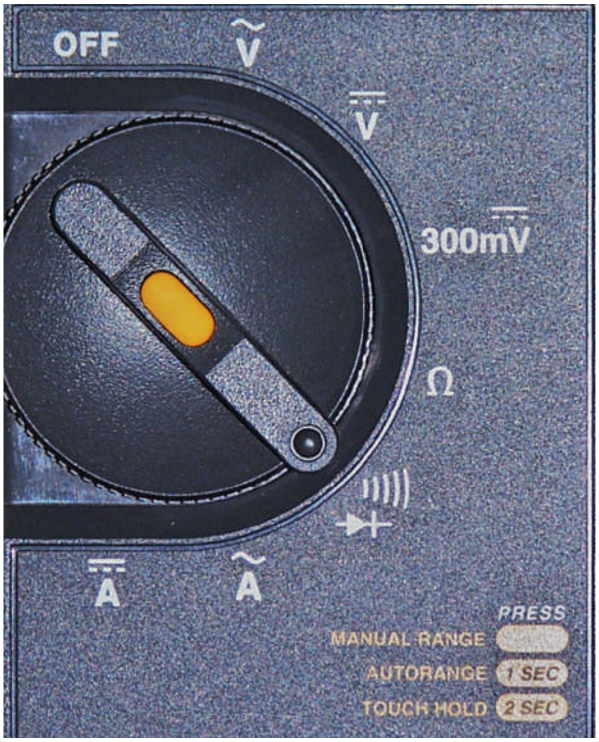


FIGURE 16-40 Selecting the continuity mode on a DMM.

MIN/MAX Readings

Some DMMs feature a MIN/MAX function. This displays the maximum, minimum, and average voltage recorded during a period of time. This is valuable when checking sensors or when looking for electrical noise. Electrical noise is primarily caused by **radio frequency interference (RFI)**, which may come from the ignition system. RFI is an unwanted voltage signal that rides on another signal. This noise can cause intermittent problems with unpredictable results. This noise causes slight increases and decreases in the voltage. When a computer receives a voltage signal with noise, it will try to react to those small changes. As a result, the computer responds to the noise rather than the true voltage signal.

PROCEDURE

To measure resistance follow these steps:

1. Make sure the circuit or component is not connected to a power source.
2. Set the DMM mode selector to measure resistance.
3. Select auto range or manually select the appropriate range.
4. You may need to calibrate the meter by holding the two test leads together and adjusting the meter to zero. On some DMMs, this calibration should be checked when the range is changed.
5. Connect the meter leads in parallel with the component or part that will be checked.
6. Read the value on the display. The DMM will show a zero or close to zero when there is good continuity. If the meter displays an infinite or OL reading, there is no continuity.

Other Measurements

Multimeters may have the ability to measure duty cycle, pulse width, and frequency. Duty cycle **(Figure 16–41)** is measured as a percentage. A 60 percent duty cycle means that a device is on 60 percent of the time and off 40 percent of one cycle. When measuring duty cycle, you are looking at the amount of time something is ON during one cycle. Pulse width **(Figure 16–42)** is normally measured in milliseconds. When measuring pulse width, you are looking at the amount of time something is on. The frequency of something states how often something is activated or is operating **(Figure 16–43)**.

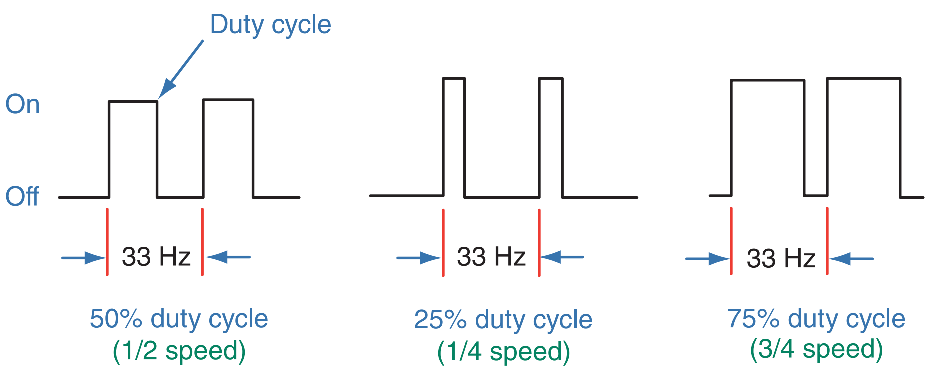


FIGURE 16-41 Duty cycle is expressed in a percentage.

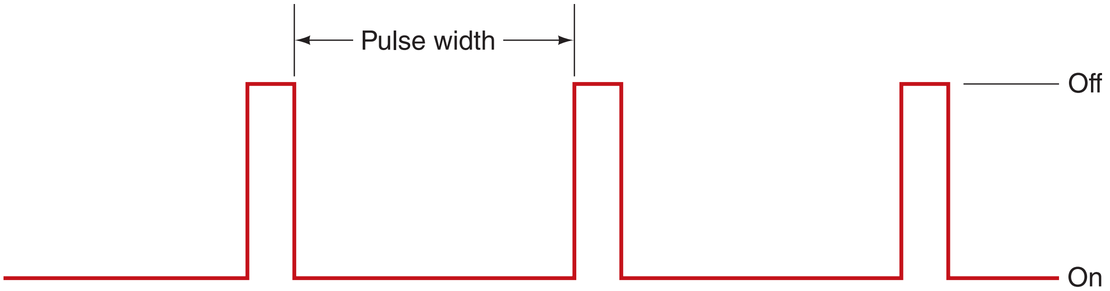


FIGURE 16–42 Pulse width.

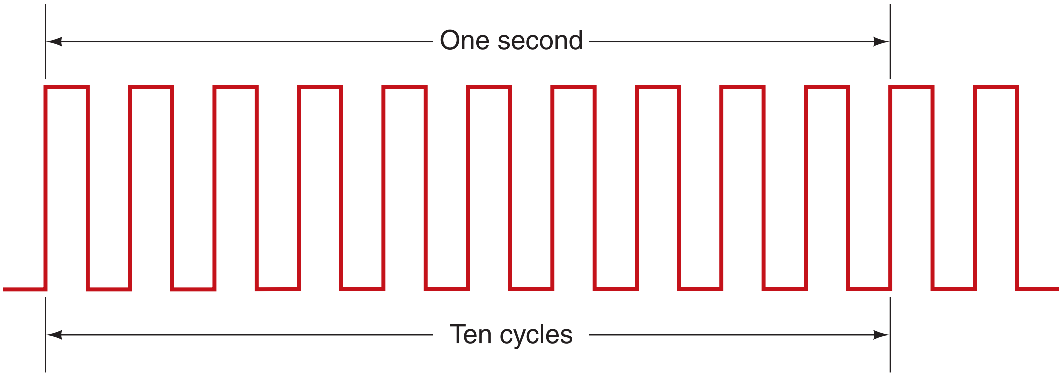


FIGURE 16–43 Frequency states how often something is activated during a one second.

To accurately measure duty cycle, pulse width, and frequency, the meter's trigger level must be set. The trigger level tells the meter when to start counting. Trigger levels can be set at certain voltage levels or at a rise or fall in the voltage. Normally, meters have a built-in trigger level that corresponds with the voltage range setting. If the voltage does not reach the trigger level, the meter will not recognize a cycle. The rise or fall in voltage used to trigger the cycle count is often referred to as a positive or negative slope trigger.

Some DMMs can measure temperature. These meters have a thermocouple. Temperature readings can be made in Fahrenheit or Celsius. The thermocouple is connected to the DMM and placed on or near the object to be checked. Many DMMs have the ability to store and download data to a PC.

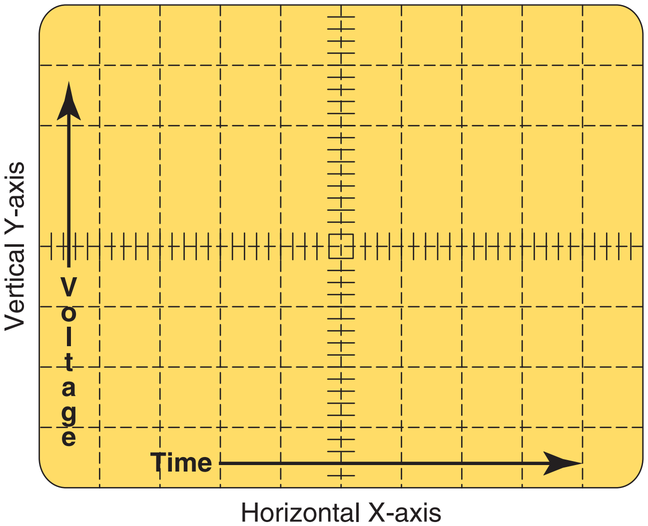


FIGURE 16–44 Grids on a scope screen that serve as a time and voltage reference.

Using Lab Scopes

The lab scope has become the diagnostic tool of choice. DMMs sample the voltage several times each second and update the meter's reading at a particular rate. If the voltage is constant, good measurements are made. A scope, however, will display any change in voltage as it occurs. This is important for diagnosing intermittent problems.

The screen is divided into small divisions of time and voltage **(Figure 16–44)**. These set up a grid pattern on the screen. Time is represented by the horizontal movement of the trace. Voltage is presented by the vertical position of the trace. The scope displays voltage over time, therefore the trace moves from the left (the beginning of measured time) to the right (the end of measured time). The value of the divisions can be adjusted to improve the view of the voltage trace.

Because a scope displays actual voltage, it will display any electrical noise or disturbances that

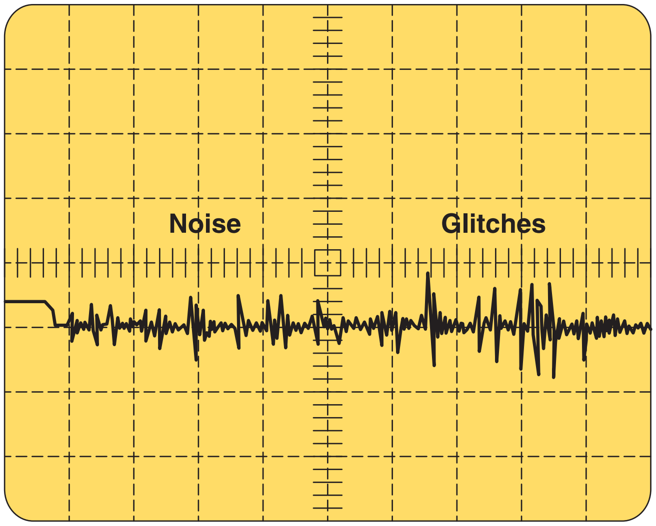


FIGURE 16–45 RFI noise and glitches may appear on a voltage signal.

accompany the voltage signal **(Figure 16–45)**. Electrical disturbances or **glitches** are momentary changes in the signal. These can be caused by intermittent shorts to ground, shorts to power, or opens in the circuit. These problems can occur for only a moment or may last for some time. A lab scope is handy for finding these and other causes of intermittent problems. By observing a voltage signal and wiggling or pulling a wiring harness, any looseness can be detected by a change in the voltage signal.

Analog versus Digital Scopes

Analog scopes show the actual activity of a circuit and are called real-time or live scopes. This means that what is taking place at that time is what you see on the screen. Analog scopes have a fast update rate that allows for the display of activity without delay.

A digital scope, commonly called a digital storage oscilloscope or DSO, converts the voltage signal into digital information and stores it into its memory. Some DSOs send the signal directly to a computer or a printer or save it to a disk. A technician can "freeze" the captured signal for close analysis. DSOs also have the ability to capture low-frequency signals. Low-frequency signals tend to flicker when they are displayed on an analog screen. A DSO displays the signal as it occurred a short time before. This delay is very slight. Most DSOs have a sampling rate of one million samples per second. This is quick enough to serve as an excellent diagnostic tool. This fast sampling rate shows slight changes in the voltage. Slight and quick voltage changes cannot be observed on an analog scope.

Digital signals may appear to be slightly choppy when compared to an analog trace. However, the voltage signal is sampled more often, which results in a more accurate waveform. The waveform is constantly being refreshed as the signal is pulled from the scope's memory.

Both an analog and a digital scope can be dual trace **(Figure 16–46)** or multiple trace **(Figure 16–47)** scopes. This means they are able to display more than one trace at one time. By watching the traces simultaneously, the cause and effect of a sensor is observed and a good or normal waveform can be compared to the one being displayed.

Waveforms

Since the height of a waveform represents voltage, any change in the height of the trace indicates a

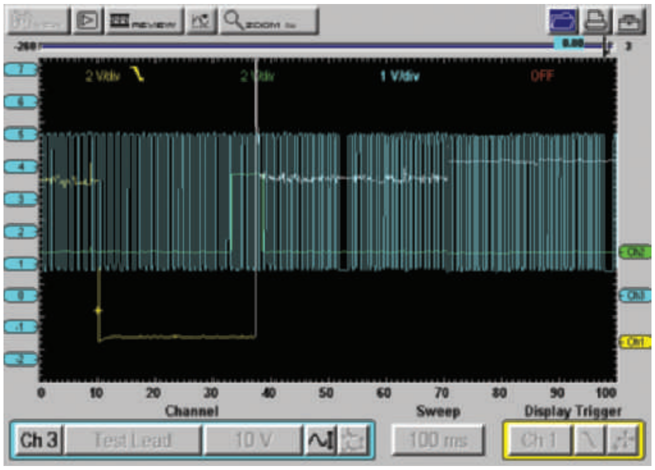


FIGURE 16–46 Two or more different signals can be observed on a multiple-channel scope. This is invaluable for diagnosis.

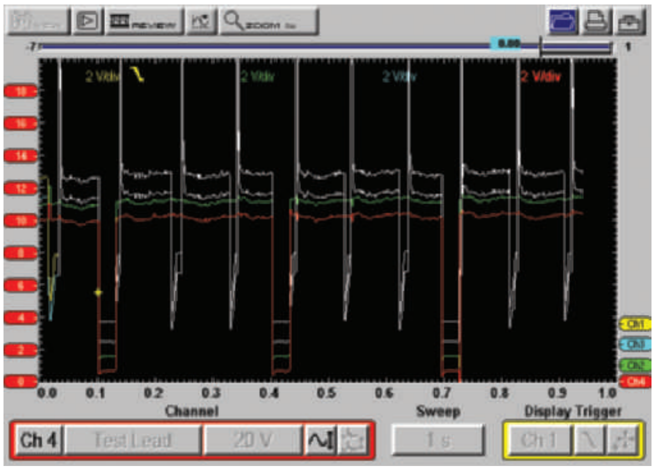


FIGURE 16–47 Some scopes and graphing meters can display many channels.

change in the voltage. When the trace is a straight horizontal line, the voltage is constant. A diagonal line up or down represents a gradual increase or decrease in voltage. A sudden rise or fall in the trace indicates a sudden change in voltage.

A normal AC signal changes its polarity and amplitude over time. The waveform created by AC voltage is typically called a sine wave **(Figure 16–48)**. One complete sine wave shows the voltage moving from zero to its positive peak then moving down through zero to its negative peak and returning to zero.

One complete sine wave is a cycle. The number of cycles that occur per second is the frequency of the signal. Frequency is measured in cycles per second (hertz or Hz). Checking frequency is one way of checking the operation of some electrical components. Input sensors are the most common components that produce AC voltage. Permanent magnet voltage generators produce an AC voltage that can be checked on a scope **(Figure 16–49)**. AC voltage waveforms

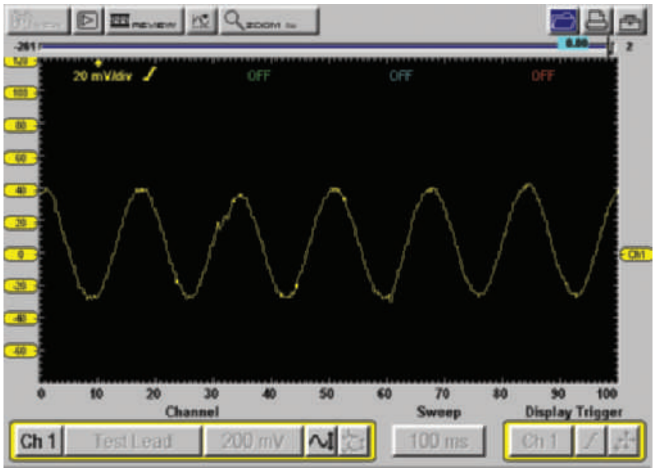


FIGURE 16–48 An AC voltage sine wave.

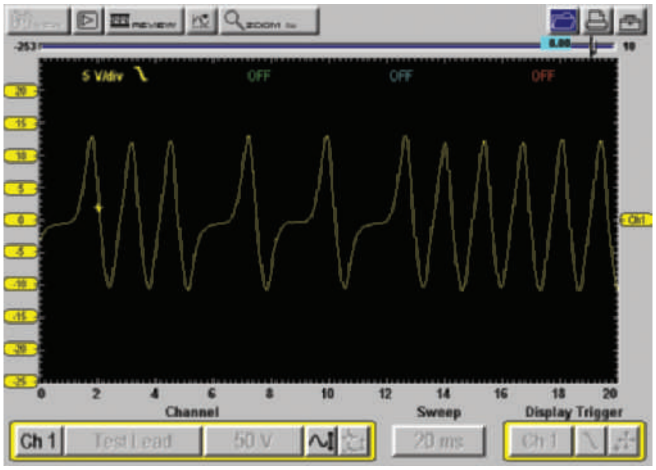


FIGURE 16–49 An AC voltage trace from a typical permanent magnet generator-type pickup or sensor.

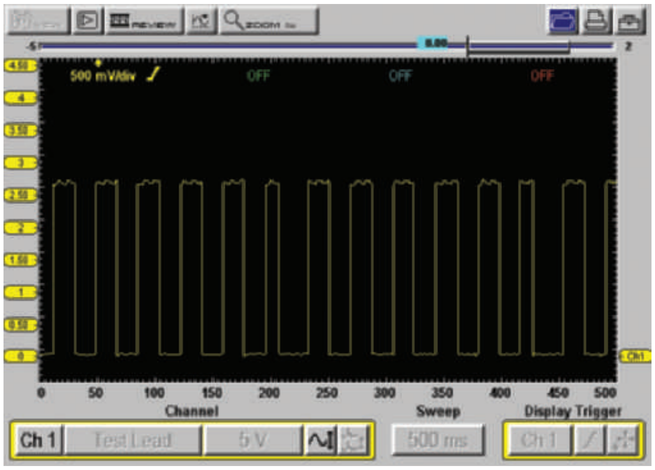


FIGURE 16–50 A typical square (on-off or high-low) wave.

should also be checked for noise and glitches. These may send false information to the computer.

DC waveforms may appear as a straight line or a line showing a change in voltage. Sometimes a DC voltage waveform will appear as a square wave that shows voltage making an immediate change **(Figure 16–50)**. Square waves have straight vertical sides and a flat top. This wave represents voltage being applied (circuit being turned on), voltage being maintained (circuit remaining on), and no voltage applied (circuit is turned off).

Scope Controls

Depending on the manufacturer and model of the scope, the variety of its controls will vary. However, nearly all scopes have vertical (Y-axis) adjustments, horizontal (X-axis) adjustments, and trigger adjustments.

The vertical adjustment controls the voltage that may be shown per division or as voltage over a preset figure, such as 20 volts **(Figure 16–51)**. If the scope is set at 0.5 (500 mV) volt, a 5-volt signal will need 10 divisions. Likewise, if the scope is set to 1 volt, 5 volts will need only 5 divisions. It is important to set the vertical so that voltage can be accurately read. Setting the voltage too low may cause the waveform to move off the screen, whereas setting it too high may cause the trace to be flat and unreadable. The horizontal position control is the time control of the trace **(Figure 16–52)**. If the time per division is set too low, the complete trace may not show across the screen. Also, if the time per division is set too high, the trace may be too crowded for detailed observation. The time per division (TIME/DIV) can be set from very short periods (millionths of a second) to full seconds.

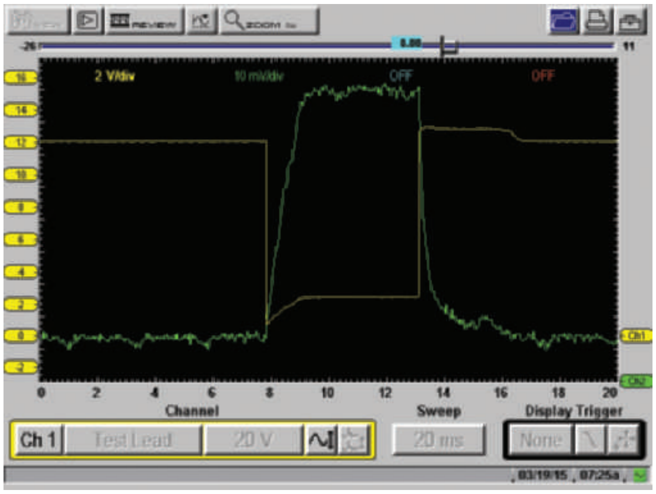


FIGURE 16–51 Vertical divisions represent voltage. Note this scope displays two different voltage ranges, one for each signal.

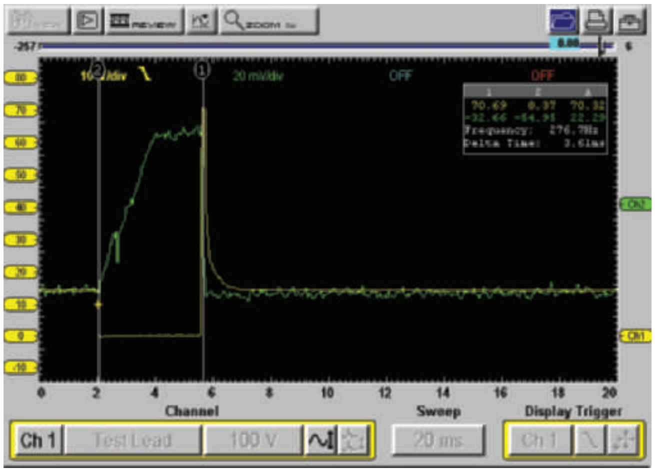


FIGURE 16–52 Horizontal divisions represent time.

Trigger controls tell the scope when to begin a trace across the screen. This is important when trying to observe the timing of something. Proper triggering will allow the trace to repeatedly begin and end at the same points on the screen. There are typically numerous trigger controls on a scope. The trigger mode selector has a NORM and an AUTO position. In the NORM setting, no trace will appear on the screen until a voltage signal occurs within the set time base. The AUTO setting will display a trace regardless of the time base.

Slope and level controls are used to define the actual trigger voltage. The slope switch determines whether the trace will begin on a rising or falling of the signal **(Figure 16–53)**. The level control sets when the time base will be triggered according to a certain point on the slope.

A trigger source switch tells the scope which input signal to trigger on. This can be Channel 1,

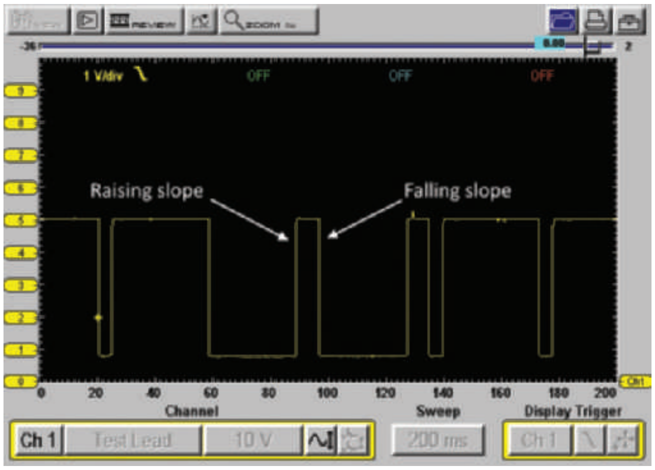


FIGURE 16–53 The trigger can be set to start the trace with a rise or fall of voltage.

Channel 2, line voltage, or an external signal. External signal triggering is very useful when observing the trace of a component that may be affected by the operation of another component. An example of this would be observing fuel injector activity when changes in throttle position are made. The external trigger would be voltage changes at the Throttle Position Sensor. The displayed trace would be the cycling of a fuel injector.

Graphing Multimeters

A graphing multimeter (GMM) is a DMM and a lab scope built into a single assembly. They can display numerical graphs of voltage, resistance, current, and frequency. GMMs are also capable of displaying data from more than one source **(Figure 16–54)**. These meters are perhaps the best tool to use for

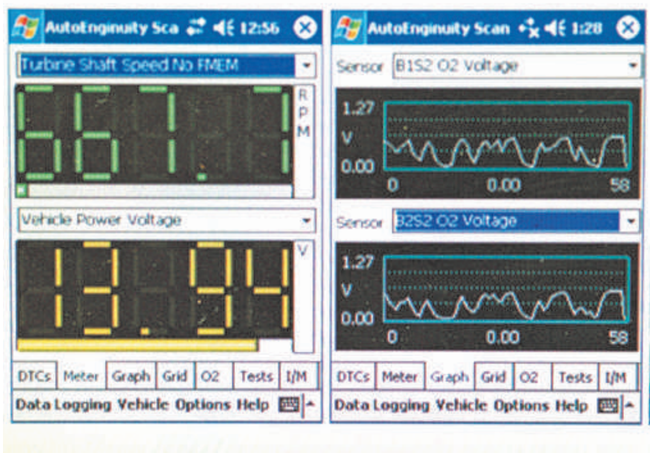


FIGURE 16–54 A sample of the information available from a GMM.

finding the cause of intermittent problems in low-voltage DC circuits.

Some GMMs feature a signal and data recorder, individual component tests, the ability to display measurements along with a graph, glitch capture, and an audible alarm. Some also have an electronic library of known good signals. These allow for a comparison of live patterns with expected values or known good waveforms. Some even have wiring diagrams and a vehicle-specific database of diagnostic and test information.

Transferring Data to a PC Many DSOs and GMMs can transfer captured information to a PC through a cable or wireless interface. This feature allows for better viewing of the waveforms and other data and also allows for the creation of a personal library. The latter can be helpful in the future.

Testing Basic Electrical Components

All electrical components can fail. For the most part, the best way to check electrical components is determined by what the component is supposed to do. If we think about what something is supposed to do, we can figure out how to test it. Often, removing the component and testing it on a bench is the best way to check it.

Protection Devices

When overloads or shorts cause too much current, the wiring heats up, the insulation melts, and a fire can result unless the circuit has some kind of protective device. Fuses, fuse links, maxi-fuses, and circuit breakers are designed to provide protection from high current. They may be used singularly or in combination.

Warning! Fuses and other protection devices normally do not wear out. They go bad because something went wrong. Never replace a fuse or fusible link, or reset a circuit breaker, without finding out why they went bad.

Circuit protection devices can be checked with an ohmmeter or testlight. If they are good, there will be continuity through them. To test a circuit protection device with a voltmeter, check for available voltage at both terminals of the unit **(Figure 16–55)**. There should be voltage on both sides.

Measuring voltage drop can tell more about a device's condition than just its continuity. If a fuse, a fuse link, or a circuit breaker is good, a voltage drop of zero will be measured. If 0 volts is read, the fuse is open. Any reading between 0 and 12 volts indicates that there is unwanted resistance and the fuse should be replaced. Make sure you check the fuse holder for resistance as well.

Fuses A fuse can be visually checked by looking at the internal metal strip. Remove the fuse from its holder and look at the element through the transparent plastic housing. Look for internal breaks and discoloration **(Figure 16–56)**. The top of blade fuses have small openings that allow meter test leads to contact the terminals of the fuse. Sometimes breaks in the fuse can be hard to see. Because of this, many technicians check voltage on both sides of the fuse with a testlight or DMM. If voltage is present only on one side of the fuse, it is open.

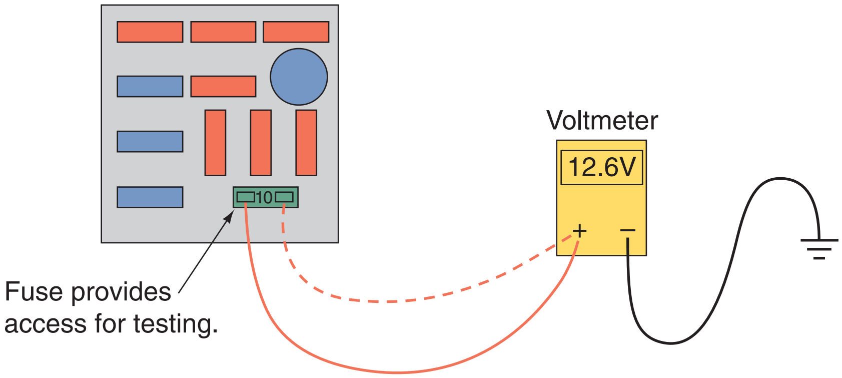


FIGURE 16–55 Circuit protection devices can be tested with a voltmeter. Make sure there is voltage present on both sides of the device.

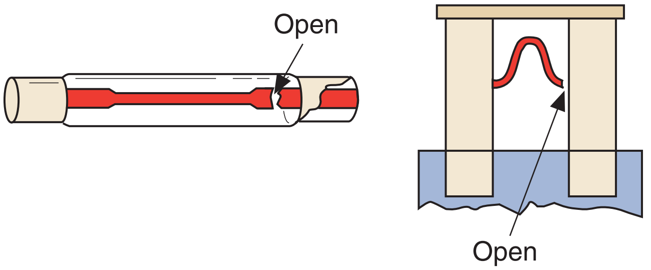


FIGURE 16-56 The condition of a fuse can often be checked visually.

SHOP TALK

To calculate the required fuse when installing new accessories, use Watt's law: watts divided by volts equals amperes. For example, if you are installing a 55-watt pair of fog lights, divide 55 by the battery voltage to find how much current the circuit will draw. In this case, the current is approximately 5 amperes. To allow for current surges, the correct inline fuse should be rated slightly higher than the normal current flow. In this case, an 8- or 10-ampere fuse would do the job.

Fuse Links Fuse link wire is covered with a special insulation that bubbles when it overheats, indicating that the link has melted. If the insulation appears good, pull lightly on the wire. If the link stretches, the wire has melted. Of course, when it is hard to determine if the fuse link is burned out, check for continuity with an ohmmeter.

Warning! Do not mistake a resistor wire for a fuse link. A resistor wire is generally longer and is clearly marked "Resistor do not cut or splice."

To replace a fuse link, cut the protected wire where it is connected to the fuse link. Then tightly crimp or solder a new fusible link of the same rating as the original link.

Warning! Always disconnect the battery ground cable prior to servicing any fuse link.

Maxi-Fuses Maxi-fuses are easier to inspect and replace than fuse links. To check a maxi-fuse, look at the fuse element through the transparent plastic housing. If there is a break in the element, it has blown. To replace it, pull it from its fuse box or panel. Always replace a blown maxi-fuse with one that has the same ampere rating.

Circuit Breakers Two types of circuit breakers are used. One is reset by removing the power from the circuit. The other type is reset by depressing a reset button. If a circuit breaker cannot be reset and remains open, replace it after making sure that there is not excessive current in the circuit.

Thermistors Some systems use a PTC thermistor as a protection device. When there is high current, the resistance of the thermistor increases and causes a decrease in current flow. These can be checked with an ohmmeter **(Figure 16–57)**. If an infinite reading is displayed, the thermistor is open. Another way of checking a thermistor is to change its temperature and see if its resistance changes.

Switches

To check a switch, disconnect the connector at the switch. Check for continuity between the terminals of the switch **(Figure 16–58)** with the switch in the on and off positions. While in the off position, there should be no continuity between the terminals. With

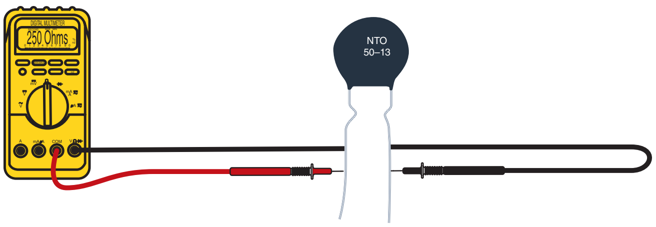


FIGURE 16-57 A PTC circuit breaker can be checked with an ohmmeter.

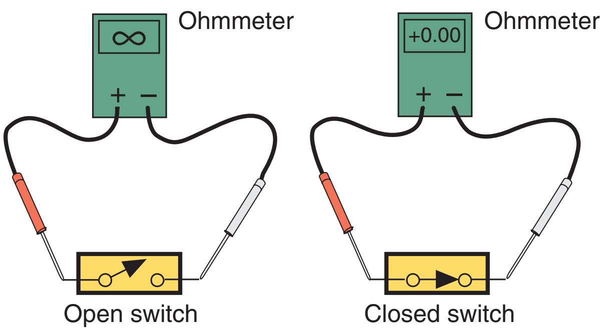


FIGURE 16-58 Checking a switch with an ohmmeter.

the switch on, there should be good continuity between the terminals. If the switch is activated by something mechanical and does not complete the circuit when it should, check the adjustment of the switch (some switches are not adjustable). If the adjustment is correct, replace the switch. Another way to check a switch is to bypass it with a jumper wire. If the component works when the switch is jumped, the switch is bad.

MPMT switches should be checked in each of its possible positions. Use a wiring diagram to identify which terminals of the switch should have continuity during each switch position.

Variable resistors can also be checked with an ohmmeter or voltmeter. To test a rheostat or potentiometer, identify the input and output terminals and connect an ohmmeter across them. These should be checked by moving through the entire range of positions, while observing the meter **(Figure 16–59)**. The readings should be within specifications and should gradually change. Any abrupt change indicates a problem with the switch. Using a scope to test variable resistors will show glitches easily as the resistance spikes up or down during the test.

Voltage drop across switches should also be checked. Ideally a closed switch should have no voltage drop. A voltage drop indicates resistance, and the switch should be replaced.

Relays

A relay can be checked with a jumper wire, a voltmeter, an ohmmeter, or a testlight. If the terminals are accessible and the relay is *not* controlled by a computer, a jumper wire and testlight will be the quickest method to use. The schematic for a relay is typically shown on the outside of the relay. If not, check a wiring diagram to identify the terminals of the relay. Also check the wiring diagram to determine if the relay is controlled by a power or ground switch.

FIGURE 16–59 Testing continuity across a potentiometer while its wiper is being moved.

If the relay terminals are not accessible, remove the relay. Use an ohmmeter to check the continuity between the relay coil terminals. If the meter indicates an infinite reading, replace the relay. If there is continuity, use a pair of jumper wires or a 9-volt battery to energize the coil. Check for continuity through the relay contacts. If there is an infinite reading, the relay is faulty. If there is continuity, the relay is good.

Refer to the resistance specifications in the service information and compare the resistance of the relay's coil to them. Low resistance indicates a shorted coil. If the coil is shorted, the transistors and/or driver circuits in the computer can be damaged by the high current flow.

Stepped Resistors

To test a stepped resistor, remove it and connect an ohmmeter across the resistor. Compare the readings to specifications. A stepped resistor can also be checked with a voltmeter. Measure the voltage after

PROCEDURE

To test a relay that is controlled by a computer, use a high-impedance voltmeter set to the appropriate DC voltage scale, and follow these steps (Figure 16–60):

1. Connect the negative lead of the voltmeter to a good ground.
2. Connect the positive lead to the output wire. If no voltage is present, continue testing. If there is voltage, disconnect the relay's ground circuit. The voltmeter should now read 0 volts. If it does, the relay is good. If voltage is still present, the relay is faulty.
3. Connect the positive voltmeter lead to the power input terminal. If near battery voltage is not measured there, the relay is faulty. If it is, continue testing.
4. Connect the positive lead to the control terminal. If near battery voltage is not measured there, check the circuit from the battery to the relay. If it is, continue testing.
5. Connect the positive lead to the relay ground terminal. If more than 1 volt is present, the circuit has a poor ground.

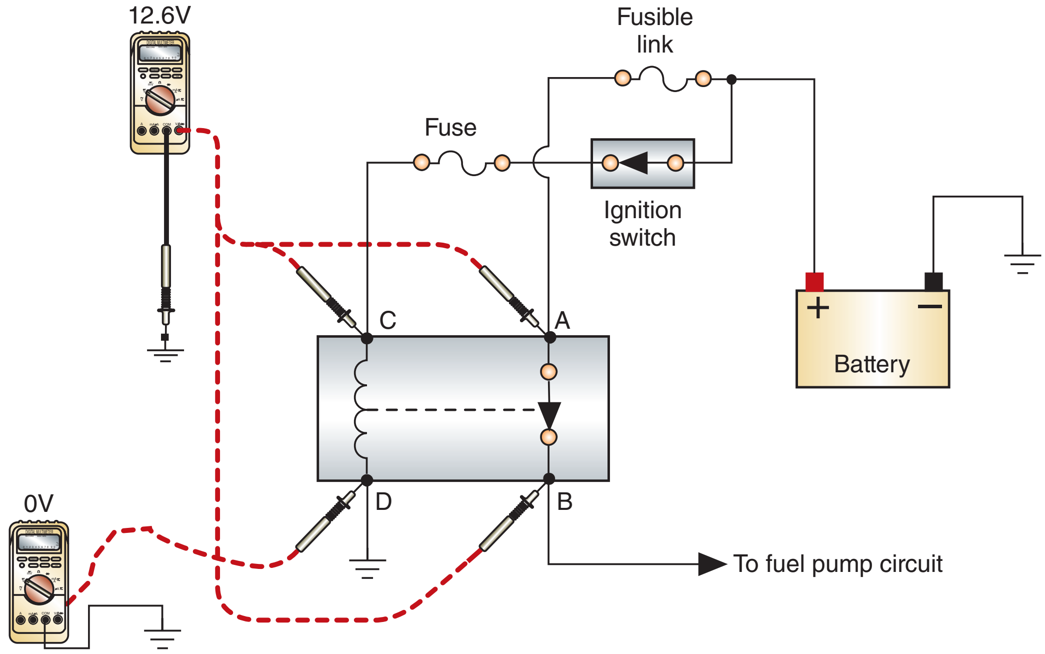


FIGURE 16-60 Testing a relay with a voltmeter.

each part of the resistor block and compare the readings to specifications.

Wiring

A wire's insulation should be in good condition. Broken, frayed, or damaged insulation can cause shorts **(Figure 16–61)**. These conditions can also create a safety hazard. Replace all wires that have damaged insulation.

When checking a circuit, make sure to check the ground connections, including the ground strap from the engine or other component to the chassis. An engine ground is typically a braided, flat cable, which provides some flexibility **(Figure 16–62)**. A bad ground cable can cause problems in many different circuits.

Wires are commonly grouped into a harness. A single-plug harness connector may form the connecting point for many circuits. Harnesses and harness connectors help organize the electrical system and provide a convenient starting point for testing many circuits. Wiring harnesses are typically shielded by plastic conduit. The color of the conduit indicates the operating voltage of the wires inside the conduit:

- Black without a painted stripe = low temperature and 12-volts
- Black with a green or blue stripe = high temperature and 12-volts

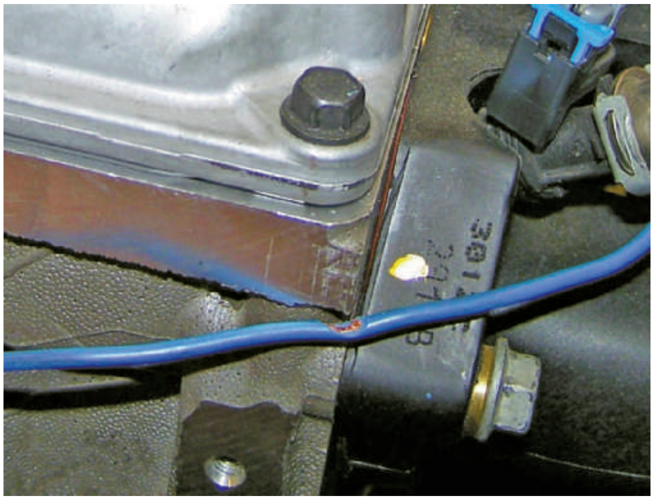


FIGURE 16-61 Broken, frayed, or damaged insulation that exposes live wires can cause shorts.

FIGURE 16-62 A flat, braided ground strap.

- Blue or Yellow = voltages ranging from 12 to 42 V
- Yellow is typically reserved for airbag and other supplemental restraint system (SRS) components and wiring
- Orange = voltages ranging from 42 to 650 V

Printed Circuits

Late-model vehicles use flexible printed circuit boards. Printed circuit boards are not serviceable and, in some cases, not visible. When these boards fail, the entire unit is replaced.

The following precautions should be observed when working with a printed circuit:

- Never touch the surface of the board. Dirt, salts, and acids on your fingers can etch the surface and set up a resistive condition.
- The copper conductors can be cleaned with a commercial cleaner or by lightly rubbing a pencil eraser across the surface.
- A printed circuit board is easily damaged because it is very thin. Be careful not to tear the surface, especially when plugging in connectors or bulbs.

Troubleshooting Circuits

When troubleshooting an electrical problem, it is important to take a logical approach. Making assumptions or jumping to conclusions can be very expensive and a total waste of time. The basic steps for diagnosis given earlier in this book should be followed. Here they are again, only modified to fit electrical problems:

Troubleshooting Logic

Remember there are three basic types of electrical problems. Knowing the type of problem that is causing the customer's concerns will dictate what tests should be conducted.

- If something does not work, the problem is most likely caused by a short or an open.
- If the fuse for that circuit is blown, the problem is a short. If the fuse is good, the problem is an open.
- If a part does not work correctly, such as a dim light bulb, the problem is high resistance.

Quick voltage checks will help define the problem. Check for voltage to the part that is not working

PROCEDURE

To troubleshoot an electrical problem, follow these steps:

1. **_Gather information about the problem_. From the customer find out when and where the problem happens and what exactly happens.**
2. **_Verify that the problem exists_. Take the vehicle for a road test or try the components of the customer's concerns and try to duplicate the problem, if possible.**
3. **_Thoroughly define what the problem is and when it occurs_. Pay attention to the conditions present when the problem happens. Also pay attention to the entire vehicle; another problem may be evident to you that was not evident to the customer. The most important thing is to fully understand the problem.**
4. **_Research all available information to determine the possible causes of the problem_. Look at all service bulletins and other service information related to the problem to see if this is a common concern. Study the wiring diagram of the system and match a system or some components to the problem.**
5. **_Isolate the problem_. Based on an understanding of the problem and circuit, make a list of probable causes. Narrow down this list of possible causes by checking the obvious or easy to check items. This includes a thorough visual inspection.**
6. **_Continue testing to pinpoint the cause of the problem_. Once you know where the problem should be, test until you find it! Begin testing to determine whether or not the most probable cause is the problem. If this is not the cause, move to the next most probable cause. Continue this until the problem is solved.**
7. **_Locate and repair the problem, then verify the repair_. Once you have determined the cause, make the necessary repairs. Never assume that your work solved the original problem. Operate all components of the circuit to be sure that the original problem has been corrected and that there are no other faults in the circuit.**

correctly. If source voltage is present, the part is bad or the ground circuit is faulty. If less than source voltage is measured at the part, there is a fault in the power feed to the part. Check the voltage on the ground for the component. A voltage reading above 200 mV indicates resistance in the ground circuit. Also, measure the voltage drop across the part; this can indicate a problem with the part. If a faulty part is suspected, it should be replaced.

When making any checks with a meter, try to take all measurements at a connector. When measurements are taken at the mating side (front) of a disconnected connector, this is called *front probing*. When measurements are taken at the back or wire side of a connected connector, this is called *backprobing*. At times it may be necessary to make direct contact with a wire by piercing through the insulation. Make sure not to damage the wire and cover the pierced area with electrical tape. This will prevent the copper wire from corroding.

Using Wiring Diagrams

During diagnosis, one of the most important sources of information is a wiring diagram. A wiring diagram shows the relationships of one circuit to the others. Based on an understanding of the diagram, electricity, and how a particular system is designed to work, testing points can be identified. Wiring diagrams are included in the electrical section of most service information.

Wiring diagrams contain a comprehensive look at each circuit with all the connectors, wiring, signal connections (buses) between the devices, and electrical or electronic components of the circuit. The diagrams are drawn with lines that represent wires between the appropriate connectors. Most diagrams are drawn so the front of the car is on the left of the diagram and show the power source on the top of the wiring diagram and the ground source at the bottom.

Wiring diagrams typically show the following:

- *Wires by wire numbers or color coding*. Wires are identified by circuit number, color, and/or, in some cases, size.
- *Wire cross-section size*. Some manufacturers indicate the wire size along with the color code.
- *Ground connections*. Most diagrams show the point at which circuits are grounded.
- *Wire connection points*. Individual connectors "C" are shown and listed by number. Note: The symbol for a connector varies with the manufacturer.
- *Reference of wire continuation*. At times, the part of a wiring diagram where a particular wire continues is referenced to another diagram or a section area.
- *Location of splices*. Where a group of wires are electrically joined together is typically designated as "S."
- *Terminal designation*. A number or other label that shows where a particular wire is located is a multipin connector.
- *Component symbols*. A wiring diagram uses a set of symbols to represent electrical components or devices. These are quite standard but may vary with the manufacturer.
- *Switches*. The placement of switches in the circuit are shown in their normal (NO or NC) position.
- *Fuse designation*. Fuses and other circuit protection devices are shown with their location and rating.
- *Relay information*. The location of all relays is shown as well as the connections to its terminals.

Getting the Right Diagram Wiring diagrams should be for the exact year, make, and model of the vehicle. Most electronic service information systems will match the wiring diagram to the VIN. To retrieve a wiring diagram that will help diagnose a problem, match the component to the wiring diagram index. The index will list a letter and number for each major component and many different connection points. Refer to those references. Most electronic information systems will

SHOP TALK

To make it easier to identify where grounds, splices, and connectors are located on the vehicle, manufacturers use a numbering system that identifies the basic location of these. For example, many manufacturers, such as GM, have a three-digit number after the G, S, and C that represents their location. Typically, 100–199 means that the ground, splice, or connector is under the hood, 200–299 means they are under the dash, 300–399 means they are in the passenger compartment, and 400–499 means they are in the trunk.

automatically display the appropriate diagram once the component is selected.

Electronic information systems may list wiring diagrams by system. Once you have selected the correct system, one or more diagrams may be available depending on the size and complexity of the system. The diagram may be interactive, meaning you can click and highlight particular wires or components to make tracing the parts of the circuit easier.

Tracing a Circuit After you have the correct wiring diagram, identify all of the components, connectors, and wires that are directly related to that component. This is done by tracing through the circuit, starting at the component. This will identify the source of power for the component, its controls and its ground circuit. Tracing the circuit will also allow you to understand the operation of the circuit and determine where to test and what to expect at those test points. Remember, all electrical circuits have a power source, a load, and a path to ground. Make sure these are identified.

Tracing the circuit will also simplify complex wiring diagrams. Complex wiring diagrams are made up of many individual circuits. Some are directly interrelated and others are not. When the circuit of concern is pulled out of the wiring diagram, it is much easier to identify its wires and components. It also reduces the chances of being distracted by wires that probably are not the cause of the problem.

After you have traced through the circuit, study it and make sure you know how the circuit is supposed to work. Then describe the problem and ask yourself what could cause this. Limit your answers to what is included in your traced wiring diagram. Also limit your answers to the description of the problem. Now look at the components and wires in the circuit to identify the items that could cause only that problem. In other words, if part of the circuit supplies power to other circuits and they work normally, it is very unlikely that the cause of the problem is located there. The same is true with the ground side of the circuit. Likewise, if an entire system is not working correctly, the cause is most likely to be in the circuit that is common to the system.

It is wise to make a list of all probable causes of the problem and then number them according to probability. For example, if all of the lights in the instrument panel do not work, it is most probable that the cause is not all bad bulbs. Rather, it is more likely that the fuse or power feed is bad. After you have listed the probable causes, in order of probability, then look at the wiring diagram to identify how you can quickly test to find out if each is the cause.

The simplest way to trace through a circuit is to draw the circuit on a piece of paper. It does not need to be pretty; it just needs to be accurate. Draw the component (can be a simple box) and draw all wires and controls that supply the power and ground; include all controls. Mark each wire with its color and make sure to note any change in color. Also label all controls and components that are included in the circuit.

Tracing can also be done by using highlighters or markers to color a copy of the wiring diagram. There are many different ways to do this; the one given here is just a suggestion. Developing your own method will work as long as you remain consistent. Find the component of concern in the wiring diagram and outline it in yellow. Follow the power wires toward the power source. The source can also supply power to other components, but ignore them for the time being. Trace the power wire leading to the component to the point where it connects to a control or load. Color that wire red. That wire should have source voltage. If the control is an on-off switch, source voltage will be present when the switch is closed; color the wire leading from the control to the component orange. If the control will pass a variable amount of voltage to the component, color the output wire green. Now look at the ground side of the component. If the path to ground is direct with no control, color that wire black. If the ground path has a control, color the wire to the control blue and the wire from the output of the control to ground black.

Coloring the circuit provides a simple reference of what to expect at each wire in the circuit. The red wire(s) should always have source voltage. The orange wire will only have source voltage when the control is closed. The voltage on the green wire will vary with changes at the control. The black wire should have 0 volts at all times. However, the blue wire should have source voltage when the control is open and 0 volts when it is closed. Your testing should be based on this logic. Use the wiring diagram to identify the test points. **Figure 16–63** shows the circuit of the right low beam headlight. Only the parts of the circuit that could cause a problem with one headlamp are noted. Note that all wires and components that would affect more than that headlamp are not traced. Doing this simplifies diagnosing the circuit.

If the power source for the component feeds more than one component or the ground is shared by others, check the operation of those components.

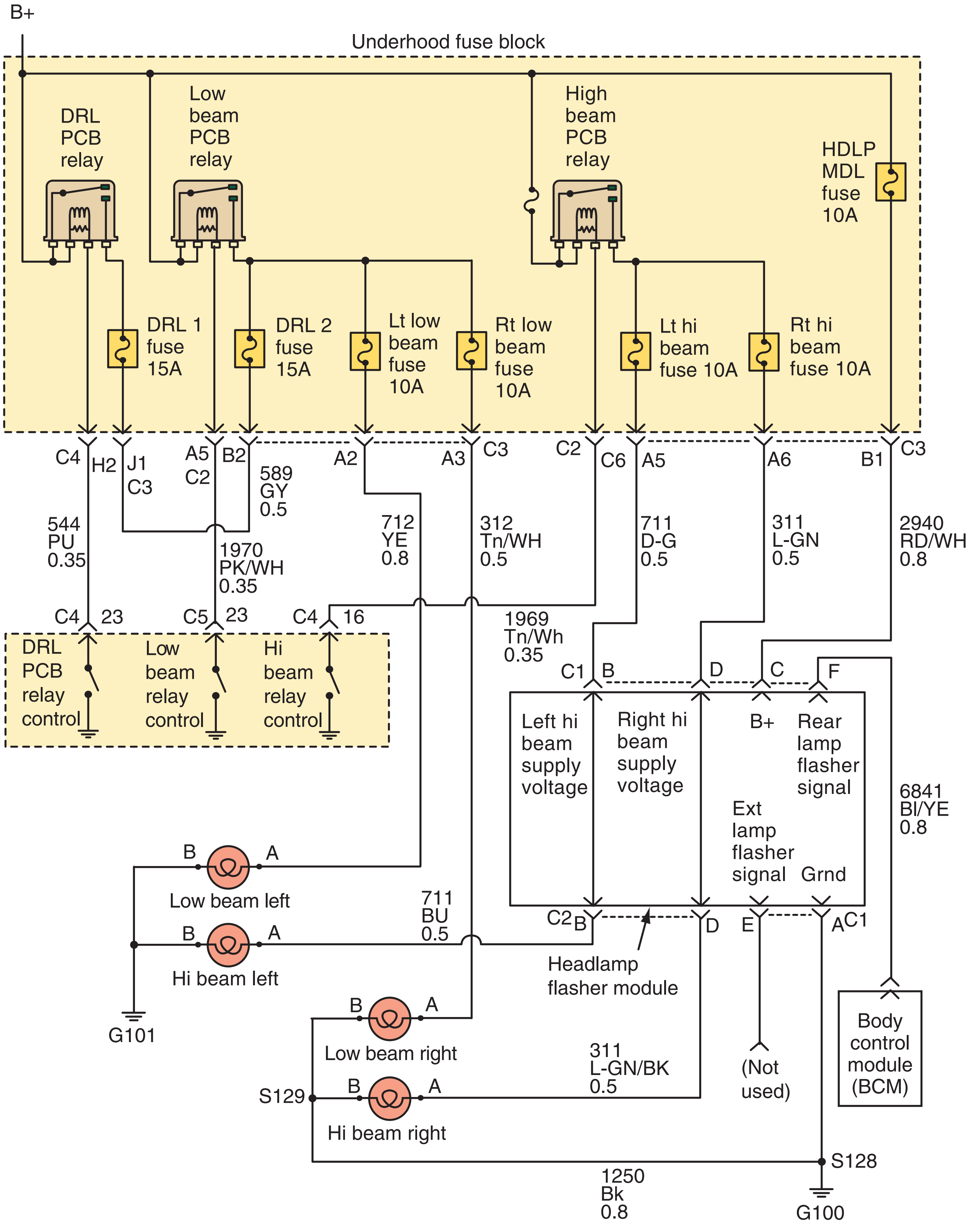


FIGURE 16–63 A wiring diagram of a headlight system with the right low beam circuit traced.

If they operate normally, you know the common power and ground circuits are good. Therefore, the problem must be between the common points. Likewise if the other components do not work correctly, you know that the problem is within the common part of the circuit.

Testing for Common Problems

It would take thousands of pages to describe all of the possible combinations of electrical problems. However, all problems can be boiled down to one of three types. Identifying which one you are looking for defines what tests you need to conduct.

Testing for Opens

An open **(Figure 16–64)** is evident by an inoperative component or circuit. Begin your testing at the most accessible place in the circuit and work from there. Check for voltage at the positive side of the load. If there are 0 volts, move to the output of the control **(Figure 16–65A)**. If there are at least 10.5 volts, the open is between the control and the load. If the reading is 10.5 volts or higher, check the ground side of the load. If the voltage there is 1 volt or lower and the load does not work, the load is bad. If the voltage at ground is greater than 1 volt, there is excessive resistance or an open in the ground circuit **(Figure 16–65B)**. If the voltage at the positive side of the load is less than 10.5 volts but above 0 volts, move the positive lead of the voltmeter toward the battery, testing all connections along the way. If 10.5 volts or more are present at any connector, there is an open or high resistance between that point and the point previously checked. If battery voltage is present at the ground of the load, there is an open in the ground circuit. Use a jumper wire to verify the location of the open.

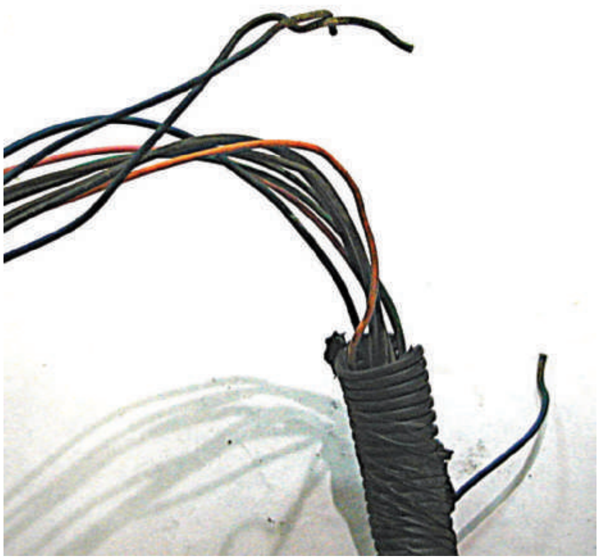


FIGURE 16–64 A damaged wiring harness caused this open.

If the circuit is intermittently open, working sometimes and not others, you likely have a problem in a connector or with poor terminal fit within a connector. Try to narrow down the part of the circuit that is opening and gently move, twist, tug, and pull on the wiring and connections. If the open comes and goes, you have likely located the area of the problem. Separate connectors and examine the terminals for signs of damage. You may need to check the pin fit or pin drag of each suspected terminal using test terminals **(Figure 16–66)**.

> **Warning!** Sometimes circuit problems are "fixed" just by unplugging and reconnecting the connectors. Terminals continue to shrink in size and contact area between two terminals can be very small. The movement separating and reconnecting the terminals may correct a loose or intermittent connection, at least for a while.

Open and "Bad" Grounds

Depending on the circuit, an open ground can present problems that you may not think of as an open circuit. For example, in a rear lighting circuit, such as that in **Figure 16–67A**, several bulbs are all connected together with a common ground. If an open occurs in the ground for the turn signal/running light, as in **Figure 16–67B**, when the left turn signal is turned on, the current can pass from turn signal filament to the running light filament. The current then continues on to the other turn signal/running light bulb to get to ground. This places three filaments in series together and creates an unwanted path affecting two circuits. Depending on the vehicle and the resistances of the bulbs, the circuit may cause both running lights to blink with the turn signal or may cause all three lights to glow dimly. Either way, it will be obvious that a problem exists in the lighting.

To diagnose this type of ground problem, first examine the wiring diagram. Because all of the rear lights in this example share a common ground, that should be the first place you check. If the ground appears intact, voltage drop the ground back to the battery. A normal voltage drop reading indicates the problem is in the ground circuits of the lights. Next, voltage drop each bulb. This type of problem will result in excessive voltage drop on the ground for the affected bulbs. The excess voltage on the ground is due to the resistance of the other bulb's filaments

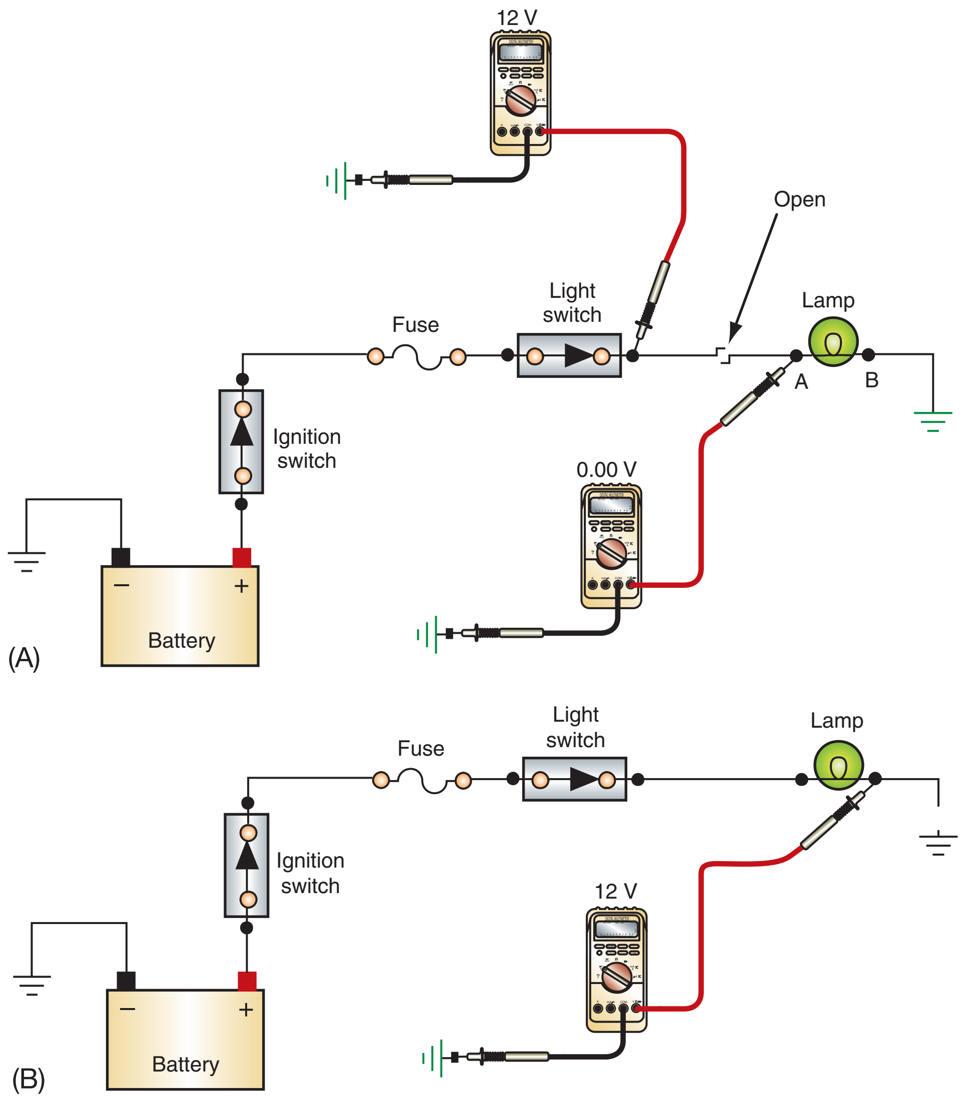


FIGURE 16-65 (A) If you have 0 volts at the load, test the output of the switch. If there is power there, the open is between the switch and the load. (B) If you have power on the ground side of the load, the ground circuit is open.

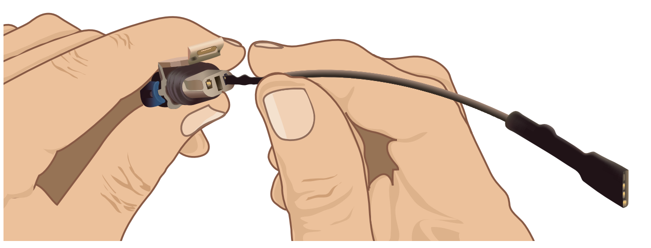


FIGURE 16-66 Check terminal or pin fit with the specified terminal tool.

that are in series with the ground. Another method of diagnosing this type of fault is by using a jumper wire to ground each bulb. When the circuit starts operating correctly, you have identified the circuit that is causing the problem.

Loose or corroded grounds can cause a variety of circuit problems depending on the how bad the connections are and what circuits are using the ground. Any excessive resistance in the ground circuit will have an effect on the voltage used by each load. The effects can range from the circuit(s) not working at all to communication bus issues and out of range sensor readings.

Testing for Shorts

Use an ohmmeter to check for an internal short in a component, such as a relay or fuel injector. If the component is good, the meter will read the specified resistance or at least some resistance. If it is shorted, it will read lower than normal or zero resistance. Also, if the component has more than two terminals

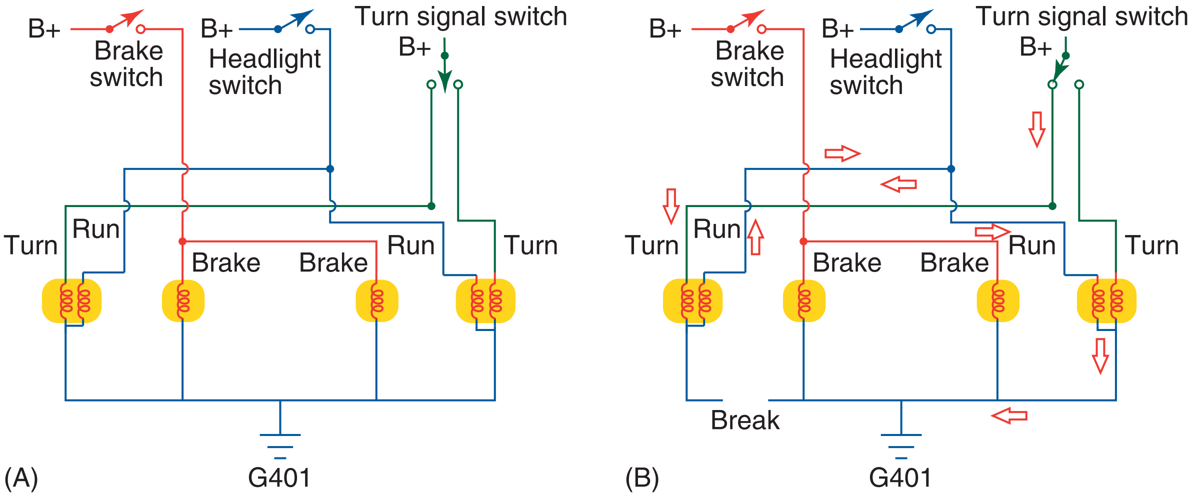


FIGURE 16–67 (A) The brake light and turn signal circuit when it is off. (B) The same circuit with an open, showing the current flow with that open.

or pins, check for continuity across all combinations of these. Refer to the wiring diagram to see where there should be continuity. Any abnormal readings indicate an internal short.

When a fuse is blown, this probably is due to a wire-to-wire short or a short to ground **(Figure 16–68)**. To test these circuits, a special jumper wire with a circuit breaker should be used as a substitute for the blown fuse. The jumper wire is fit with a 10- or 20-amp self-resetting circuit breaker. This will allow for testing the circuit without causing damage to the wires and components in the circuit. Some tool companies include a buzzer inline with the breaker.

When a wire-to-wire short is suspected **(Figure 16–69)**, check the wiring diagram for all of the affected components. Identify all points where the affected circuits share a connector. Check the circuit protection devices for the circuits. Check the wiring for signs of burned insulation and melted conductors. High current due to the short will cause this. If a visual inspection does not identify the cause of the short, remove one of the fuses for the affected circuits. Install the special jumper wire across the fuse holder terminals. Activate that circuit and disconnect the loads that should be activated by the switch. This will create open circuits and, normally, current will not flow. If sound is coming from the buzzer in the jumper wire, current is still flowing somewhere in the circuit. Disconnect all connectors in the circuit one at a time. If the buzzer stops when a connector is disconnected, the short is in that circuit.

A common type of wire-to-wire short is when circuits short or cross connect within multifunction switches. This problem can cause unrelated circuits, such as windshield wipers, to become active when the turn signals are activated. Check if there are any common points between the affected circuits by

FIGURE 16–68 Use a circuit breaker to protect the circuit when checking for a short to ground.

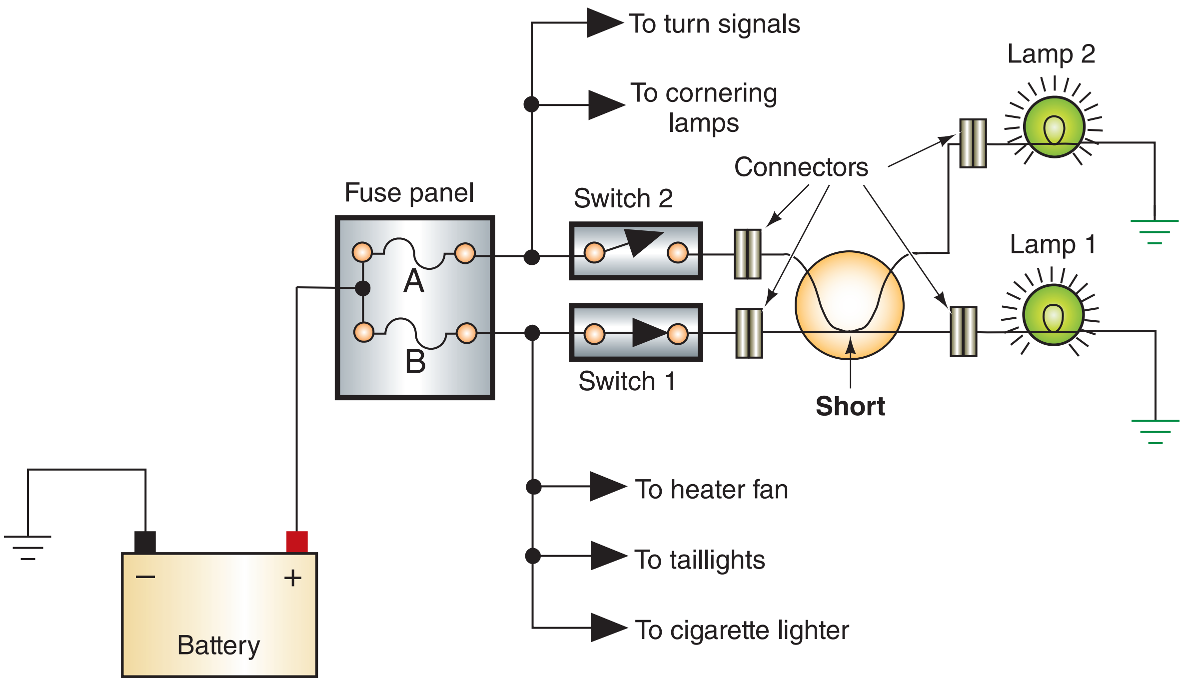


FIGURE 16–69 A damaged wiring harness caused this open and a short.

examining the wiring diagram. If the only common point is the switch, test at the switch's connector to see if power is present to the affected circuit when operating the other circuit. Replace the switch if it is the cause of the short.

If the problem is a short to ground, the circuit's fuse or other protection device will be open. If the circuit is not protected, the wire, connector, or component will be burned or melted. To keep current flowing in the circuit so you can test it, connect the special jumper wire across the fuse holder. The circuit breaker will cycle open and closed, allowing you to test for voltage in the circuit. Connect a testlight in series with the cycling circuit breaker. Using the wiring diagram, identify the location of the connectors in the circuit. Starting at the ground end of the circuit, disconnect one connector at a time. Check the testlight after each connector. The short is in the circuit that was disconnected when the light went out.

SHOP TALK

Many manufacturers do not recommend using a circuit breaker as a substitute for the fuse during testing; rather a sealed beam headlight **(Figure 16–70)** is connected with jumper wires across the fuse holder. The headlight serves as load and limits the current in the circuit. The headlight will light as long as current is flowing through the circuit. Some technicians use a headlight and horn or buzzer wires in parallel as a substitute. The horn provides an audible indicator and is useful when working away from the fuse box and the headlight is not visible.

Short Detector Some technicians use a compass or Gauss gauge to find the location of a short **(Figure 16–71)**. A magnetic field is formed around a current-carrying conductor and a compass reacts to magnetic fields. The shorted circuit will have high current; therefore, a large magnetic field will be formed around the shorted circuit. With the wiring diagram and other service information, locate the routing of the wires in the affected circuit. Connect the jumper wire with a circuit breaker across the fuse holder for the blown fuse. Position the compass over or close to the wiring harness. The magnetic field in the wire will cause the compass' needle to move away from its north position. As the circuit breaker cycles, the needle will fluctuate. As the compass is slowly moved across the wire, it will continue to fluctuate until it passes the point where the short is. To find the exact location of the short, inspect the wire in that area. Look for signs of overheating and broken, cracked, exposed, or punctured wires.

Testing for Unwanted Resistance

High-resistance problems are typically caused by corrosion on terminal ends **(Figure 16–72)**, loose or

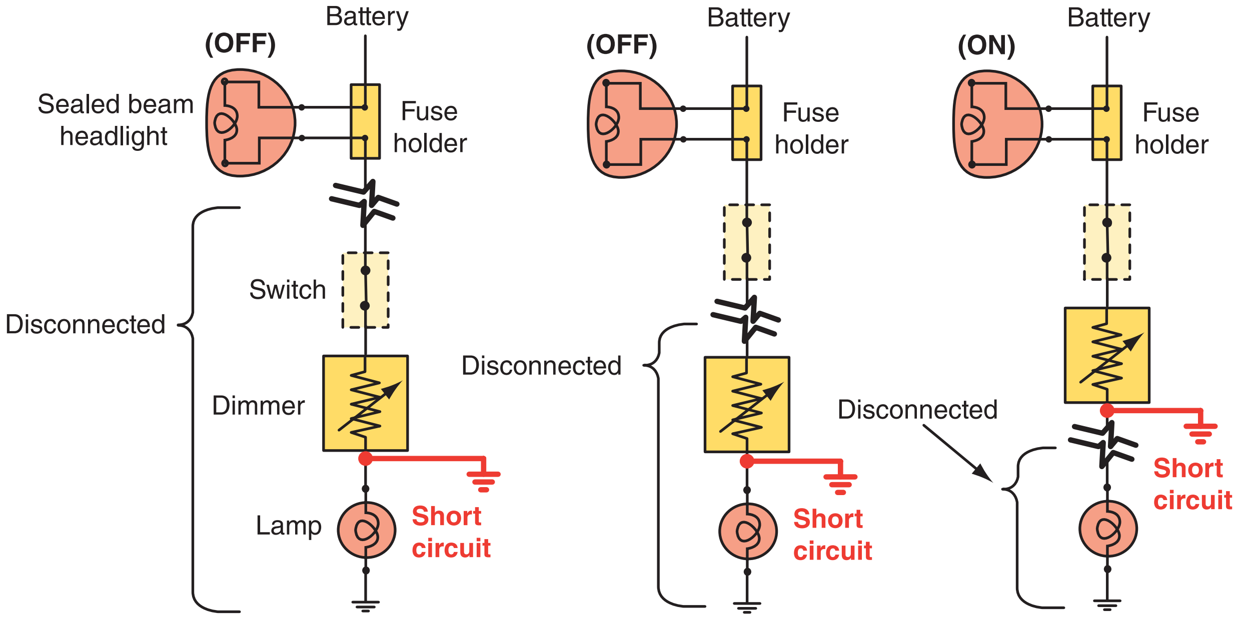


FIGURE 16–70 Many manufacturers do not recommend using a circuit breaker as a substitute for the fuse during testing; rather a sealed beam headlight is connected with jumper wires across the fuse holder.

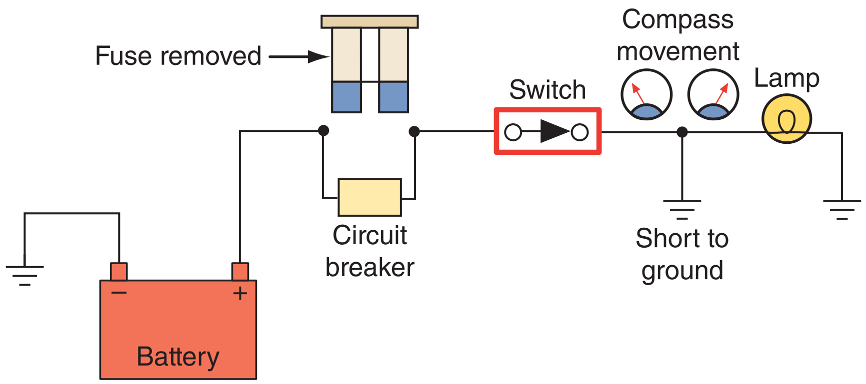


FIGURE 16–71 Use a compass to locate the cause of a short.

FIGURE 16–72 Corroded terminals.

poor connections, or frayed and damaged wires. Whenever excessive resistance is suspected, both sides of the circuit should be checked. Begin by checking the voltage drop across the load. This should be close to battery voltage unless the circuit contains a resistor located before the load. If the voltage is less than desired, check the voltage drop across the circuit from the switch to the load. If the voltage drop is excessive, that part of the circuit contains the unwanted resistance. If the voltage drop was normal, the high resistance is in the switch or in the circuit feeding the switch.

Check the voltage drop across the switch. If the voltage drop is excessive, the problem is the switch. If the voltage drop is normal, the high resistance is in the circuit feeding the switch. If battery voltage is present at the load, the ground circuit for the load should be checked. Connect the red voltmeter lead to the ground side of the load and the black lead to the grounding

point for the circuit. If the voltage drop is normal, the problem is the grounding point. If the voltage drop is excessive, move the black meter lead toward the red. Check the voltage drop at each step. Eventually you will read a high-voltage drop at one connector and then a low-voltage drop at the next. The point of high resistance is between those two test points.

Connector and Wire Repairs

Many electrical problems are caused by faulty wiring or connections. Loose or corroded terminals; frayed, broken, or oil-soaked wires; and faulty insulation are the most common causes. Keep in mind that a wire's insulation does not always appear to be damaged when the wire inside is broken. Also, a terminal may be tight but still may be corroded.

Wire Terminals and Connectors

Many different types of connectors, terminals, and junction blocks are used on today's vehicles. In most cases, the type used in a particular application is shown in a wiring diagram. Wire end terminals are used as connecting points for wires. They are generally made of tin-plated copper and come in many shapes and sizes. They may be either soldered or crimped in place. When installing a terminal, select the appropriate size and type of terminal. Be sure it fits the unit's connecting post or prongs and it has enough current-carrying capacity for the circuit.

Check all connectors for corrosion, dirt, and looseness. Nearly all connectors have pushdown release-type locks. Make sure these are not damaged. Many connectors have covers over them to protect them from dirt and moisture. Make sure these are properly installed to provide for that protection.

Warning! Always follow the manufacturer's wiring and terminal repair procedures. On some components and circuits, manufacturers recommend complete wiring harness replacement rather than making repairs to the wiring. For most vehicles, SRS air bag harness components, including wiring, insulation, and connectors, should not be repaired **(Figure 16–73)**. Any SRS harness damage requires replacement of the related harness.

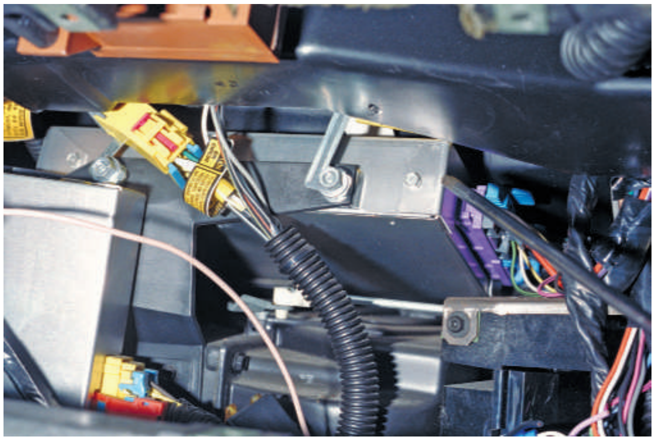


FIGURE 16–73 The wiring for SRS systems has yellow connectors, and all precautions and service procedures for dealing with these should be followed.

When a connector needs to be replaced because the original has melted **(Figure 16–74)** or is otherwise damaged, attempt to replace it with the same type and size. This may be difficult because many different types are used and all the various designs may not be available. Normally available connectors are based on common shapes with a common number of terminal cavities. Therefore, it is best to use a connector that meets the need; this may mean that some of the terminal cavities are left empty. For example, if the original connector has six terminals but the available replacement has eight, arrange the wire connections to the connector as if the connector had six. This will keep the wires in order for future diagnostics and leave the end pair blank. Of course, to do this, the male and female ends of the connector must be replaced. Sometimes, the replacement connector will require different terminal ends than the original. This requires the replacement of terminal ends on the wires for the male and female connectors.

If there is damage to a terminal or connector, the wires and terminals need to be removed from the connector. If the connector is a one-piece molded

FIGURE 16–74 A melted wire and corroded connector.

type, it cannot be disassembled for repairs. If it is damaged, it must be replaced.

> **Warning!** When working with connectors, never pull on the wires to separate the connectors. This can create an intermittent contact and an intermittent problem that can be very difficult to find later. Always use the special tools designed for separating connectors to prevent this problem.

Hard shell connectors normally have a locking tab to retain the terminal. To remove the terminal, a connector pick is used to depress the locking tab **(Figure 16–75)**. After repairs are made, use the connector pick to bend the tang back to its original shape before inserting it into the connector **(Figure 16–76)**.

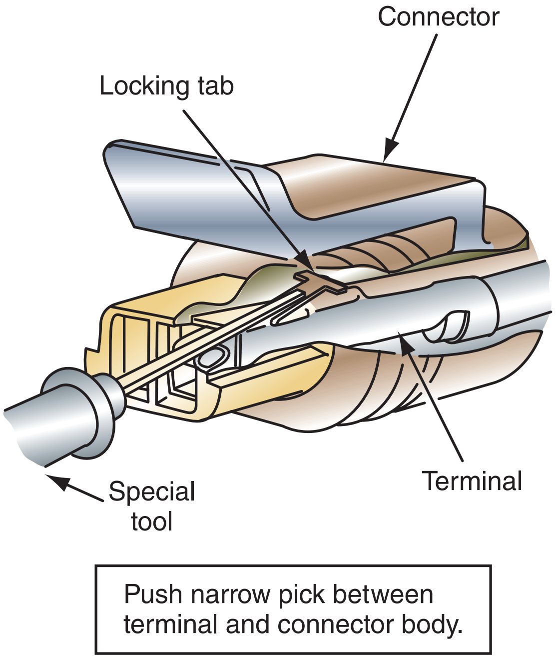


FIGURE 16–75 Depress the locking tang to remove the terminal from the connector.

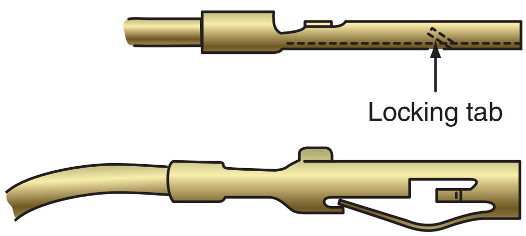


FIGURE 16–76 Before inserting the terminal back into the connector, return the tang to its original shape.

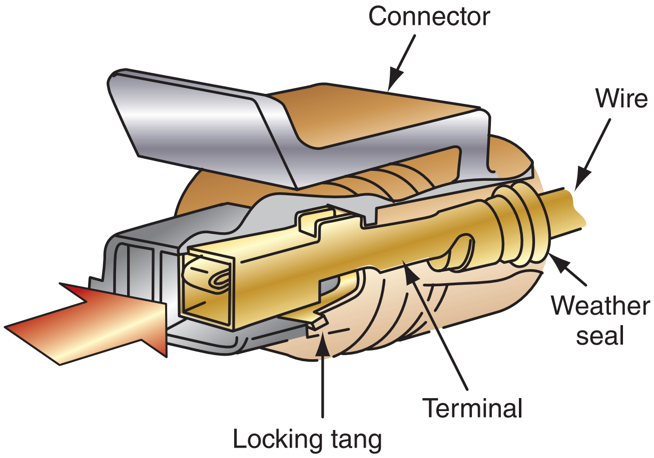


FIGURE 16–77 The locking tang in a metri-pack connector.

A terminal in a metri-pack connector can be removed by inserting a pick into the connector and under the locking tang to unlock it **(Figure 16–77)**. Push the terminal and wire out of the front of the connector.

If the terminals in a weather-pack connector need to be removed, the male and female connectors are separated by moving the primary lock up and pulling the connector apart **(Figure 16–78)**. Then unlock the secondary lock and open them **(Figure 16–79)**.

With a specified tool, depress the terminal locking tangs by pushing the tool over the terminal **(Figure 16–80)**. With the locking tangs depressed,

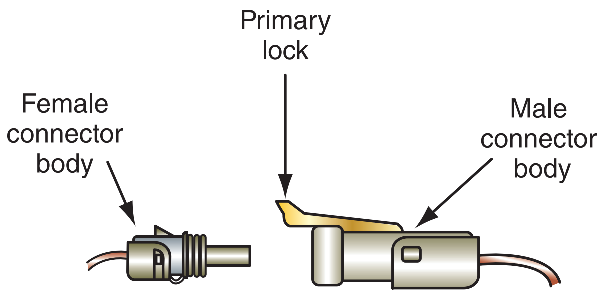


FIGURE 16–78 A weather-pack connector has two locks. The primary lock is lifted up to separate the two halves.

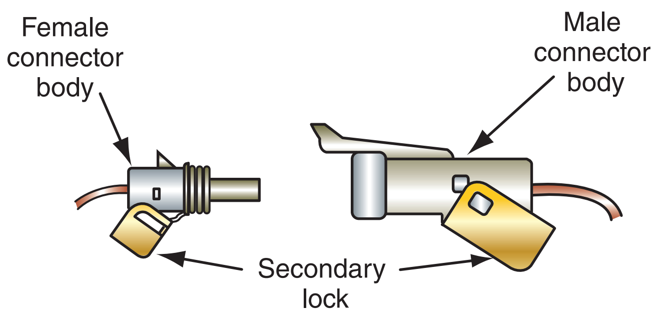


FIGURE 16–79 Unlock the secondary lock to remove the terminals.

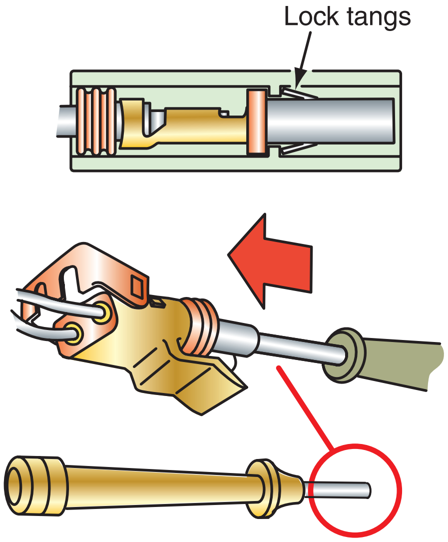


FIGURE 16-80 Use the recommended tool to unlock the tangs on the terminal.

remove the wire and terminal from the back of the connector.

Use a weather-pack repair kit, which includes new seals. After the repair has been made, push the wire through the connector's seal. Re-form the locking tang and assemble the two halves of the connector.

Replacing a Terminal

Terminal ends are replaced when they are damaged or to accommodate the use of a connector. The replacement process must be done to provide for good continuity and to prevent electrical problems in the future.

Never reroute wires when making repairs. Rerouting wires can result in induced voltages in nearby components. **Induced voltages** produce unwanted signals through magnetism rather than from the components within the circuit. These stray voltages can interfere with the function of electronic circuits. If making repairs to twisted pair wiring, be sure to maintain the necessary number of twists per foot. Failing to re-twist data bus wiring can cause communication problems as electronic interference may not cancel out if the wires are untwisted.

SHOP TALK

Apply dielectric grease to all connections before you assemble them. This will prevent future corrosion problems. Some manufacturers suggest using petroleum jelly at the connectors.

PROCEDURE

Guidelines for Terminal Replacement

1. Measure the diameter of the wire's insulation with a micrometer or vernier caliper.
2. Identify the type of terminal and use the measurement to select the correct size for the replacement terminal.
3. Select the correct size for the replacement wire.
4. Cut the old terminal from the wire in the harness.
5. Use the old wire as a guide and cut the replacement wire slightly longer.
6. Strip the insulation from the wire **(Figure 16–81)** in the harness and both ends of the replacement wire. Normally, $^{3}/_{8}$-inch of insulation should be removed. Make sure the strands of wire are not damaged while removing the insulation.
7. If heat shrink will be used to seal the connections, slip the appropriate length of tubing over the end of the wire that will be spliced.
8. Place the ends of the wires into the terminal and connectors and crimp the terminal **(Figure 16–82)**. To get a proper crimp, place the open area of the connector facing toward the anvil of the tool. Make sure the wire is compressed under the crimp.
9. Install the terminal into the connector. Make sure the locking clip is in the proper position. If it is not, use the terminal pick to gently bend it back to its original shape.
10. Push the terminal into the connector until a click is heard.
11. Gently pull on the wire. If the terminal is locked in the connector, it will not move.
12. Tape the new wire to the wiring harness **(Figure 16–83)**. If the harness is contained in conduit, make sure it is fully enclosed and tape the outside of the conduit.

Replacement Wire Selection

Often electrical problems require the replacement of a wire or two. It is important that this is done in a way that corrects the original problem but does not create a new problem. All replacement wires should be of the same size or larger than the original.

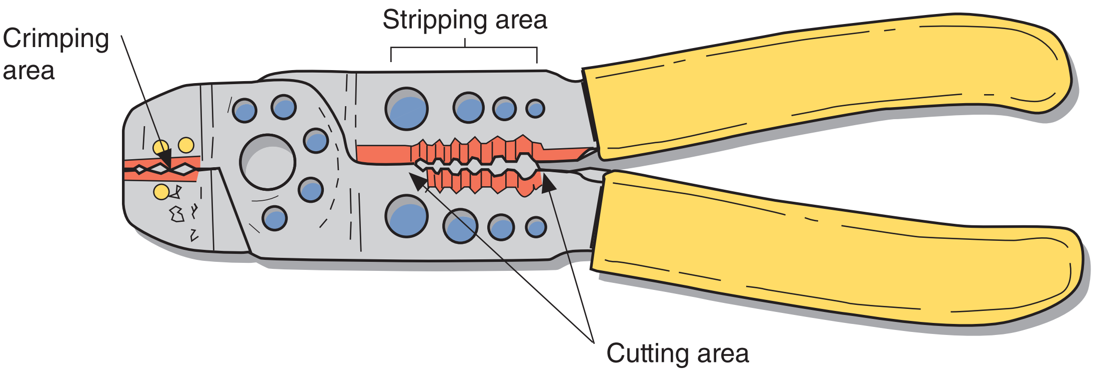


FIGURE 16–81 A typical crimping tool used for making electrical repairs.

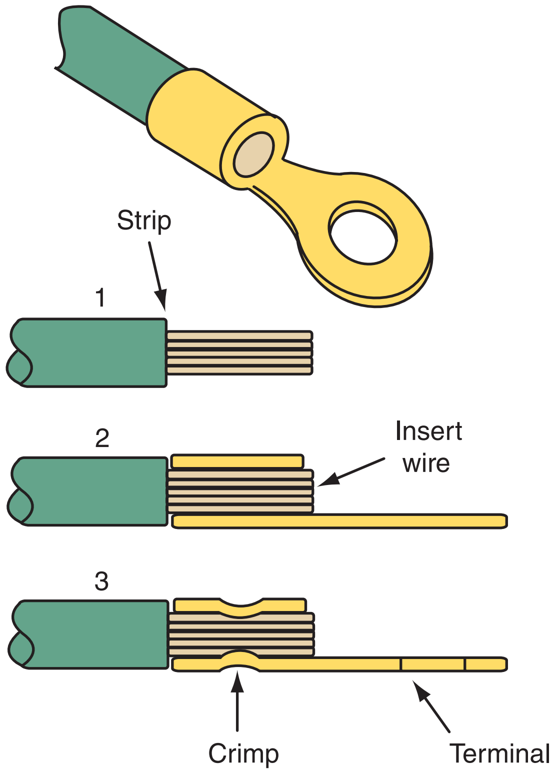


FIGURE 16–82 Placing a wire into and crimping it in a connector.

If adding an accessory, the new wire should be large enough to ensure safe and reliable performance. However, overly large wires add weight and expense, and add to the difficulty of splicing wires together. If the wire is too small, an unwanted voltage drop can occur. The two factors that should always be considered when determining the correct size of a wire are the total circuit amperage and the total length of wire (resistance increases with length) used in each circuit, including the ground. Allowance for the circuits, including grounds, has been computed in **Table 16–2**.

FIGURE 16–83 Tape all wire repairs to prevent corrosion and damage.

Warning! SRS air bag harness insulation and the related connectors are usually color coded yellow or orange. Do not connect any accessories or test equipment to SRS-related wiring.

Connecting Wires

When a section of a wire needs to be replaced, cut the damaged end of the wire from the main wire. Match the dimensions of the new wire to the old one. Measure the required length of the replacement wire; make sure it is slightly longer than the section that was removed. Then connect the two wires together.

There are several ways of connecting the original wire to a replacement wire. Butt connectors can provide a good joint between the wires. However, the

TABLE 16-2 AMPERAGE CAPACITY ACCORDING TO WIRE SIZE AND LENGTH

Approx. Circuit Current in Amps at 12 V:	Required Wire Gauge per Length in Feet								
	3	5	7	10	15	20	25	30	40
1	18	18	18	18	18	18	18	18	18
2	18	18	18	18	18	18	18	18	18
4	18	18	18	18	18	18	18	16	16
6	18	18	18	18	18	18	16	16	16
8	18	18	18	18	16	16	16	16	16
10	18	18	18	18	16	16	16	14	12
15	18	18	18	18	14	14	12	12	12
20	18	18	16	16	14	12	10	10	10
30	18	16	16	14	10	10	10	10	10
40	18	16	14	12	10	10	8	8	6
50	12	12	10	10	6	6	4	4	4
100	10	10	8	8	4	4	2	2	2
200	10	8	8	6	4	4	2	2	1

preferred way to connect wires or to install a connector is by soldering. Soldering joins two pieces of metal together by melting a lead and tin alloy and allowing it to flow into the joint. A soldering iron or gun is used to heat the solder. There are different types of solder, but only rosin-type or resin-type flux core solder should be used for electrical work.

Before using a soldering iron, make sure the tip is clean and tinned. The tip is made of copper, which corrodes through use. A corroded tip cannot transfer heat as it should. Use a file to remove all residue from the tip. When finished, the tip should be smooth and flat. Turn the iron on and allow it to heat. Then dip the hot tip into some soldering rosin flux. Remove the tip from the flux and immediately apply rosin core solder to all surfaces. The solder should flow over the tip. The tip is now tinned.

Photo Sequence 14 shows the procedure for soldering two copper wires together. Some manufacturers use aluminum in their wiring. Aluminum cannot be soldered. Follow the manufacturer's guidelines when repairing aluminum wiring.

Warning! Never use acid core solder. It creates corrosion and can damage electronic components.

After a joint has been made, it must be insulated. This can be done with heat shrink tubing or tape. When using tape, place one end of the tape about 1 inch from the joint. Tightly wrap the tape around the wire. As the tape is being wrapped, about one-half of the previous wrap should be covered by the tape as it completes one turn around the wire. Once the wrapping has reached 1 inch beyond the joint, cut the tape. Firmly press on the tape at that end to form a good seal.

When using heat shrink tubing, make sure the tubing is slightly larger than the diameter of the splice. Cut a length of the tubing so that it is longer than the splice. Before joining the wires together, slip the tubing over one of the wires. Proceed to make the joint. After the wires are connected, move the shrink tubing over the splice. Use a heat gun and heat the tubing until it shrinks tightly around the splice. The tubing will only shrink a certain amount; therefore, do not continue to heat it after it is in place. Doing this can melt the tubing and/or the insulation of the wire.

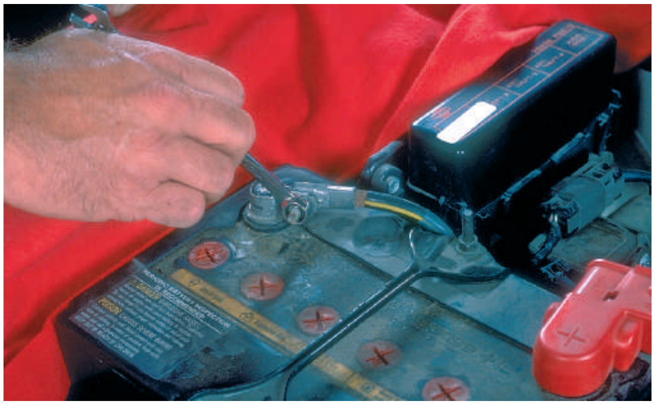
SHOP TALK

Rather than using a splice, some technicians twist the wire ends tightly together before soldering the joint. When doing this, it is important to realize that the solder does not provide for a mechanical joint. Therefore, it is important that the twisting provides a secure joint before soldering.

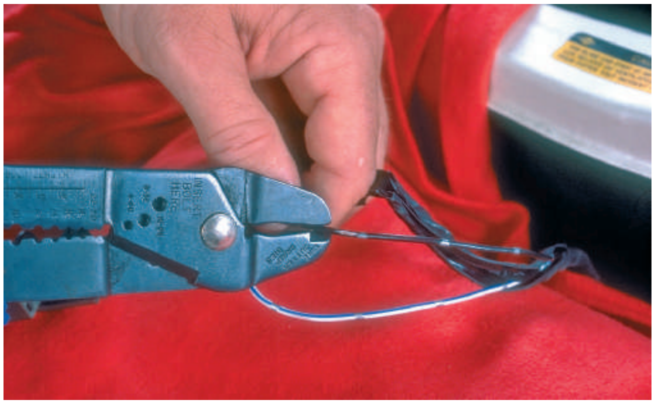
PHOTO SEQUENCE 14

Soldering Two Copper Wires Together

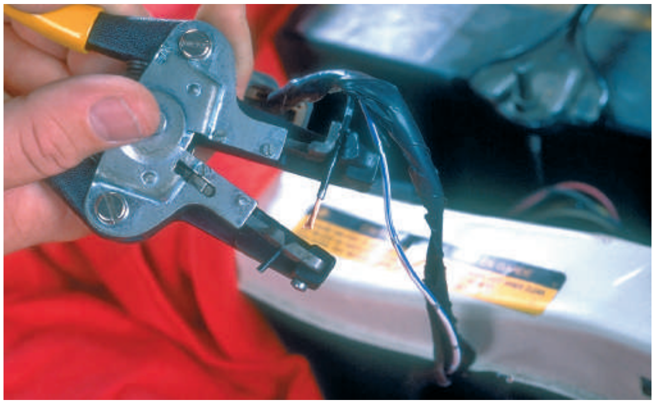
P14-1 Tools required to solder copper wire: 100-watt soldering iron, 60/40 rosin core solder, crimping tool, splice clip, heat shrink tube, heating gun, and safety glasses.



P14-2 Disconnect the fuse that powers the circuit being repaired. Note: If the circuit is not protected by a fuse, disconnect the ground lead of the battery.

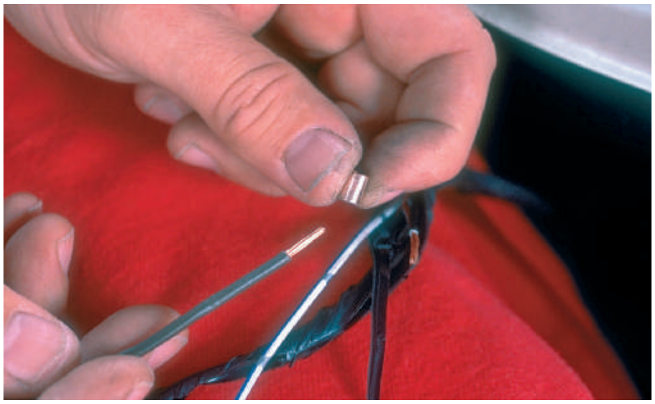


P14-3 Cut out the damaged wire.



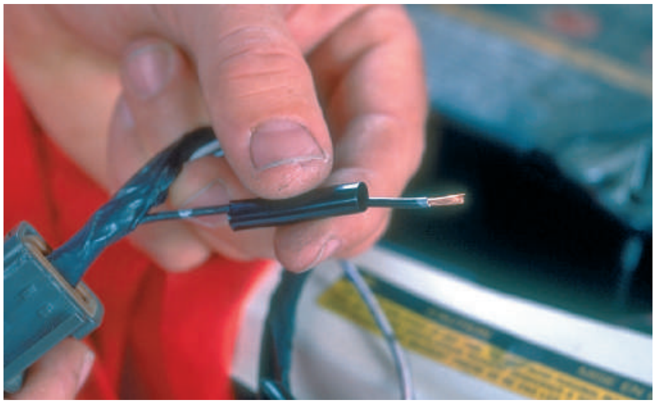
P14-4 Using the correct size stripper, remove about ½ inch of the insulation from both wires.

P14-5 Now remove about ½ inch of the insulation from both ends of the replacement wire. The length of the replacement wire should be slightly longer than the length of the wire removed.

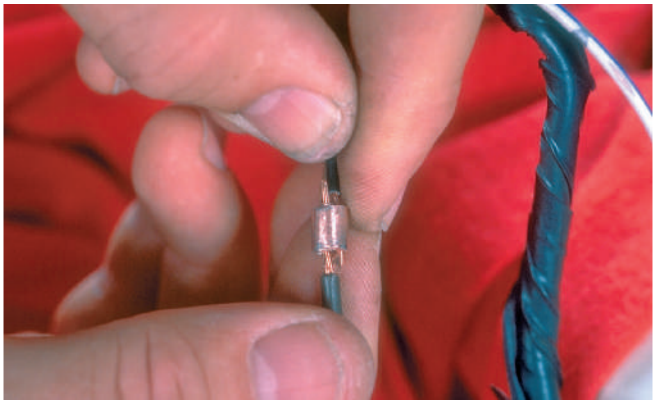


P14-6 Select the proper size splice clip to hold the splice.

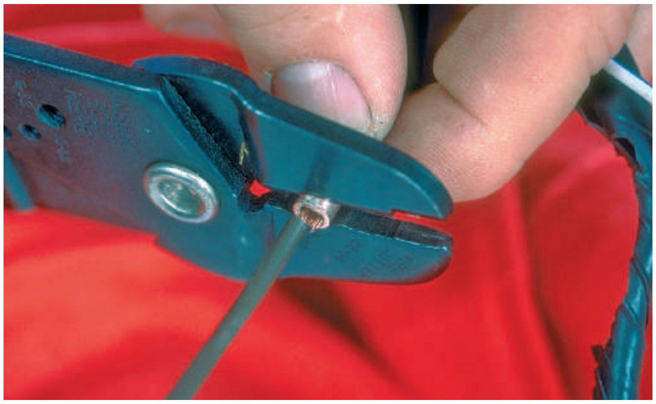
Soldering Two Copper Wires Together *(continued)*



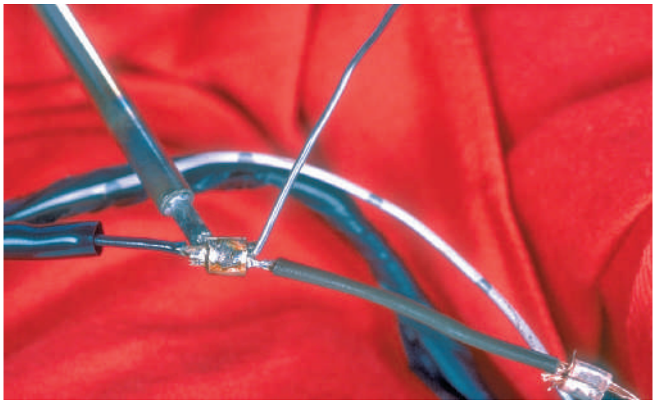
P14-7 Place the correct size and length of heat shrink tube over the two ends of the wire.



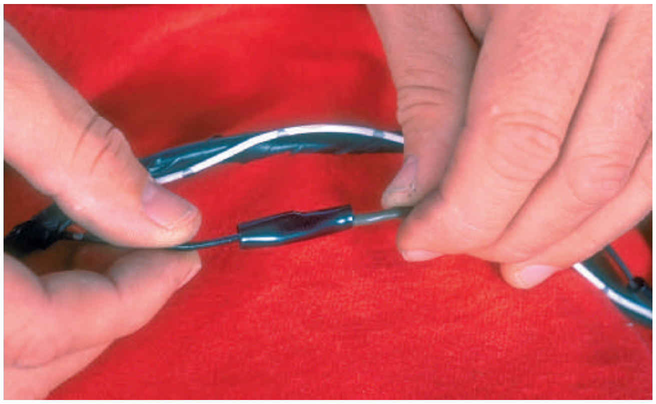
P14-8 Overlap the two splice ends and center the splice clip around the wires, making sure that the wires extend beyond the splice clip in both directions.



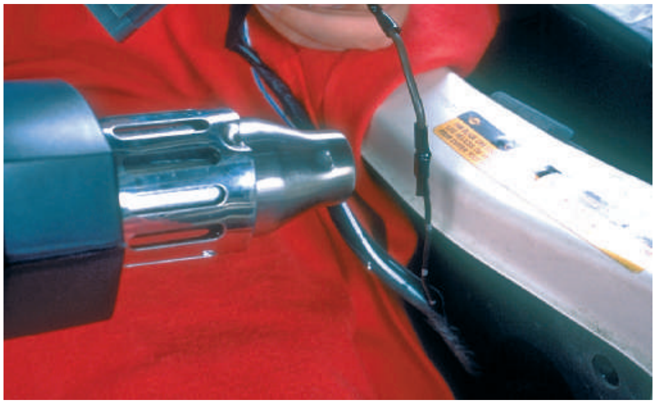
P14-9 Crimp the splice clip firmly in place.



P14-10 Apply the tip flat of the soldering iron against the splice to hear it. At the same time, apply solder to the opening of the clip. Do not apply solder to the iron. The iron should be 180 degrees away from the opening of the clip. As the splice and wires heat, the solder will flow through the splice.



P14-11 Place the hot soldering iron in its stand and unplug it. After the solder cools, slide the heat shrink tube over the splice.



P14-12 Heat the tube with the hot air gun until it shrinks around the splice. Do not overheat the heat shrink tube.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2010	**Make:** Mazda	**Model:** RX-8	**Mileage:** 118,551	**RO:** 15875
Concern:	Customer states stop lights do not work. When he replaced the fuse, it blew as soon as the brake pedal was pressed.			
The technician confirms that the fuse blows as soon as the light are turned on. Noticing the car has aftermarket tail light assemblies, he inspects the rear lights and wiring. He replaces the fuse and the stop lights work with the trunk open, but the fuse blows with the trunk shut.				
Cause:	Checked wiring to all rear lights. Found harness to center high-mounted stop light chaffed against trunk hinge and damaged wires.			
Correction:	Inspection of the harness revealed a wire that had rubbed through the insulation against the hinge. Rerouted harness and repaired wire.			

KEY TERMS

Average responding
Glitches
Induced voltage
Radio frequency interference (RFI)
Root mean square
Schematics
Short

SUMMARY

- All electrical problems can be classified as an open, short, or high-resistance problem. Identifying the type of problem will allow for the identification of the correct tests to conduct when diagnosing an electrical circuit.
- Wiring diagrams show where wires are connected, the circuit's components, the color of the wires' insulation, and sometimes the wire gauge size.
- Voltmeters, ohmmeters, ammeters, and volt/amp meters are used to test and diagnose electrical systems. These are used with jumper wires, testlights, and variable resistors.
- Multimeters are multifunctional and can test DC and AC volts, ohms, and amperes. Some multimeters can also be used to measure engine rpm, duty cycle, pulse width, frequency, and temperature.
- There are two ways that DMMs display AC voltage: RMS and average responding.
- Some DMMs also feature a MIN/MAX function, which displays the maximum, minimum, and average voltage the meter recorded during the time of the test.
- On a lab scope, an upward movement of the trace indicates an increase in voltage, and a downward movement of this trace represents a decrease in voltage. As the trace moves across the screen, it represents a specific length of time.
- To troubleshoot a problem, begin by verifying the customer's complaint. Then operate the system and others to get a complete understanding of the problem. Use the correct wiring diagram and identify testing points and probable problem areas. Test and use logic to identify the cause of the problem.
- Wiring diagrams are invaluable for diagnostics. Tracing the diagram allows you to think about how the circuit should work and where it should be tested.
- Many automotive electrical problems can be traced to faulty wiring, such as loose or corroded terminals; frayed, broken, or oil-soaked wires; and faulty insulation.
- The preferred way to connect wires or to install a connector is by soldering. Never use acid core solder. It creates corrosion and can damage electronic components.

REVIEW QUESTIONS

Short Answer

1. How will an electrical circuit behave if there is a short in the circuit?
2. What happens to an electrical circuit when there is unwanted resistance in it?
3. What is indicated by a reading of battery voltage on the ground side of a component?
4. What type of solder should be used to repair electrical wiring?

True or False

1. *True or False?* The MIN/MAX function on some DMMs can be used to check for electrical noise.
2. *True or False?* A zero reading on an ohmmeter means the circuit or component is open.
3. *True or False?* The maximum allowable voltage loss due to voltage drops across a single connector in a 12-volt circuit is 1.2 volts.
4. *True or False?* While troubleshooting a problem, the key to identifying the exact cause of the problem is testing all of the vehicle's components and circuits until the problem is found.
5. *True or False?* When tracing a circuit in a wiring diagram, remember that all circuits have a power source, a load, and a path to ground and they need to be identified.

Multiple Choice

1. An ammeter is always connected in ___ with the circuit, whereas a voltmeter is connected in ___ with the circuit.
   a. parallel, series
   b. parallel, parallel
   c. series, parallel
   d. series, series
2. Which of the following is *not* a typical cause of unwanted or high resistance in a circuit?
   a. Corrosion on terminal ends
   b. A power wire contacting the chassis
   c. Loose or poor connections
   d. Frayed and damaged wires
3. Wiring harnesses are typically shielded by plastic conduit. What color is normally used to shield SRS-related wiring?
   a. Black
   b. Green
   c. Yellow
   d. Orange
4. Which of the following lab scope controls must be set when trying to observe how long an event takes place?
   a. Intensity
   b. Vertical
   c. Horizontal
   d. Trigger
5. Which of the following statements is true?
   a. A short to ground causes decreased current flow.
   b. An open causes unwanted voltage drops.
   c. High-resistance problems can cause damage to wiring and connections.
   d. High-resistance problems may cause a fuse to blow.
6. Which of the following information is not given in a wiring diagram?
   a. Wire-by-wire color coding
   b. Location of wire harness travel
   c. Terminal designation
   d. Component designations

ASE-STYLE REVIEW QUESTIONS

1. While discussing electricity: Technician A says that an open causes unwanted voltage drops. Technician B says that high-resistance problems cause increased current flow. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. While discussing NTC thermistors: Technician A says that some systems use this type of thermistor as a protection device. Technician B says that when there is high current in a circuit, the resistance of the thermistor increases and causes a decrease in current flow. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. While measuring the resistance of a wire with an ohmmeter: Technician A says that if low resistance is shown on the meter, the wire is shorted. Technician B says that if infinite resistance is measured, the wire is shorted. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

4. While testing variable resistors: Technician A says that while checking a rheostat with a voltmeter, the voltage should change smoothly with a change in the control. Technician B says that a potentiometer can be checked with a scope. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. While using an ohmmeter to measure the resistance values of a component: Technician A says that if the component has the specified resistance, the part is good. Technician B says that having resistance does not guarantee a part is good. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. Technician A uses a testlight to test circuit protection devices. Technician B uses a voltmeter to test circuit protection devices. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. Technician A uses a testlight to detect high resistance. Technician B uses a jumper wire to test circuit breakers, relays, and lights. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. While diagnosing the location of a wire-to-wire short: Technician A checks the wiring of the affected circuits for signs of burned insulation and melted conductors. Technician B checks common connectors shared by the two affected circuits. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. While measuring resistance: Technician A uses an ohmmeter to measure resistance of a component before disconnecting it from the circuit. Technician B uses a voltmeter to measure voltage drop. A circuit with very low resistance will drop zero or very little voltage. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While discussing how to test a switch: Technician A says that the action of the switch can be monitored by a voltmeter. Technician B says that continuity across the switch can be checked by measuring the resistance across the switch is in its different positions. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER

17 BATTERIES: THEORY, DIAGNOSIS, AND SERVICE

The primary source for electrical power in all automobiles is the battery **(Figure 17–1)**. The battery has undergone many changes through the years. However, lead-acid batteries have been, and continue to be, the most common power source for conventional vehicles. The introduction of hybrid vehicles and the promise of fuel cell vehicles have drastically changed the basic design of an automotive battery. Many different types of batteries are available or under development to exceed the needs of hybrid or fuel cell vehicles. Each of these energy-storing devices is discussed in this chapter.

OBJECTIVES

- Describe how a battery works.
- List the precautions that must be adhered to when working with or around batteries.
- Describe the basic construction of an electrochemical cell.
- Explain how electrochemical cells can be connected to increase voltage and current.
- Explain the different methods used to recharge a battery.
- List and describe the various ways a battery may be rated.
- List and describe the various types of batteries according to their chemistries that may be used in automobiles.
- Describe the construction and operation of a lead-acid battery.
- Describe the various types of lead-acid batteries that are available today.
- Describe the basic services and testing procedures for a lead-acid battery.

Basic Battery Theory

Electrical current is caused by the movement of electrons from something negative to something positive. The strength of the attraction of the electrons (negative) to the protons (positive) determines the amount of voltage present. When a path is not

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2013	**Make:** Cadillac	**Model:** XTS	**Mileage:** 88,951	**RO:** 16078
Concern:	The vehicle will not start after sitting overnight without having to jump the battery.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

FIGURE 17-1 A typical 12-volt battery.

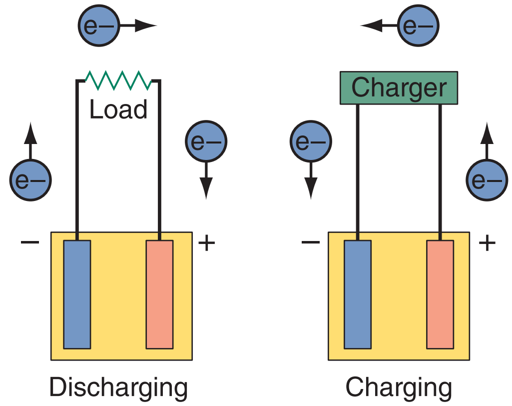


FIGURE 17-3 The flow of electrons in a battery while discharging and charging.

present for the electrons to travel through, voltage is still present but there is no current flow. When there is a path, the electrons move and there is current. This is the basic operation of batteries.

Basic Construction

Batteries convert chemical energy into electrical energy. Chemical reactions that produce electrons are called **electrochemical reaction**. A battery stores DC voltage and releases it when it is connected to a closed circuit. Inside the battery are two **electrodes** or **plates** surrounded by an electrolyte. These three elements make up an electrochemical cell **(Figure 17–2)**. Batteries are normally made up of electrochemical cells connected together.

One of the plates has an abundance of electrons (negative plate or anode) and the other has a lack of electrons (positive plate or cathode). The electrons want to move to the positive plate and do so when a circuit connects the two plates. Batteries have two terminals, a positive that is connected to the positive plates and a negative that is connected to the negative plates.

Electrolytes are chemical solutions that react with the metals used to construct the plates. These chemical reactions cause a lack of electrons on the positive electrode and an excess on the negative electrode. The reactions continue to provide electrons for current flow until the circuit is opened or the chemicals inside the battery become weak. At that time, the battery has run out of electrons (the battery is worn out), the number of electrons on the positive and negative sides are equal, or all of the protons are matched with an electron. Recharging simply moves the electrons that moved to the positive electrode back to the negative electrode **(Figure 17–3)**.

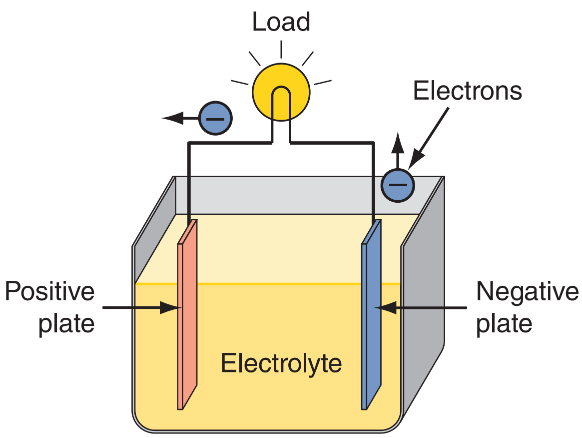


FIGURE 17-2 A simple electrochemical cell.

Charging

Charging a battery restores the chemical nature of the cells. To do this, a chemical reaction takes place, causing current flow within the cells. Discharging allows for current flow outside the cell. To understand the charging process, remember that current flows from a higher potential (voltage) to a lower potential. If the voltage applied by an outside source to the battery is higher than the voltage of the battery, current will flow into the battery. This means the charging voltage must be higher than the battery's voltage in order to charge it.

SHOP TALK

Each battery design has its own charging requirements. It is important to follow the correct procedure and charger for the battery being charged. It is also important to prevent the battery from overheating during charging.

Cell Arrangements

The voltage produced by an individual battery cell varies with the chemicals and materials used to construct the cell. Most cells produce between 1.2 and 4 volts. Likewise, there is a limited amount of current available from an individual cell. To provide higher battery voltages and increase available current, cells are connected together. Cells can be connected in series or in parallel, or both.

Series Connections Cells are connected in series to provide higher voltages. The total battery voltage is the sum of the voltages in each cell. For example, a lead-acid cell, commonly used in starting batteries, produces about 2.1 volts. By connecting six cells together in series, the battery has a voltage of 12.6 volts. Series connections have the positive terminal of one cell connected to the negative terminal of another, the positive terminal of that cell connected to the negative of another, and so on **(Figure 17–4)**. Individual batteries can also be connected in series. Forty-two-volt systems use a 36-volt battery pack (actual voltage is 37.8 volts), which can be made from three 12-volt batteries **(Figure 17–5)** or eighteen 2-volt cells connected in series. Forty-two volts are provided by the charging system.

Parallel Connections Cells are connected in parallel to increase the amperage of the pack of cells. In this arrangement, all of the positive terminals are connected together, and all of the negative terminals are connected together. The total amperage is the sum of amperages from each cell. The voltage is equal to the voltage of an individual cell.

Series-Parallel Connections Groups of cells are wired in parallel and then those groups are connected in series to provide an increase in voltage and amperage **(Figure 17–6)**. Any number of cells can be connected together as long as each group of parallel cells that are connected in series has the same output.

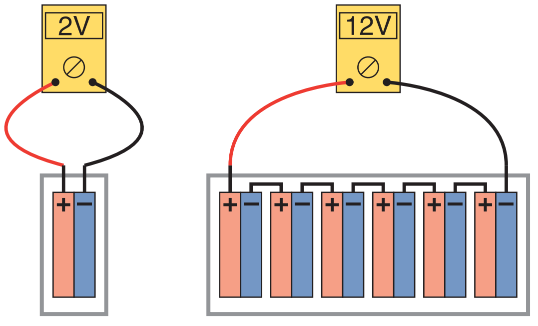


FIGURE 17–4 When individual cells are connected in series, the total voltage is equal to the sum of the cells. Parallel connections increase amperage.

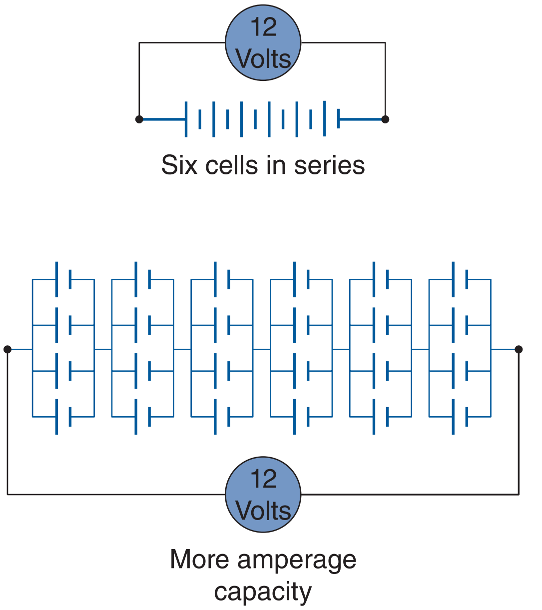


FIGURE 17–6 12-volt batteries are arranged in series-parallel. Series to achieve 12.6 volts and parallel to increase current capacity.

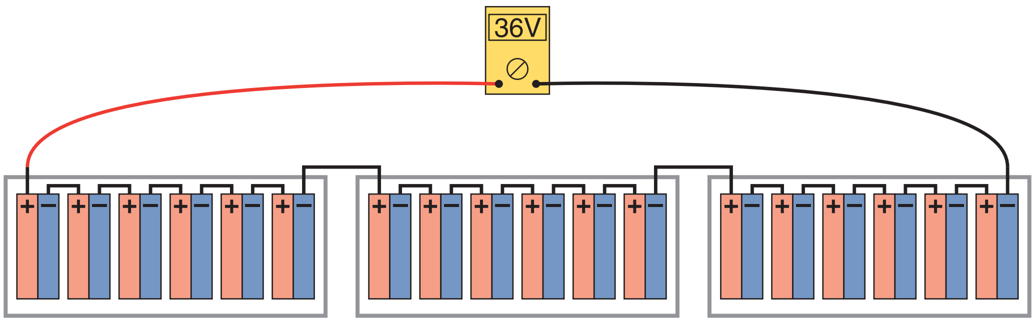


FIGURE 17–5 A 36-volt battery pack can be made from three 12-volt batteries or eighteen 2-volt cells connected in series.

Battery Hardware

Many different components and systems are necessary to have an efficiently operating battery or battery pack.

Battery Cables

Battery cables connect the battery to the vehicle's electrical system. They are large diameter wires because they must be able to carry the required current to operate the starter motor. Normal 12-volt cable size is 2 or 4 gauge. The positive cable is normally red and the negative cable is black. Smaller wires for other circuits are either connected to the battery, remote junction box, or the starting system. Various forms of clamps and terminals are used to ensure a good electrical connection at each end of the cable **(Figure 17–7)**. Connections must be clean and tight to prevent arcing and corrosion.

The high-voltage cables in nearly all hybrid vehicles are colored orange and have markings on them. Sometimes the cables are enclosed in an orange casing. It is important to remember that some hybrids power other accessories with high voltage; these cables are orange just like the battery cables **(Figure 17–8)**.

Battery Holddowns

All batteries must be held securely in the vehicle to prevent damage to the battery and to prevent the terminals from shorting to the vehicle. Battery holddowns are made of metal or plastic **(Figure 17–9)**.

Cooling System

The performance and durability of batteries, especially high-voltage battery packs, are heavily dependent on

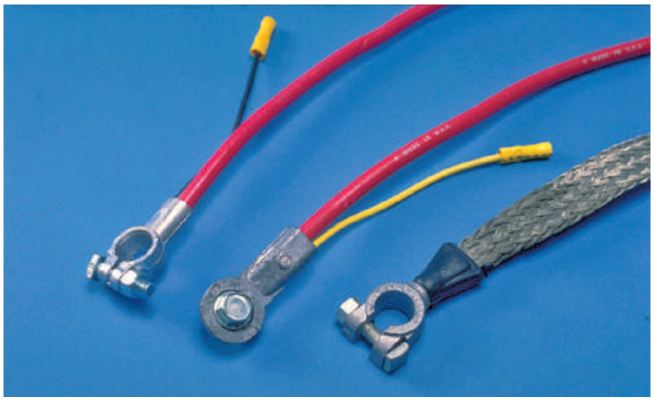


FIGURE 17–7 The battery cable is designed to carry the high current required to start the engine and supply the vehicle's electrical systems.

FIGURE 17–8 High voltage cables are colored orange or are enclosed in orange conduit.

FIGURE 17–9 A typical battery holddown.

maintaining specific temperatures. Each battery design has its own optimal temperature range. Some battery designs work best when they are warm. To provide for this warmth, a battery blanket or heater is used to keep the battery warm especially during extremely cold weather.

Other batteries develop too much heat when they are being recharged and need to be constantly cooled. These batteries may have a heat shield made of plastic or another material to protect the battery from high underhood temperatures. Others are housed in a box or container with a cooling fan. The box not only secures the battery, but also serves as a conduit for cooling air from the fan **(Figure 17–10)**. Other battery boxes are designed to allow coolant to flow through to cool the cells.

Recycling Batteries

The materials used to make a battery can be successfully recycled. Batteries should not be discarded

FIGURE 17–10 This assembly is made up of a cooling fan and air ducts to cool the HV battery inside the case.

Caution! A battery should never be incinerated; doing this can cause an explosion.

with regular trash because they contain metals and chemicals that are hazardous to the environment.

In 1994, the Rechargeable Battery Recycling Corporation (RBRC) was established to promote recycling of rechargeable batteries in North America. RBRC is a nonprofit organization that collects batteries from consumers and businesses and sends them to recycling companies. Collected batteries are sorted by their chemical makeup. Then they are broken apart and their elements separated. The chemicals or materials are further separated and then collected.

The majority of all used lead-acid batteries are recycled. During the recycling process, the lead, plastic, and acids are separated. The electrolyte (sulfuric acid) can be reused or is discarded after it has been neutralized. The plastic casing is cut into small pieces, scrubbed, and melted to make new battery cases and other parts. The lead is also melted and poured into ingots to be used in new batteries.

Battery Ratings

The voltage rating of a battery may be expressed as open circuit or operating voltage. **Open circuit voltage** is the voltage measured across the battery when there is no load on the battery. Operating voltage is the voltage measured across the battery when it is under a load.

The available current from a battery is expressed as the battery's capacity to provide a certain amount of current for a certain amount of time and at a certain

FIGURE 17–11 The sticker on this battery shows its CA and CCA ratings.

temperature. Basically, a capacity rating expresses how much electrical energy a battery can store. Battery ratings are found on the battery sticker, as shown in **Figure 17–11**. The sticker on some batteries will not reference all possible ratings. However, most will give the BCI group number, CCA, and CA.

BCI Groups

The BCI or Battery Council International group number defines the physical qualities of a battery, such as terminal location and the height, width, and depth of the battery. This is a standardized system that ensures that a battery in a specific group will have similar physical characteristics no matter who manufactures the battery or where it is purchased. An example of a BCI rating is shown in **Figure 17–12**.

Cold Cranking Amps

The **cold cranking amps (CCA)** rating is the common method of rating starting batteries. It expresses the amount of amperage a battery can deliver for 30

FIGURE 17–12 A battery sticker with a BCI group number and additional information.

seconds at 0 °F (–17.7 °C) without its voltage dropping below a predetermined level. That voltage level for a 12-volt battery is 7.2 volts. The normal CCA range for automotive batteries is between 300 and 600 CCA; some batteries have a rating as high as 1,100 CCA.

Cranking Amps

The **cranking amps (CA) rating** is similar to CCA and expresses the amount of the current a battery can deliver at 32 °F (0 °C) for 30 seconds and maintain voltage at a predetermined level. Normally, the CCA rating of a battery is about 20 percent less than its CA rating.

Reserve Capacity

The **reserve capacity (RC) rating** represents the number of minutes that a fully charged battery can be discharged at 25 amperes before battery voltage drops below 10.5 volts. A battery with a reserve capacity of 120 would be able to deliver 25 amps for 120 minutes before its voltage drops below 10.5 volts.

Ampere-Hour

In the past, the ampere-hour rating was the common rating method for lead-acid batteries. The **ampere-hour (AH) rating** represents the amount of steady current a fully charged battery can supply for 20 hours at 80 °F (26.7 °C) without the cell's voltage dropping below a predetermined level. For example, if a 12-volt battery can be discharged for 20 hours at a rate of 4.0 amperes before its voltage drops to 10.5 volts, it would be rated at 80 AH (20 hours × 4 amps = 80 AH).

Watt-Hour Rating

Some battery manufacturers rate their batteries in watt-hours. The watt-hour rating is determined at 0 °F (–17.7 °C) because the battery's capacity changes with temperature. The rating is calculated by multiplying a battery's AH rating by the battery's voltage. The watt-hour rating of a battery may be listed in units of kilowatts. Most hybrid and electric vehicle batteries are rated in kilowatts (kW) or kilowatt hours (kWh). The kilowatt rating indicates how much power can flow into or out of a battery at any given instant of time. Kilowatt hours represents the power a battery can deliver or absorb over time. A kWh is equal to 1,000 watts (1 kW) consumed or produced per hour. For example, if you left ten 100-watt bulbs burning for 1 hour, they would consume 1,000 watt-hours or 1 kWh of electricity. A 12-volt battery rated at 100-amp hours (20 amps × 5 hours) is rated at 1,200-watt hours or 1.2 kilowatt hours.

Common Types of Batteries

There are many different types and designs of batteries available. Batteries differ in size, from small single cells to large battery packs, comprised of many cells. They also have different ratings (not always dependent on size) and service lives. The primary difference between batteries is the chemicals used in the cells. The following battery designs are currently in use or are being considered for automotive use in the future.

- Lead-Acid
- Nickel-Cadmium (NiCad)
- Nickel-Metal Hydride (NiMH)
- Lithium-Ion (Li-Ion)
- Lithium-Polymer (Li-Poly)

A simple comparison of the battery types is shown in **Figure 17–13**. Some of these designs will be discussed in more detail in later chapters.

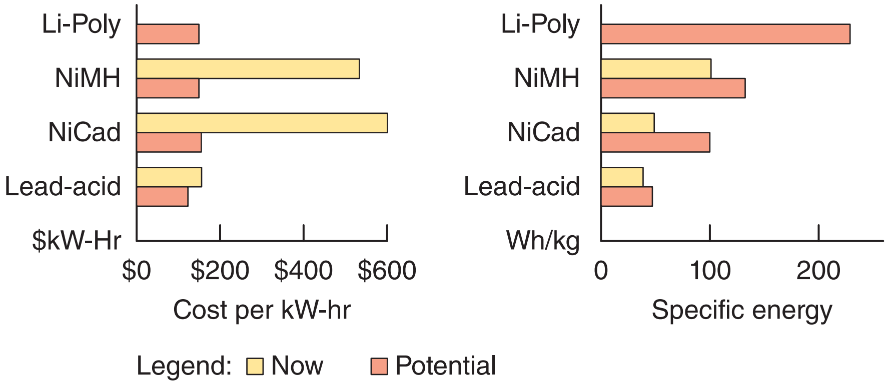


FIGURE 17–13 A chart comparing different battery designs and the main reasons Li-Poly batteries are being heavily researched for use in electric drive vehicles.

Lead-Acid Batteries

The most commonly used type of battery in an automobile is the lead-acid. The wet cell, gel cell, absorbed glass mat (AGM), and valve regulated are versions of a lead-acid battery.

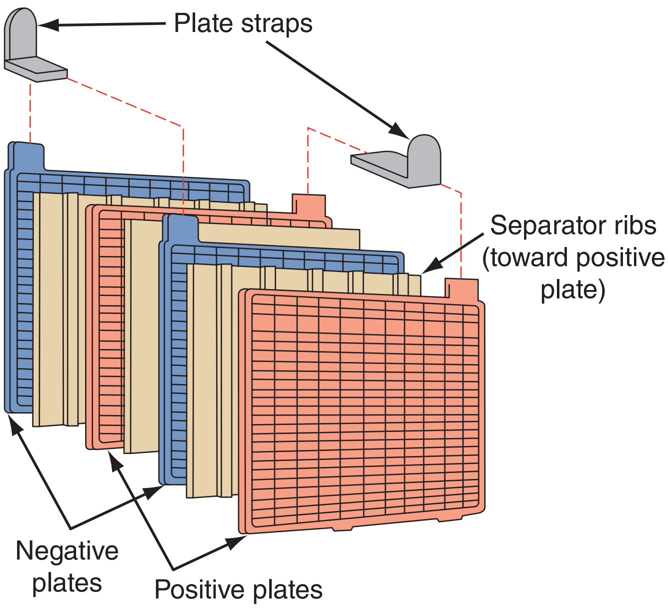


FIGURE 17–15 The parts of a typical battery element.

Basic Construction

A lead-acid battery consists of grids, positive plates, negative plates, separators, elements, electrolyte, a container, cell covers, vent plugs, and cell containers **(Figure 17–14)**. A **grid** is a lead alloy frame that supports the active material of each plate. Plates are typically flat, rectangular components that are either positive or negative, depending on the active material they hold.

The positive plate has a grid filled with its active material, lead peroxide. Lead peroxide (PbO_2) is a dark brown, crystalline material. The material pasted onto the grids of the negative plates is **sponge lead (Pb)**. Both plates are very porous and allow the liquid electrolyte to penetrate freely.

Each battery contains a number of elements. An **element** is a group of positive and negative plates **(Figure 17–15)**. The plates are formed into a plate group, which holds a number of plates of the same polarity. The like-charged plates are welded to a lead alloy post or **plate strap**. The plate groups are placed alternately within the battery—positive, negative, positive, negative, and so on. There is usually one extra set of negative plates to balance the charge.

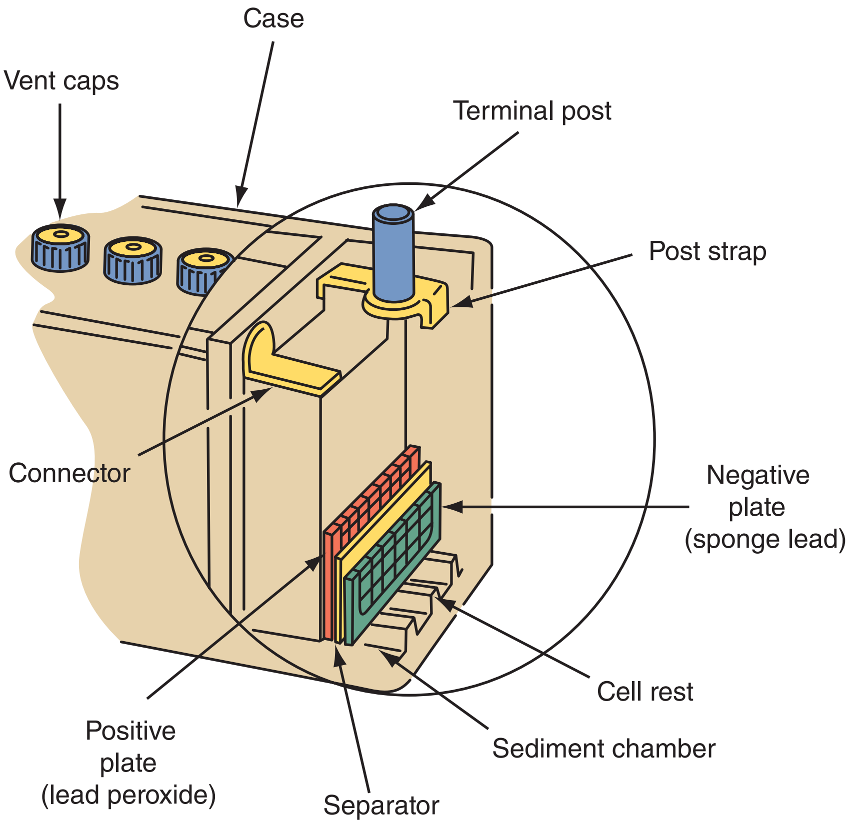


FIGURE 17–14 Components of a typical lead-acid storage battery.

To prevent the different plate groups from touching each other, separators are inserted between them. **Separators** are porous plastic sheets that allow for a transfer of ions between plates. When the element is placed into the battery case and immersed in electrolyte, it becomes a cell.

The electrolyte is a solution of sulfuric acid and water. The sulfuric acid (H_2SO_4) supplies sulfate, which chemically reacts with both the positive and negative plates to release electrical energy. To cause the required chemical reaction, the electrolyte must be the correct mixture of water and sulfuric acid. At 12.6 volts, the desired solution is 65 percent water and 35 percent sulfuric acid. Available voltage decreases when the percentage of acid in the solution decreases.

Casing Design The container or shell of the battery is usually a one-piece, molded assembly of polypropylene, hard rubber, or plastic. The case has a number of individual cell compartments. Cell connectors are used to join all cells of a battery in series.

The top of the battery is encased by a cell cover. The cover of nearly all newer batteries is a one-piece design. The cells of older batteries had individual removable covers or a cover that closed off more than one cell opening **(Figure 17–16)**. The cover must have vent holes to allow hydrogen and oxygen gases to escape. These gases are formed during charging and discharging. Battery vents can be permanently fixed to the cover or be removable. Vent plugs or caps are used on some batteries to close the openings in the cell cover and to allow for topping off the cells with electrolyte or water.

At the bottom of some battery casings is a sediment chamber. The chamber collects the materials that fall from the plates. If the sediments do not fall below the plates, they could cause a short between the plates. Some batteries do not have a sediment chamber; rather envelope-type separators are used to contain all sediments and keep them from contacting the plates.

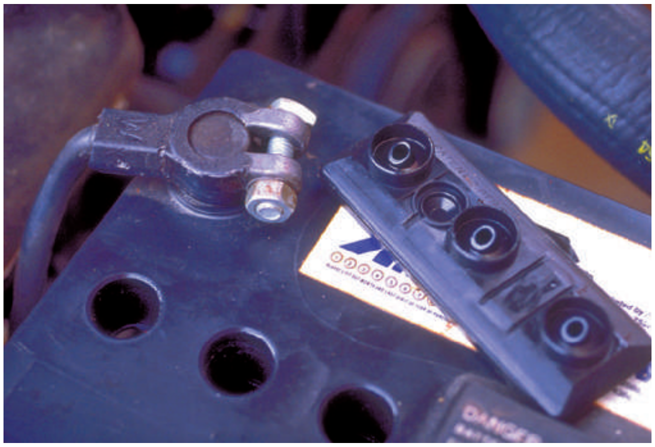


FIGURE 17–16 A battery with removable cell caps.

Caution! When lifting a battery, excessive pressure on the end walls could cause acid to spew through the vent caps, resulting in personal injury. Lift with a battery carrier or with your hands on opposite corners.

Terminals The battery has two external terminals: a positive (+) and a negative (−). These terminals are two tapered posts, "L" terminals, threaded studs on top of the case, or two internally threaded connectors on the side **(Figure 17–17)**. The terminals have either a positive (+) or a negative (−) marking, depending on which end of the series they represent.

The size of the tapered terminals is specified by standards set by the BCI and SAE. This means that all positive and negative cable clamps will fit any corresponding battery terminal, regardless of the battery's manufacturer. The positive terminal is slightly larger, usually around $^{11}/_{16}$ inch in diameter at the top, whereas the negative terminal usually has a $^{5}/_{8}$-inch diameter. This minimizes, but does not prevent, the danger of installing the battery cables in reverse polarity.

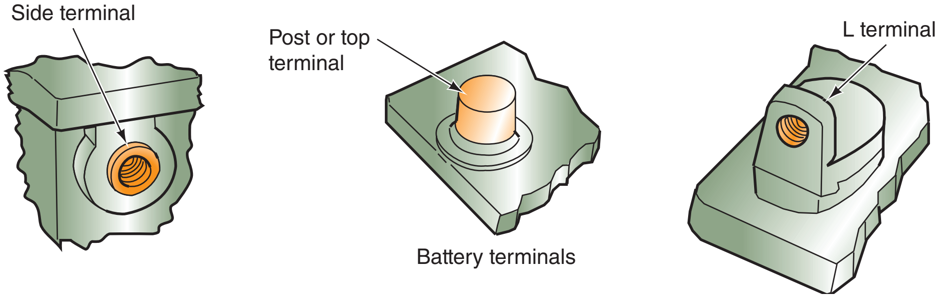


FIGURE 17–17 The most common types of automotive battery terminals.

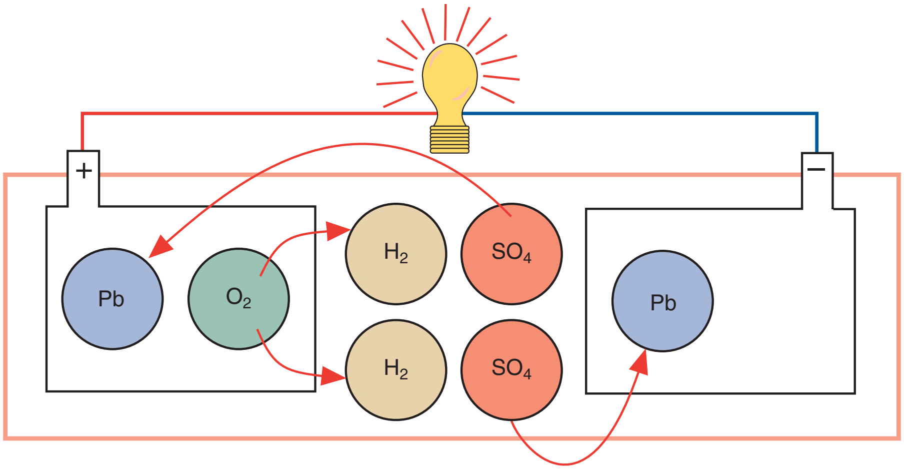


FIGURE 17–18 Chemical action inside a battery during the discharge cycle.

Side terminals are positioned near the top of the battery case. These terminals are threaded and require a special bolt to connect the cables. Some batteries are fitted with both top and side terminals to allow them to be used in many different vehicles.

Discharging and Charging

When a battery discharges **(Figure 17–18)**, lead in the lead peroxide of the positive plate combines with the sulfate radical (SO_4) to form lead sulfate ($PbSO_4$). A similar reaction takes place at the negative plate. The lead (Pb) of the negative plate combines with the SO_4 to also form lead sulfate ($PbSO_4$), a neutral and inactive material. Therefore, lead sulfate forms at both plates as the battery discharges.

During this chemical reaction, the extra oxygen from the lead peroxide and the hydrogen from the sulfuric acid combine to form water (H_2O). As discharging takes place, the electrolyte becomes weaker and the positive and negative plates become like one another.

The recharging process **(Figure 17–19)** is the reverse of discharging. Electricity from an outside source, such as the generator or a battery recharger, is forced into the battery. The lead sulfate ($PbSO_4$) on both plates separates into lead (Pb) and sulfate (SO_4). As the sulfate (SO_4) leaves both plates, it combines with hydrogen in the electrolyte to form sulfuric acid (H_2SO_4). At the same time, the oxygen (O_2) in the electrolyte combines with the lead (Pb) at the positive plate to form lead peroxide (PbO_2). As a result, the negative plate returns to its original form of lead (Pb), and the positive plate reverts to lead peroxide (PbO_2).

An unsealed battery gradually loses water due to its conversion into hydrogen and oxygen; these gases escape the battery through the vent caps. If the lost water is not replaced, the level of the electrolyte falls below the tops of the plates. This results in a high concentration of sulfuric acid in the electrolyte and permits the uncovered material of the plates to dry and harden. This reduces the service life of a battery and is why the electrolyte level must be frequently checked.

Designs

Lead-acid batteries can be designed as a starting battery or a deep cycle battery. Deep cycle batteries are designed to go through many charge and discharge

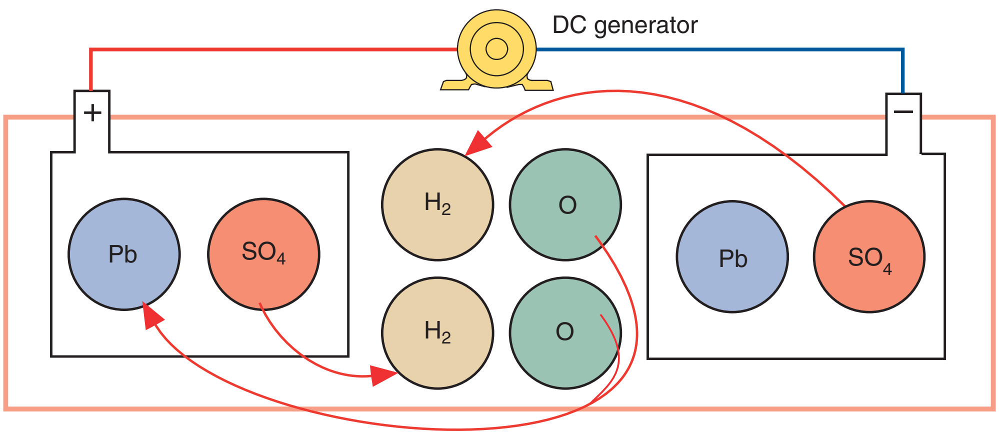


FIGURE 17–19 Chemical action inside a battery during the charge cycle.

cycles. They have thicker and fewer plates than a starting battery. The exact chemical composition of lead-acid batteries also depends on the designed purpose of the battery. However, all lead-acid batteries are based on the reaction of lead and acid.

Maintenance-Free and Low-Maintenance Batteries The majority of batteries installed in today's vehicles are low-maintenance or maintenance-free designs. A low-maintenance battery is a heavy-duty version of a normal lead-acid battery. Many of the parts are thicker and made with different, more durable materials. Low-maintenance batteries have vent holes and caps, which allow water to be added to the cells. However, a low-maintenance battery requires additional water substantially less often than a conventional battery.

Maintenance-free batteries are similar in construction but made with different plate materials. This type of battery experiences little gassing during discharge and charge cycles, therefore, maintenance-free batteries do not have external holes or caps **(Figure 17–20)**. They are equipped with small gas vents that prevent gas pressure buildup in the case. Water is never added to maintenance-free batteries.

Recombination Batteries A recombination or **recombinant battery** (often referred to as a gel battery) is a completely sealed maintenance-free battery that uses a gel-type electrolyte. In a gel cell battery, gassing is minimized and vents are not needed. During charging, the negative plates never reach a fully charged condition and therefore cause little or no release of hydrogen. Oxygen is released at the positive plates, but it passes through the separators and recombines with the negative plates. During normal use, hydrogen and oxygen within the battery are captured and recombined to form water within the electrolyte. This eliminates the need to ever add water to the battery.

An **absorbed glass mat (AGM) battery** is a common example of a recombinant battery. The electrolyte in AGM batteries is held in moistened fiberglass matting. The matting is sandwiched between the battery's plates, where it doubles as a vibration dampener.

Rolls of high-purity lead plates are tightly compressed into six cells **(Figure 17–21)**. The plates are separated by acid-permeated vitreous separators. Vitreous separators absorb acid in the same way a paper towel absorbs water. Each of the cells is enclosed in its own cylinder within the battery case, forming a sealed, closed system that resembles a six-pack of soda.

Another recombinant battery is the **valve-regulated lead-acid (VRLA) battery**. The oxygen produced on the positive plates is absorbed by the negative plate. That, in turn, decreases the amount of hydrogen produced at the negative plate. The combination of hydrogen and oxygen produces water, which is returned to the electrolyte.

One plate in a VRLA is made of a lead-tin-calcium alloy with porous lead dioxide; the other is also made of a lead-tin-calcium alloy but has spongy lead as the active material. The electrolyte is sulfuric acid that is absorbed into plate separators made of a glass-fiber fabric. The battery is equipped with a

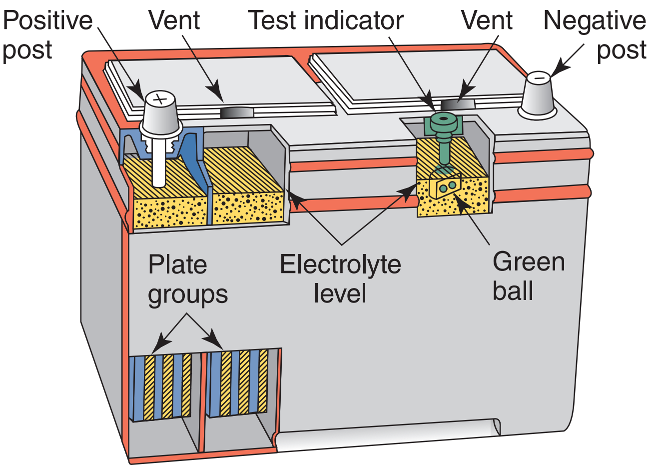


FIGURE 17–20 Construction of a maintenance-free battery showing the location of the gas vents.

Courtesy of Exide Technologies.

FIGURE 17–21 The construction of an AGM battery.

valve that opens to relieve any excessive pressure that builds up in the battery. At all other times the valve is closed and the battery is totally sealed.

Newer, enhanced flooded batteries (EFB) are being used in vehicles with automatic start-stop systems. EFBs offer more power at lower states of charge than standard lead-acid batteries and can support a higher number of total engine starts over their lifetime. The cell grid designs and materials allow EFBs to outperform standard lead-acid batteries.

Factors Affecting Battery Life

All storage batteries have a limited service life; lead-acid batteries are typically good for 3 to 7 years. However, many conditions can shorten this time.

Improper Electrolyte Levels Batteries with cell caps need to be periodically checked. The water in the electrolyte is lost due to evaporation during hot weather and gassing during charging. Maintaining the electrolyte level is a basic step in extending battery life for these batteries.

Temperature Lead-acid batteries do not work well when they are cold. At 0 °F (–17.7 °C) a battery is only capable of working at 40 percent of its capacity. There is also the possibility of the battery freezing when it is very cold and its charge is low. When the battery is allowed to get too hot, the water in the electrolyte can evaporate. Batteries used in hot climates should have their electrolyte level checked very frequently.

Corrosion Battery corrosion is commonly caused by spilled electrolyte or electrolyte condensation from gassing. In either case, the sulfuric acid corrodes, attacks, and can destroy not only connectors and terminals but holddown straps and the battery tray.

Corroded connections increase resistance, which reduces the applied voltage to the rest of the electrical system. Corrosion on the battery cover can also create a path for current, which can allow the battery to slowly discharge.

Overcharging Batteries can be overcharged by either the charging system or a battery charger. In either case, the result is a violent chemical reaction within the battery that causes a loss of water in the cells. This can permanently reduce the capacity of the battery. Overcharging can also cause excessive heat, which can oxidize the positive plate grid material and even buckle the plates, resulting in a loss of cell capacity and early battery failure.

Undercharge/Sulfation The charging system might not fully recharge the battery due to a fault in the system. This causes the battery to operate in a partially discharged condition. A battery in this condition will become sulfated as the sulfate normally formed in the plates becomes dense, hard, and chemically irreversible. This is the result of the sulfate remaining in the plates for a long period and is referred to as **sulfation** of the plates.

Poor Mounting Loose or missing holddown straps allow the battery to vibrate or bounce during vehicle operation. This can shake the active materials off the plates and severely shorten battery life. It can also loosen the plate connections to the plate strap, loosen cable connections, or even crack the battery case.

Cycling Heavy and repeated cycling can cause the positive plate material to break away from its grids and fall into the sediment chambers at the base of the case. This problem reduces battery capacity and can lead to short circuiting between the plates. Fortunately, the new envelope design found in many batteries reduces this problem.

Servicing and Testing Batteries

If the electrolyte level in a lead-acid battery is low, it can be brought to its normal level by adding distilled water. If the level is very low, there is a good chance the battery will fail tests even after the water has been added. Low electrolyte levels can

Caution! Always wear safety glasses or goggles when working with batteries. When a battery is charging or discharging, it gives off highly explosive hydrogen gas. Some hydrogen gas is present in the battery at all times. Any flame or spark can ignite this gas, causing the battery to violently explode, propelling the vent caps at a high velocity and spraying acid in a wide area. Sulfuric acid can cause severe skin burns. If electrolyte contacts your skin or eyes, flush the area with water for several minutes. When eye contact occurs, force your eyelids open and flush your eyes with eyewash solution. Do not rub your eyes or skin and call a doctor immediately.

also shorten a battery's service life by exposing the upper portions of the plates to air, allowing them to dry and become brittle. If the electrolyte level is low, the cause should be determined. Possible causes include a leaking case, overcharging, and a cell that is failing.

Testing batteries is an important part of electrical system service. Prior to conducting any battery tests, make sure the battery is fully charged. Also remove the surface charge of the battery by turning on the headlights with the engine off. Keep the lights on for at least 3 minutes. Poor and inaccurate tests can lead to expensive and unneeded repairs. Depending on the design of the battery, its state of charge and capacity can be determined in several ways: specific gravity tests, visual inspection of batteries with a built-in hydrometer, open circuit voltage tests, and the capacity test.

Inspection

Testing a lead-acid battery should begin with a thorough inspection of the battery and its terminals **(Figure 17–22)**. The following items should be checked:

1. Check the age of the battery by looking at the date code on the battery.
2. Check the condition of the case. A damaged battery should be replaced.
3. If the battery is not sealed, check the electrolyte levels in all cells and correct them as necessary. If water is added, charge the battery before conducting any test on the battery.
4. Check the condition of the battery terminals and cables. Clean any corrosion from the cable ends and terminals. Make sure the cable ends are tightly fastened to the terminals.
5. Make sure the battery holddowns are holding the battery securely in place.

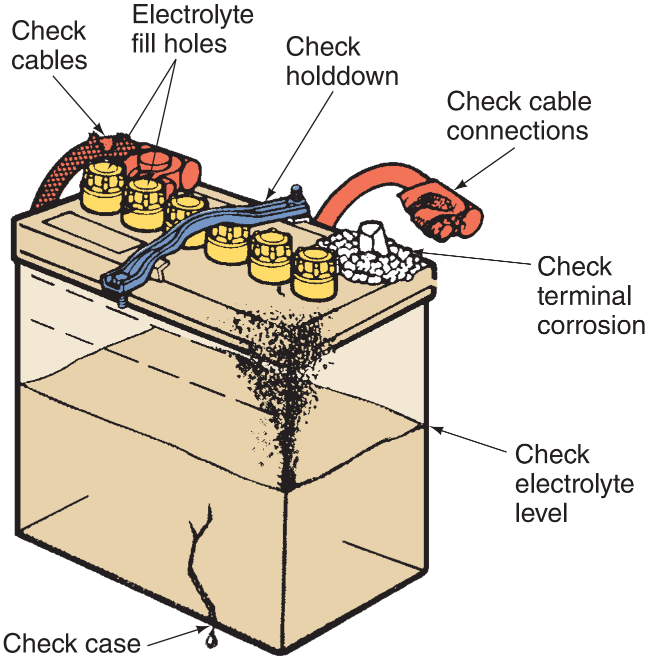


FIGURE 17–22 Batteries should be carefully checked for damage, dirt, and corrosion.

GO TO Chapter 8 for lead-acid battery inspection, maintenance, and cleaning procedures.

Battery Leakage Test

To perform a battery leakage test, set a voltmeter to a low DC volt range. Connect the negative lead to the negative post. Then move the meter's positive lead across the top and sides of the case **(Figure 17–23)**. If some voltage is read, current is leaking from the battery. The battery should be cleaned and then rechecked. If voltage is again measured, the battery should be replaced; the case is porous or cracked.

Cleaning the Battery and Terminals

Before removing the battery terminals or the battery, always neutralize any accumulated corrosion on the terminals and other metal parts. Apply a solution of baking soda and water or ammonia and water. Do not splash the solution or corrosion onto the vehicle's paint, metal or rubber parts, or onto your hands and face. Make sure the solution

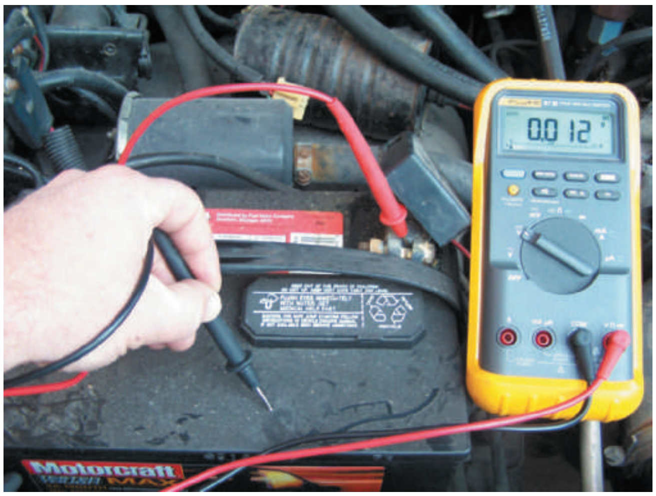


FIGURE 17–23 Performing a battery leakage test.

FIGURE 17-24 Use a brush to spread the cleaning solution and remove heavy deposits.

> **SHOP TALK**
> Remember to connect a memory saver and/or obtain security codes for the vehicle before disconnecting the battery.

cannot enter the battery's cells. A stiff-bristle brush is ideal for removing heavy buildup **(Figure 17–24)**. Dirt and accumulated grease can be removed with a detergent solution or solvent. After cleaning, rinse the battery and terminals with clean water. Dry everything with a clean rag or low-pressure compressed air.

To clean the inside surfaces of the battery terminals, remove the cables. Always begin with removing the ground cable first. For connectors that rely on nuts and bolts, loosen the nut using a box-end wrench and/or cable-clamp pliers **(Figure 17–25)**. Using ordinary pliers or an open-end wrench can cause problems. These tools might slip off under pressure with enough force to break the cell cover or damage the casing.

Spring-type cable connectors are removed by squeezing the ends of their prongs together with wide-jaw, vise-gripping, channel lock, or battery pliers. These will expand the connector so it can be lifted off the terminal post.

Always grip the cable while loosening the terminal's nut. This reduces the pressure on the post that could break it or loosen its mounting in the battery. If the connector does not lift easily off the terminal when loosened, use a clamp puller. Prying with a screwdriver or bar strains the terminal post and the plates attached to it. This can break the cell cover or pop the plates loose from the terminal post.

Once the connectors have been removed, open the connector using a connector-spreading tool. Neutralize any remaining corrosion by dipping it in a baking soda or ammonia solution. Next, clean the inside of the connectors and the posts using a wire brush with external and internal bristles **(Figure 17–26)**.

Begin reinstallation by expanding the opening of the clamp **(Figure 17–27)** so that force is not

FIGURE 17-25 It is best to loosen a battery clamp with a box-end wrench and/or cable-clamp pliers.

FIGURE 17-26 Combination external/internal wire brushes clean both terminals and inside cable connector surfaces.

FIGURE 17–27 Before reinstalling the cable end onto the battery, use terminal end expanders to make sure the end does not need to be forced onto the battery post.

needed to place it over the post. Then position and tighten the terminal on its post. Do not overtighten any nuts or bolts; this could damage the post or terminal.

Battery Hydrometer

Batteries with removable vent caps should have the specific gravity of the electrolyte checked. The electrolyte of a fully charged battery is usually about 64 percent water and 36 percent sulfuric acid. This corresponds to a specific gravity of 1.270. Pure water has a specific gravity of 1.000, whereas battery electrolyte should have a specific gravity of 1.260 to 1.280 at 80 °F (26.7 °C). The specific gravity of the electrolyte decreases as the battery discharges. This is why measuring the specific gravity of the electrolyte can be a good indicator of how much charge a battery has lost.

The electrolyte's specific gravity can be measured with a battery hydrometer that uses a glass float in a glass tube to measure the electrolyte's specific gravity. When filled with the electrolyte, the float bobs in the electrolyte. The depth at which the float sinks indicates the electrolyte's relative weight compared to water.

Because temperature affects the specific gravity of a substance, the reading should be corrected by adjusting it according to the temperature of the electrolyte. Most hydrometers have a built-in thermometer to measure the temperature of the electrolyte.

Refractometer The refractometer used to test engine coolant can also be used to check the specific gravity of electrolyte. These tools use a prism to analyze fluids and feature automatic temperature compensation.

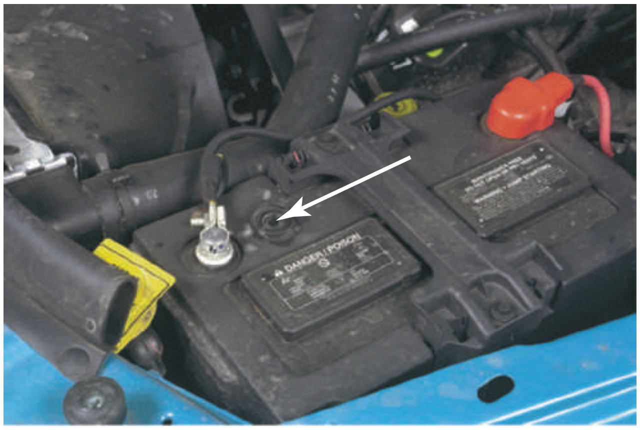


FIGURE 17–28 Sight glass in a maintenance-free battery.

Built-In Hydrometers

On some maintenance-free batteries, a special temperature-compensating hydrometer is built into the battery case **(Figure 17–28)**. A quick visual check indicates the battery's SOC. When observing the hydrometer it is important that the battery's top is clean in order to see the indication. A flashlight may be necessary in poorly lit areas. Always look straight down when viewing the hydrometer.

Most newer batteries do not have a built-in hydrometer. A voltage check is the only way to check the battery's SOC. Because the batteries are sealed, the specific gravity cannot be checked. Never attempt to check each cell by prying the cell caps off the battery.

Open Circuit Voltage Test

An open circuit voltage check measures the voltage output of a battery without a load. As the battery is charged or discharged, slight changes occur in the battery's voltage. Therefore, battery voltage with no load can give an indication of the SOC.

To check a battery's open voltage, the temperature should be between 60° and 100 °F (15.5° and 37.7 °C). The voltage should be allowed to stabilize for at least 10 minutes with no load applied. On batteries that have been recently recharged, apply a heavy load for 15 seconds to remove the surface charge, then allow the battery to stabilize. Once voltage has stabilized, use a DMM to measure the battery voltage to the nearest one-tenth of a volt **(Figure 17–29)**. A fully charged 12-volt battery should have a terminal voltage of 12.6 volts.

FIGURE 17–29 Measuring open circuit voltage across battery terminals using a voltmeter.

FIGURE 17–31 A battery load tester.

Open Circuit Voltage Table	
Open Circuit Voltage	Charge Percentage
11.7 volts or less	0%
12.0 volts	25%
12.2 volts	50%
12.4 volts	75%
12.6 volts or more	100%

FIGURE 17–30 Open circuit voltage test results relate to the specific gravity of the battery's cells.

However, sealed AGM and other gel cell batteries may have a slightly higher voltage (12.8 to 12.9 volts). Use **(Figure 17–30)** to interpret the results. If the test indicates an SOC below 75 percent, recharge the battery and perform the capacity test to determine battery condition.

Battery Load Test

The capacity or **load test** determines how well a battery will perform under a load. A battery load tester **(Figure 17–31)** or a volt/ampere tester (VAT) is used for this test. A VAT can be used to test batteries, starting systems, and charging systems. These testers have a voltmeter, an ammeter, and a carbon pile. The carbon pile is a variable resistor. When the tester is attached to the battery and operated, the carbon pile draws current from the battery. The ammeter reads the amount of current draw. The maximum current draw from the battery, with acceptable voltage, is compared to the rating of the battery.

Some battery load testers and VATs automatically adjust the load or carbon pile. Battery information is inputted into these machines and the tester does the rest **(Figure 17–32)**.

The load or capacity test can be performed with the battery either in or out of the vehicle. The battery must be at or very near a full SOC. Use the open circuit voltage test to determine the SOC, and recharge the battery if needed. For best results, the electrolyte should be as close to 80 °F (26.7 °C) as possible. Cold batteries show considerably lower capacity. Never load test a sealed battery if its temperature is below 60 °F (15.5 °C). Photo Sequence 15 shows the correct way to use a VAT-40 to conduct a load test.

During a load test, a load that simulates the current draw of a starting motor is put on the battery. The amount of current draw is determined by the rating of the battery and the battery's voltage is observed for 15 seconds.

When performing a battery load test, follow these guidelines:

FIGURE 17-32 A typical automatic VAT.

- Place the inductive pickup around either the testers positive or negative cable to the battery. Orient the inductive pickup so that the arrow indicating current flow is away from the battery if on the negative or toward that battery if on the positive cable.
- Observe the correct polarity and make sure that the test leads are making good contact with the battery posts.
- If the tester is equipped with an adjustment for battery temperature, set it to the proper setting.
- To test the battery, turn the load control knob to draw current at the rate of three times the battery's ampere-hour rating or one-half of its CCA rating.
- Discontinue the load after 15 seconds.

SHOP TALK

On batteries with side terminals, obtaining a good connection for the tester can be a problem. To get a good connection, use the appropriate adapter (Figure 17–33). If an adapter is not available, use a 3/8-inch coarse bolt with a nut on it. Carefully bottom out the bolt and then back it off a turn. Then tighten the nut against the contact. Now attach the lead to the nut.

Interpreting Results If the voltage reading exceeds 10.5 volts during the load, the battery is supplying sufficient current. The battery should maintain at least 9.6 volts when tested at 70 °F (21 °C). If the reading is right on 9.6 volts, the battery might not have the reserve necessary to handle cranking during low temperatures.

If after the load is turned off the voltage reads below the minimum, watch the voltmeter. After a couple of minutes the voltage should stabilize and be at least 12.4 volts. If the voltage is below 12.4 volts, the battery can be recharged and retested, but the results are likely to be the same.

If the voltage is below the minimum under load and does not rise above 12.4 volts when the load is removed, the problem may be a low SOC. Recharge the battery and load test again. If the battery fails the load test, perform a three-minute charge test.

Three-Minute Charge Test

The three-minute charge test, also called a battery sulfation test, is used to determine if a traditional lead-acid battery has sulfated plates. Do not use the three-minute charge test on AGM batteries as the voltage and current supplied can damage or destroy the batteries. Sulfation interferes with the battery's

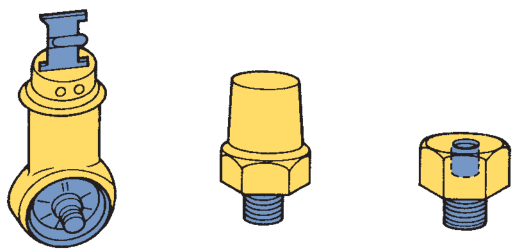
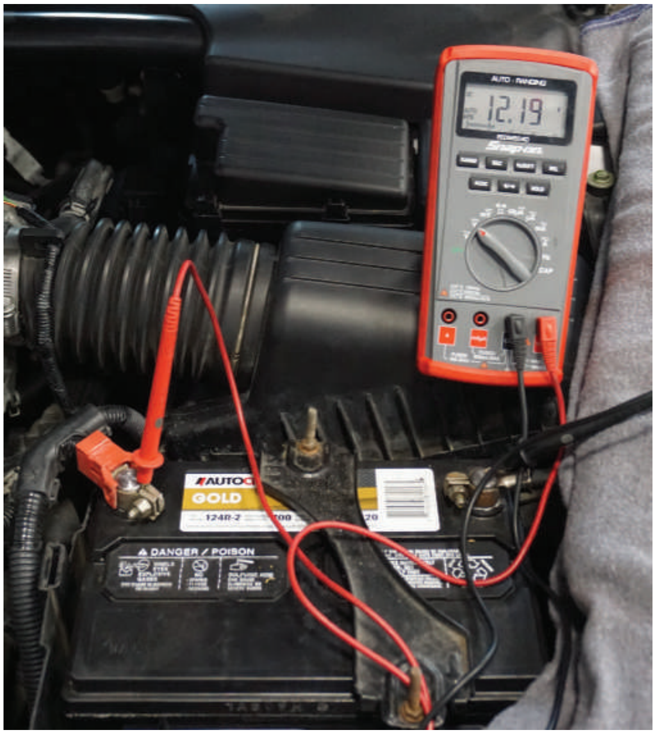


FIGURE 17-33 Adapters may be needed to test and change batteries with side-mount terminals.

PHOTO SEQUENCE 15

Conducting a Battery Load Test



P15-1 Charge the battery to at least 75% SOC and allow the battery to stabilize.

P15-2 Check the battery's ratings on its sticker and determine the correct load test specification.

P15-3 Check the temperature of the battery; it should be around 70°F (21°C).

P15-4 Attach the tester's battery leads to the correct terminals on the battery.

Conducting a Battery Load Test *(continued)*

P15-5 Clamp the tester's inductive lead around the tester's negative cable. Normally the arrow on the clamp should face away from the negative post of the battery.

P15-6 "Zero Adjust" the tester until the ammeter reads zero.

P15-7 Rotate the load control until the ammeter reads the amount determined in step # 2.

P15-8 After 15 seconds, read the voltage of the battery and turn the load control off. Then disconnect the tester's leads.

ability to accept a charge and to deliver current. Sulfation is typically caused by the charging system not fully recharging the battery. This may be due to a generator problem, excessive voltage drop in the charging circuit or battery cables, or insufficient generator belt tension. A parasitic draw that discharges the battery can also be battery sulfation.

To perform this test, disconnect the negative battery cable if the battery is installed in the vehicle. Connect a battery charger and set the charging rate of 30 to 40 amps. Use a voltmeter to monitor battery voltage during the charge. At the end of the 3 minutes, with the charger still set on 30 to 40 amps, note the battery voltage. Voltage should not exceed 15.5 volts. A reading above 15.5 volts indicates the battery's internal resistance is excessive, the plates are sulfated, or there is a poor connection within the battery's cells. A sulfated battery should be replaced.

Battery Capacitance Test

Checking the capacitance or conductance of a battery tests the battery's ability to conduct current. Measuring conductance provides a reliable indication of a battery's condition and is correlated to battery capacity. Conductance can be used to detect cell defects, shorts, normal aging, and open circuits, which can cause the battery to fail.

A fully charged new battery will have a high conductance reading anywhere from 110 percent to 140 percent of its CCA rating. As a battery ages, the plate surface can sulfate or shed active material, which will lower its capacity and conductance. A **capacitance test** is the only test that will yield accurate measurements of a battery with low SOC.

When a battery has lost a significant percentage of its cranking ability, the conductance reading will fall well below its rating and indicate that the battery should be replaced.

To measure conductance, the tester **(Figure 17–34)** creates a small signal that is sent through the battery and then measures a portion of the AC response. The tester will indicate that the battery is good, needs to be recharged and tested again, has failed, or will fail shortly.

Many conductance testers display a code when the test is completed. Identify what the code indicates before taking any action in response to the results.

GO TO Chapter 6 for a detailed list of battery safety precautions.

FIGURE 17–34 A conductance (capacitance) battery tester.

Battery Drains

Many of today's vehicles have parasitic loads. Parasitic loads are current drains that exist when the key is off. This drain is caused by systems that operate when the engine is not running. A parasitic load is normal unless it exceeds specifications. These drains can cause a battery to lose its charge overnight or after a few days **(Table 17–1)**. The drains can also deplete the battery and cause various driveability problems. The computer may go into its back-up mode, set false codes, or raise idle speeds to compensate for the low battery voltage. A constantly low battery will also have a shortened service life.

Most manufacturers specify the maximum allowable amount of parasitic drain. All vehicles will have some drain because small amounts of current are needed to maintain the memory in various systems.

TABLE 17–1 A LOOK AT HOW LONG IT TAKES DIFFERENT CURRENT DRAINS TO DROP A BATTERY'S STATE-OF-CHARGE (SOC) TO 50%

Constant Current Drain	50% SOC In:
25 mA	30½ Days
50 mA	16½ Days
100 mA	8¼ Days
250 mA	3¼ Days
500 mA	1½ Days
750 mA	1 Day
1A	19 Hours
2A	12 Hours

A drain of 30 mA is normal for most. Excessive current drains are caused by problems and they will run down a battery. The most common cause is a light that is not turning off—such as the glove box, trunk, or engine compartment light. The problem can also be in an electronic system. Many of these systems are designed to periodically monitor conditions; these episodes are called wake-up times. If an electronic unit wakes up but does not shut down soon afterward, it is malfunctioning and will drain the battery.

When a battery quickly loses its charge, a battery drain test should be conducted. The current drain can be measured with a DMM connected in series with the negative battery cable or by placing a low current probe around the cable.

A DMM can be used to measure voltage drop through fuses to determine which circuit is causing a key-off drain **(Figure 17–35)**. The current flowing through the circuit results in a voltage drop at the fuse, which can be measured and used to find which circuit is at fault. Because current drains tend to be low amperage draws, the voltage drop across the fuse is also small, in the millivolt range.

Photo Sequence 16 shows how to check parasitic drain with a current clamp and ammeter.

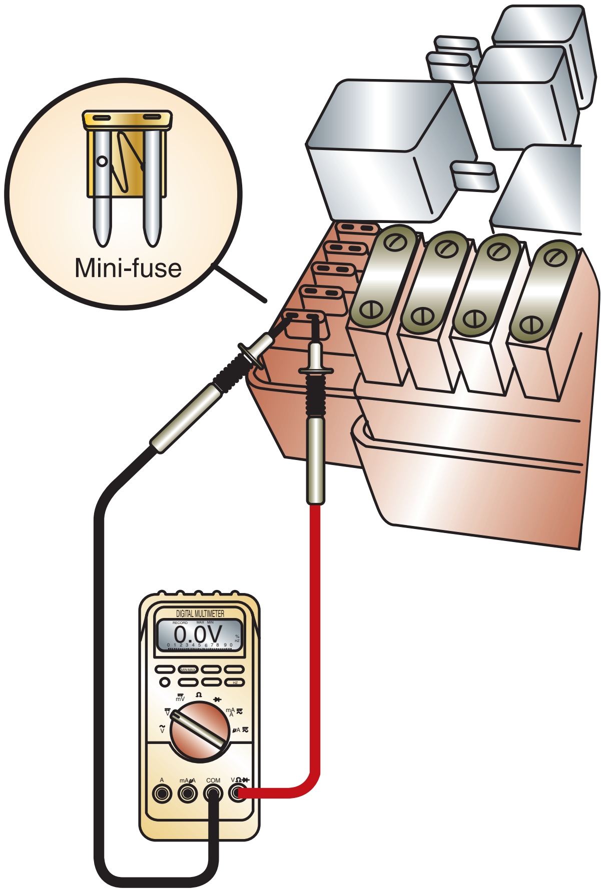


FIGURE 17-35 Measuring the voltage drop across fuses to find parasitic drains.

HEV and EV 12-Volt Auxiliary Battery Testing

All HEVs and EVs still use a 12-volt battery to power-up the electrical system. These batteries tend to be of smaller capacity, 300–400 CCAs, since they are not used to crank the engine. Most manufacturers recommend using a conductance tester on the auxiliary battery. Simply program the tester for the battery type, rating, and test. Replace the battery if it cannot supply the necessary voltage and current.

Battery Cables

A battery's performance is affected by its cables. Poor connections and corrosion at the terminals and cable ends will cause voltage drops, which will reduce the available voltage at all of the vehicle's systems. The terminals may also be out of shape, loose, or damaged; these will cause excessive resistance. All battery cables should be inspected and tested for excessive voltage drops. During the inspection, heavily corroded terminals **(Figure 17–36)** will be obvious, but corrosion can form a nearly invisible barrier between the battery terminals and cables. This is why conducting a voltage drop test is preferred.

All voltage drop tests should be done with the circuit under a load. When checking the battery cables, running the starter motor is the best load. Allow a drop of 0.1 volt for each cable connection;

FIGURE 17-36 Corroded battery terminals reduce the efficiency of the battery and cause voltage drops.

PHOTO SEQUENCE 16

Parasitic Draw Testing

P16-1 A current probe and DMM can be used to check parasitic draw without disconnecting the battery. Install fender covers to protect the vehicle before you begin testing.

P16-2 The current clamp is used in place of the standard meter leads. Remove the positive and negative meter leads and insert the red lead from the clamp into the DC voltage jack and the black lead into the common jack.

P16-3 This clamp allows you to select the amperage and voltage range. For this meter, the scale will show 20A. For this scale, a current draw of 1A will show a reading of 0.5 mv.

P16-4 The meter is set to measure DC voltage. The current probe will convert the strength of the magnetic field into an amperage reading, that is then converted into a DC voltage reading on the meter.

Parasitic Draw Testing *(continued)*

P16-5 Place the current clamp around the battery negative cable.

P16-6 If the clamp has an arrow indicating the direction of current flow, place the clamp with the arrow facing away from the battery.

P16-7 The meter is reading 0.15 volts. This equals a current draw of 3 amps. To determine if the draw is excessive, refer to the manufacturers service information. For this vehicle, the draw exceeds specs.

P16-8 Begin diagnosing the current draw by making sure all interior and exterior accessories and lights are off. Depending on the vehicle, you may have to allow an hour or more for all modules to shut down before an accurate reading can be obtained.

P16-9 If the draw remains, you will need to isolate which circuit or circuits are causing the draw. This is typically done by removing one fuse at a time and watching the current draw. If the draw remains, the circuit the fuse protects is not the cause. If, however, the draw is reduced or eliminated, you have found the circuit causing the problem. Once the circuit is known, begin checking each load in the circuit for a fault that may cause a draw on the battery. For example, a relay that is stuck closed or a module that is not shutting down. Unplug the component and recheck draw. If the draw is eliminated, you have located the source of the problem.

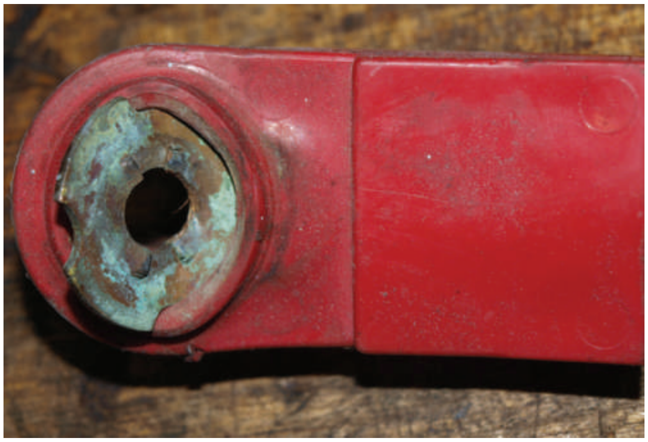


FIGURE 17–37 Corroded side-post battery cable connections may go unnoticed.

a total voltage drop across all battery connections should not exceed 0.2 volt.

On vehicles with side post battery connections, you will need to remove the cable from the battery to inspect its condition. Side post connections can and do develop corrosion problems but unless removed for inspection, often go unchecked **(Figure 17–37)**. This is because of the location of some side post batteries. Sometimes they are overlooked because they are not easily inspected visually. Connect an auxiliary power supply, such as a battery booster pack to the vehicle, and disconnect the side post terminals. Check for corrosion, damage, and acid leaks around the terminals. Overtightening or using the wrong size bolt in a side post battery can damage the terminal and cause acid to leak. Corrosion often builds up in the plastic terminal covers and requires taking the terminal apart to clean.

Battery Chargers

Battery chargers are designed to supply a constant voltage or constant current, or a combination of the two. Constant voltage chargers provide a specific amount of voltage to the battery. The current varies with the voltage of the battery. When the potential difference between the charger's voltage and the battery's voltage is great, the current is high. As the battery charges, the charging current drops off. A constant current charger varies the voltage applied to the battery in order to maintain a constant current.

Both of these techniques work fine as long as the temperature of the battery is maintained. Some chargers have a thermometer to monitor battery temperature. These chargers reduce the charging voltage and/or current in response to rising temperatures.

There are many "smart" or "intelligent" battery chargers available. These are designed to charge a battery in three basic steps: bulk, absorption, and float. During bulk charging, current is sent to the battery at a maximum safe rate until the voltage reaches approximately 80 percent of its capacity. Once the voltage reaches that level, the charger begins the absorption step. During this time, charging voltage is held constant while the current changes according to the battery's voltage. Once the battery is fully charged, the charger switches to the float step. During this step, the charger supplies a constant voltage that is slightly more than the battery's voltage. This is a maintenance charge and is intended to keep a battery charged while it is not being used.

If module programming or flashing is performed, the shop should use a special clean battery charger to maintain correct system voltage during programming operations. Some battery chargers can allow small amounts of A/C current to pass through the charger and into the vehicle's electrical system. This can cause communication problems and even programming failure.

Some chargers can supply voltage and current to a battery according to the needs of the vehicle. **Fast charging** quickly charges a battery by supplying large amounts of voltage and current. Although the battery is charged quickly, it can also overheat it if it is not closely monitored. Batteries must be in good condition to accept a fast charge. Sulfation of the battery's plates can lead to excessive gassing, boiling, and heat buildup during fast charging.

Slow or **trickle charging** applies low current to the battery. Slow charging is slow and takes quite some time to fully charge a battery. However since low current is applied to the battery, it is unlikely that the battery will overheat. Slow charging is the only safe way to charge sulfated batteries. The type of battery should always be considered before fast charging or slow charging a battery.

Always charge a battery in a well-ventilated area away from sparks and open flames. The charger should be turned off before connecting or disconnecting the leads to the battery **(Figure 17–38)**. Remember to wear eye protection, and never attempt to charge a frozen battery. All battery chargers have specific operating instructions that must be followed.

FIGURE 17-38 Careless use of a battery charger caused this battery to explode.

SHOP TALK

Before connecting a battery charger to a vehicle, check if the battery negative cable should be removed. Some manufacturers, such as Honda, advise that if possible remove the negative cable from the battery before charging it in the car.

Jump-Starting

If the vehicle will not start, several things can be the cause. If the engine does not crank over, the battery may be discharged or dead. If the dash or headlights dim severely or go out when trying to crank the engine, suspect the battery is discharged. If the lights do not come on at all, the battery may be completely dead or there may be a very poor battery connection. Before attempting to jump-start a vehicle, inspect the battery connections and if possible, measure battery voltage. A discharged battery should be recharged with a battery charger instead of jump-started. It is not recommend that a vehicle be jump-started. This is because of the extensive use of electronics on modern vehicles. Jump-starting can cause voltage spikes in the electrical system that can damage electronic components. This is especially true in situations where a loose or poor battery connection is present. Before attempting to jump-start a battery, check the service information for the vehicle and note if any

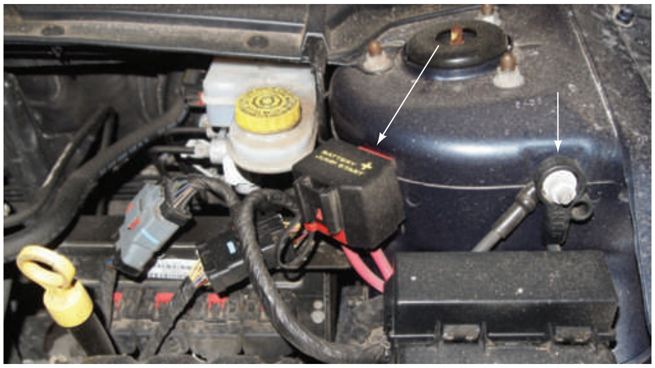


FIGURE 17-39 Because of the locations of batteries vary, jump-starting terminals are often located under the hood.

special precautions are given or procedures are required to jump-start the vehicle.

If jump-starting is necessary, always follow all battery safety precautions to prevent injury or damage to the vehicle.

When possible, use a booster pack to jump-start a dead battery. Because not all batteries are located under the hood or in accessible areas, the vehicle may have special connection points for jump-starting **(Figure 17–39)**.

1. Connect the positive booster pack lead to the battery positive terminal or positive connection point as specified by the vehicle manufacturer.
2. Connect the negative booster pack lead to a good engine ground or the negative connection point as specified by the vehicle manufacturer.
3. Attempt to crank and start the engine.
4. If the engine starts, let it idle or drive the vehicle for at least 20 minutes.

It is possible that the vehicle's battery will be so discharged that jump-starting will not work. In this case, the battery should be recharged or replaced.

To jump-start a typical vehicle with the battery of another vehicle, follow this procedure:

1. Park the booster vehicle close to the hood of the disabled vehicle making sure the two vehicles do not touch.
2. Set the parking brake on both vehicles.
3. Open the hood or trunk to gain access to the starting or auxiliary battery. On some vehicles with the battery in the trunk, there is a special jump-starting terminal under the hood.
4. Connect the clamp of the positive (red) jumper cable to the positive terminal on the battery or the jump-starting terminal.

5. Connect the clamp at the other end of the positive (red) jumper cable to the positive (+) terminal on the booster battery.
6. Connect the clamp of the negative (black) jumper cable to the negative (–) terminal on the booster battery.
7. Connect the clamp at the other end of the negative (black) jumper cable to an exposed metal part of the dead vehicle's engine **(Figure 17–40)**, away from the battery and the fuel injection system. Never use a fuel line, engine camshaft or rocker arm covers or the intake manifold as the grounding point for making this negative connection.
8. Make sure the jumper cables are clear of fan blades, belts, moving parts of both engines, or any fuel delivery system parts.
9. Run the engine of the booster vehicle at a medium speed for about 5 minutes.
10. Now, attempt to start the vehicle.
11. If the vehicle will not start, check the connections of the jumper cables and if a problem was found, correct it and try again. If the engine still does not start, the battery should be charged or replaced.

SHOP TALK

It is possible for a battery to be so discharged that it cannot be jump-started. If this occurs and you need to get the vehicle started, disconnect the negative battery cable. Connect a booster pack to the positive and negative cables and try to start the engine. Removing the dead battery from the circuit will often allow the engine to crank and start.

12. Once the disabled vehicle has started, allow both engines to run for about 5 minutes.
13. Then disconnect the negative cable from the vehicle, and then from the booster battery.
14. Next, disconnect the positive cable from the vehicle, and from the booster battery.

Caution! Never connect the end of the second cable to the negative terminal of the battery that is being jumped.

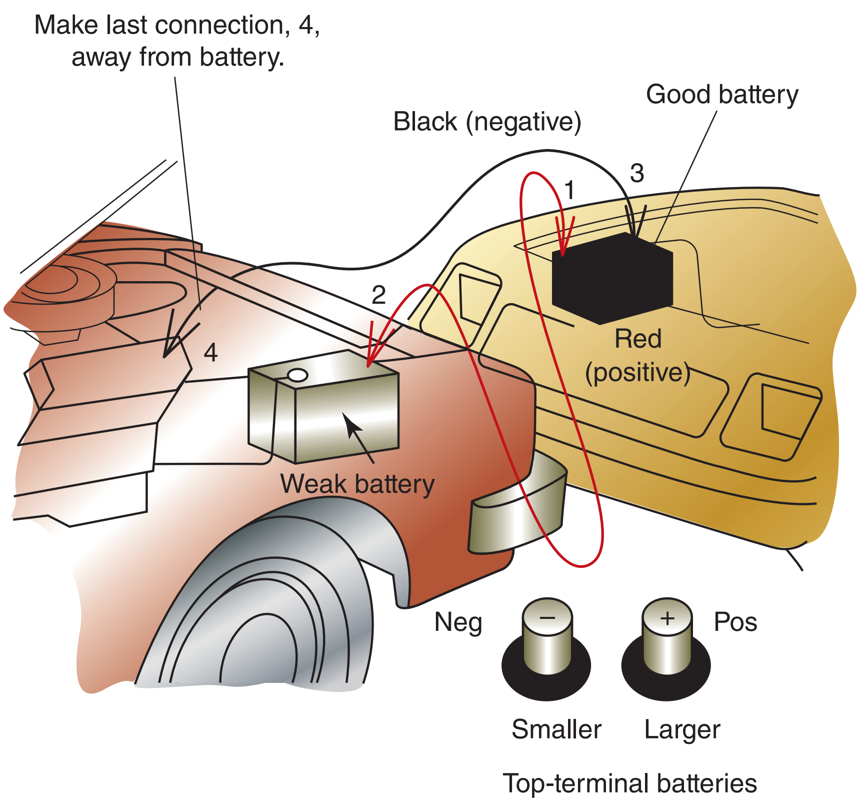


FIGURE 17–40 The proper jumper cable connections and sequence for jump-starting a vehicle.

Replacing a 12-Volt Battery

When a battery needs to be replaced, several things need to be considered when selecting the new battery: its capacity, ratings, and size. Make sure the new battery meets or exceeds the power requirement of the vehicle. The battery needs to fit the battery holding fixtures in the vehicle. The height of the battery is also important. The top of the battery and its terminals must fit safely under the hood without the possibility of shorting across the terminals.

Before disconnecting the battery, install a memory saver. Modern vehicles often have numerous systems that will require reset if battery power is lost. These include the following:

- Powertrain and transmission control module adaptive memories
- Infotainment and personality system settings
- Memory seat, mirror, and steering column positions
- Climate control settings
- Power window position memory

In addition, loss of battery power can cause the airbag system, anti-theft, and hybrid drive systems to set codes and it clears emission-related test results.

Before replacing a 12-volt battery, check the service information for any specific precautions or procedure that need to be followed. In general, the following steps are common for battery replacement:

1. Remove any components that cover or obstruct access to the battery.
2. Loosen and remove the negative cable and then the positive cable.
3. Remove the battery holddown.
4. Use a battery carrying strap to carefully lift the battery out and set it aside for recycling in the designated storage area.
5. Clean and inspect the battery cable ends and holddown.
6. Make sure the replacement battery is correct and will fit into the space.
7. Carefully set the new battery in place and secure the holddown.
8. Reattach and tighten the positive then the negative cables.
9. Reinstall any components that were removed to access the battery.
10. Start the vehicle and perform any relearns, registrations, or items as needed.

FIGURE 17–41 An example of a battery energy management decal.

Replacing a battery may require performing a battery registration or entering a battery energy management (BEM) code into the powertrain control module (PCM). On many vehicles, the engine computer monitors and tracks electrical system operation, charging system status, and the age of the battery. A new original equipment (OE) battery should have a BEM decal **(Figure 17–41)**. Program the code into the computer using a scan tool. If a new but non-OE battery is installed and the system not reset, the PCM may not self-calibrate to the new battery. This can affect charging system performance and affect the life of the new battery.

Replacing an HV Battery

There are over four million HEVs and EVs on the road as of 2016, many of which have reached the end of their HV battery life. Replacement battery packs are available from the vehicle manufacturers and many aftermarket sources are supplying rebuilt or used packs as less expensive alternatives to new.

Replacing HV battery pack should only be performed by a shop with the tools and equipment to safely and correctly perform the repair. You should never attempt to service or replace high-voltage components without the proper training and equipment.

Once a battery pack has been removed, it should be returned to the supplier for recycling. The materials of nickel-metal hydride batteries are completely recyclable as the metals are reclaimed and used again. Lithium-ion batteries are also recyclable, though depending on the chemistry, may not be 100 percent so. Regardless of type and size, high-voltage batteries should always be returned to either the supplier or taken to an approved recycling facility.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2013	**Make:** Cadillac	**Model:** XTS	**Mileage:** 88,951	**RO:** 16078
Concern:	The vehicle will not start after sitting overnight without having to jump the battery.			
The technician checks the battery's open circuit voltage and finds the voltage is 12.3 volts after the vehicle has sat for a few hours. Knowing the OCV should be higher, the technician suspects a faulty battery. However, after charging the battery and performing several battery tests, the battery is found to be good				
Cause:	Charged and tested battery. Battery passed load and conductance tests. Measured 1.95 amp key-off draw. Found body control module not shutting down.			
Correction:	Verified all other modules are shutting down, replaced and reprogrammed the body control module. Key-off battery draw now 32 mA after all modules shut down.			

KEY TERMS

Absorbed glass mat (AGM) battery
Ampere-hour (AH) rating
Capacitance test
Cold cranking amps (CCA)
Cranking amps (CA) rating
Electrochemical reaction
Electrodes
Element
Fast charging
Grid
Load test
Maintenance-free batteries
Open circuit voltage
Plate strap
Plates
Recombinant battery
Reserve capacity (RC) rating
Separator
Sponge lead (Pb)
Sulfation
Trickle charge
Valve-regulated lead-acid (VRLA) batteries

SUMMARY

- The primary source for electrical power in all automobiles is the battery.
- Batteries are devices that convert chemical energy into electrical energy through electrochemical reactions.
- Batteries are normally made up of electrochemical cells connected together. Each cell has three major parts: an anode (negative plate or electrode), a cathode (positive plate or electrode), and electrolyte.
- Open circuit voltage is the voltage measured across the battery when there is no load on the battery.
- Operating voltage is the voltage measured across the battery when it is under a load.
- The ampere-hour (AH) rating is the amount of steady current that a fully charged battery can supply for 20 hours at 80 °F (26.7 °C) without the cell's voltage dropping below a predetermined level.
- A battery's watt-hour rating is determined at 0 °F (–17.7 °C) and is calculated by multiplying a battery's amp-hour rating by the battery's voltage.
- The cold cranking amps (CCA) rating is determined by the load, in amperes, that a battery is able to deliver for 30 seconds at 0 °F (–17.7 °C) without its voltage dropping below a predetermined level.
- The cranking amps (CA) rating is a measure of the current a battery can deliver at 32 °F (0 °C) for 30 seconds and maintain voltage at a predetermined level.
- The reserve capacity (RC) rating is determined by the length of time, in minutes, that a fully charged starting battery at 80 °F (26.7 °C) can be discharged at 25 amperes before battery voltage drops below 10.5 volts.
- There are many different types and designs of batteries available; the primary difference is the chemicals used in the cells, such as lead-acid,

nickel-cadmium (NiCad), nickel-metal hydride (NiMH), sodium-sulfur (NaS), sodium-nickel-chloride, lithium-ion (Li-Ion), lithium-polymer (Li-Poly), and nickel-zinc.

- The most common automotive batteries are lead-acid designs. The wet cell, gel cell, absorbed glass mat (AGM), and valve regulated are versions of the lead-acid battery.
- A lead-acid battery consists of grids, positive plates, negative plates, separators, elements, electrolyte, a container, cell covers, vent plugs, and cell containers. Maintenance-free batteries have no holes or caps, but they do have gas vents. Sealed maintenance-free batteries do not require the gas vents used on other maintenance-free designs.
- Improper electrolyte levels, temperature, corrosion, overcharging, undercharging/sulfation, poor mounting, and cycling affect the service life of a battery.
- Depending on the design of the battery, its condition, SOC, and capacity can be measured by different tests: battery leakage test, specific gravity tests, built-in hydrometers, open circuit voltage test, capacity test, and capacitance or conductance test.
- Parasitic loads are current drains that exist when the key is off and may be normal or caused by a problem.
- To charge a battery, a given charging current is passed through the battery for a period of time. Fast chargers are more popular, but slow charging is the only safe way to charge a sulfated battery.
- Always follow the correct procedure when jump-starting a vehicle.

REVIEW QUESTIONS

Short Answer

1. Define an electrolyte and its role in battery operation.
2. What design characteristics determine the voltage and the current capacity of a battery?
3. How is a battery leakage test conducted?
4. Describe parasitic draw.
5. How can you identify the high-voltage system in most hybrid vehicles?
6. How many volts are present in a fully charged 12-volt battery?
7. What is meant by the term *specific gravity*?
8. What causes gassing in a battery?
9. List five things that shorten the life of a battery.

True or False

1. *True or False?* All electrochemical batteries have three major parts: two electrodes or plates, and an electrolyte.
2. *True or False?* A fully charged new battery will have a low conductance reading.
3. *True or False?* A battery is an electromechanical device.
4. *True or False?* The BCI determines battery ratings for CCA, CA, and reserve capacity.

Multiple Choice

1. Which of the following statements about battery types is *not* true?
   a. Deep cycle batteries are designed to go through many charge and discharge cycles.
   b. A low-maintenance battery is a heavy-duty version of a normal lead-acid battery.
   c. Maintenance-free batteries require external holes or vent caps.
   d. In a gel cell battery, gassing is minimized and vents are not needed.
2. Which of the following statements about battery ratings is true?
   a. The ampere-hour rating is defined as the amount of steady current that a fully charged battery can supply for 1 hour at 80 °F (26.7 °C) without the cell voltage falling below a predetermined voltage.
   b. The cold cranking amps rating represents the number of amps that a fully charged battery can deliver at 0 °F (–17.7 °C) for 30 seconds while maintaining a voltage above 9.6 volts for a 12-volt battery.
   c. The cranking amp rating expresses the number of amperes a battery can deliver at 32 °F (0 °C) for 30 seconds and maintain at least 1.2 volts per cell.
   d. The reserve capacity rating expresses the number of amperes a fully charged battery at 80 °F can supply before the battery's voltage falls below 10.5 volts.

ASE-STYLE REVIEW QUESTIONS

1. Technician A uses a current probe to test the open circuit voltage of a battery. Technician B uses the results of an open circuit voltage test to determine the battery's state of charge. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. Technician A says that the reserve rating of a battery is the amount of steady current that a fully charged battery can supply for 20 hours without the voltage falling below 10.5 volts. Technician B says that ampere-hour ratings state how many hours the battery is capable of supplying 25 amperes. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. Technician A says that battery straps should be used whenever a battery is lifted. Technician B says that when a battery is removed, the positive cable should be disconnected first. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. Technician A says jump-starting a battery can damage electronic components. Technician B says a dead battery should be jump-started instead of recharged. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Technician A says that battery corrosion is commonly caused by spilled electrolyte. Technician B says that battery corrosion is commonly caused by electrolyte condensation from gassing. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. Technician A says that before a battery is removed, a memory saver ought to be installed. Technician B says that before a battery is removed, the positive cable should be disconnected and the area around the battery should be cleaned. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. Technician A says that side post terminals need to be removed to inspect them for corrosion. Technician B says that side post terminals can be damaged by overtightening the terminal bolt. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. A vehicle's battery goes dead after sitting for two days. Technician A says a thorough battery inspection should be performed. Technician B says a check for a parasitic draw should be performed. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. Technician A always wears safety glasses or goggles when working with batteries. Technician B says that there is no need to seek medical help if electrolyte gets in your eyes as long as you flush your eyes immediately after the electrolyte hits them. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While discussing the results of a load test: Technician A says that if a battery fails a load test but the voltage rises above 12.4 volts when the load is removed, the battery should be replaced. Technician B says that if a battery fails a load test but the voltage rises above 12.4 volts when the load is removed, the battery is able to hold a charge. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER 18

STARTING AND MOTOR SYSTEMS

OBJECTIVES

- Describe the basic operation of all electric motors.
- Identify the major parts of a DC motor.
- Explain the purpose of the starting system.
- Describe the purpose and major components of the starting and starter control circuits.
- Describe the different types of magnetic switches and starter drives.
- Describe the different types of starting motors used in today's vehicles.
- Inspect and test starter relays and solenoids and the switches, connectors, and wires of starter control circuits.
- Perform starter circuit voltage drop tests and the starter current draw test.

Prior to the use of an electric starter motor, vehicles had a hand crank that turned the engine in an attempt to start the engine **(Figure 18–1)**. The difficulty and inconvenience of the hand crank lead to the development of an electric starter motor.

Today, electric motors are used to start the engine and, in hybrid and electric vehicles, to move the vehicle. Electric motors are also used to operate many different accessories. For the most part, the basic difference between the type of motor is the size and power output. Most motors are powered by DC voltage and are part of relatively simple circuits. Traction or drive motors use AC voltage and are controlled by rather complex circuits. Regardless of the voltage used to power the motor, the operation of all electric motors is based on the basic principles of magnetism.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2008	**Make:** Toyota	**Model:** Corolla	**Mileage:** 149,051	**RO:** 16225
Concern:	Car towed-in. Customer states engine doesn't crank when key is turned.			

Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.

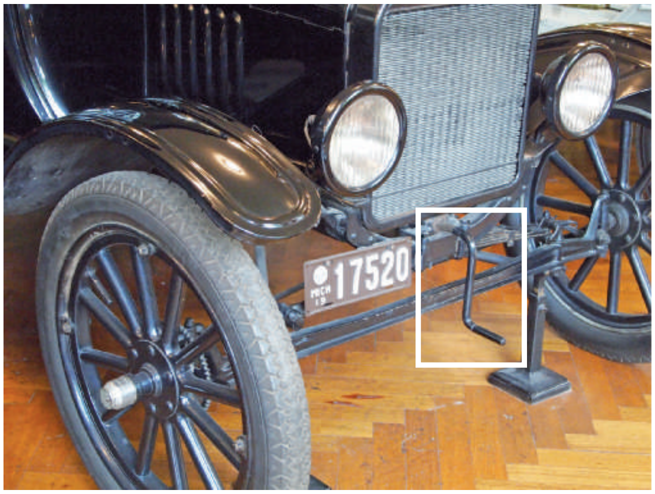


FIGURE 18–1 A crank used to start the engine, this was the common way before the introduction to electric starter motors.

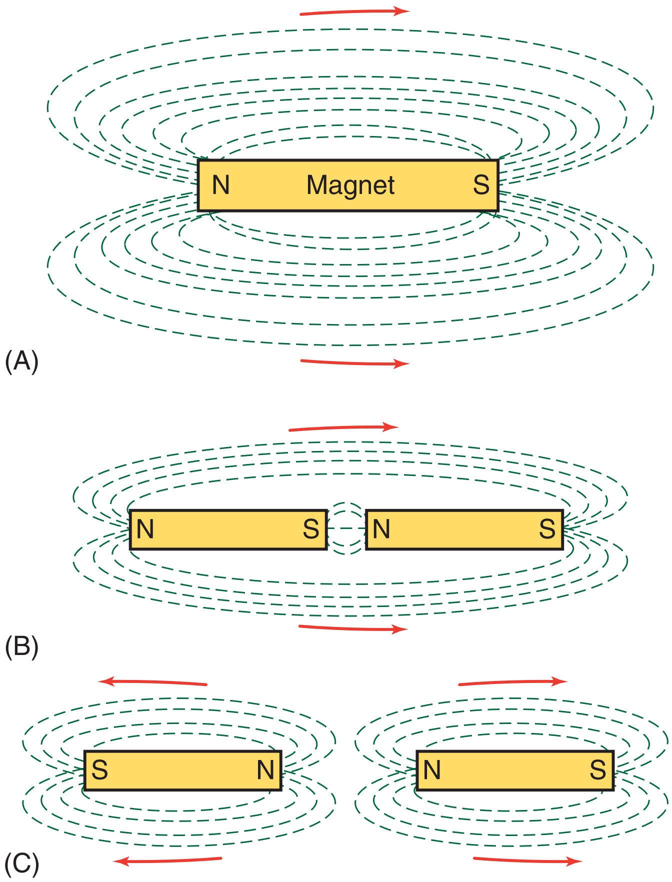


FIGURE 18–2 (A) In a magnet, lines of force emerge from the north pole and travel to the south pole before passing through the magnet back to the north pole. (B) Unlike poles attract, while (C) similar poles repel each other.

Basics of Electromagnetism

Electricity and magnetism are related. One can be used to create the other. Current flowing through a wire creates a magnetic field around the wire. Moving a wire through a magnetic field creates current flow in the wire.

Magnetism

A substance is said to be a magnet if it has the property of magnetism—the ability to attract such substances as iron, steel, nickel, or cobalt. A magnet has two points of maximum attraction, one at each end of the magnet. These points are designated the north pole and the south pole **(Figure 18–2A)**. When two magnets are brought together, opposite poles attract **(Figure 18–2B)**, while similar poles repel each other **(Figure 18–2C)**.

A magnetic field, called a **flux field**, exists around every magnet. The field consists of lines along which the magnetic force acts. These lines emerge from the north pole and enter the south pole, returning to the north pole through the magnet itself. All lines of force leave the magnet at right angles to the magnet. None of the lines cross each other and all are complete.

Electromagnets

Magnets can occur naturally in the form of a mineral called magnetite. Artificial magnets can be made by inserting a bar of magnetic material inside a coil of insulated wire and passing current through the coil. Another way of creating a magnet is by stroking the magnetic material with a bar magnet. Both methods force the randomly arranged molecules of the magnetic material to align themselves along north and south poles.

Artificial magnets can be either temporary or permanent. Temporary magnets are usually made of soft iron. They are easy to magnetize but quickly lose their magnetism when the magnetizing force is removed. Permanent magnets are difficult to magnetize. However, once magnetized they retain this property for very long periods.

The earth is a very large magnet, having a North Pole and a South Pole, with lines of magnetic force running between them. This is why a compass always aligns itself to straight north and south.

In 1820, a simple experiment discovered the existence of a magnetic field around a current-carrying wire. When a compass was held over the wire, its needle aligned itself at right angles to the wire **(Figure 18–3)**. The lines of magnetic force are

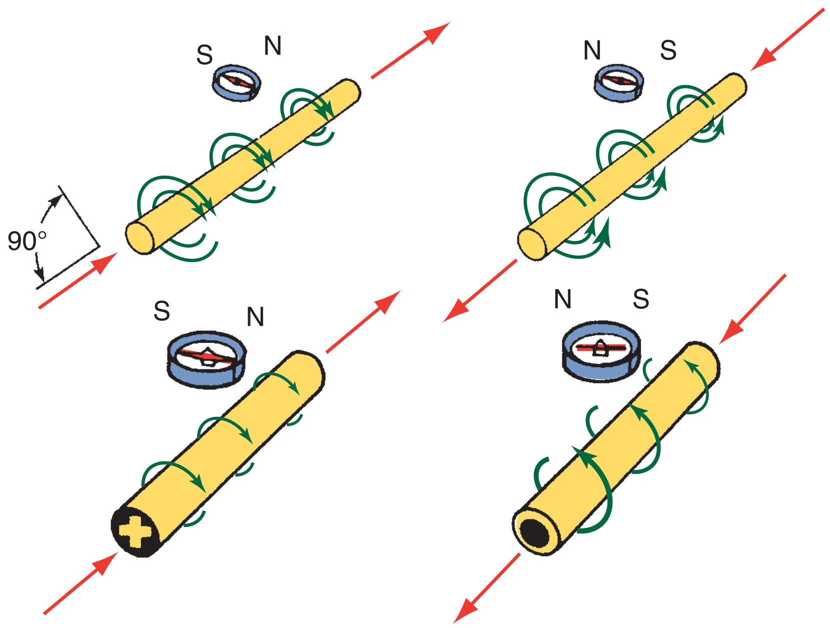


FIGURE 18–3 When current is passed through a conductor such as a wire, magnetic lines of force are generated around the wire at right angles to the direction of the current flow.

concentric circles around the wire. The density of these circular lines of force is very heavy near the wire and decreases farther away from the wire. As is also shown in the same figure, the polarity of a current-carrying wire's magnetic field changes depending on the direction the current is flowing through the wire. These magnetic lines of force or flux lines do not move or flow around the wire. They simply have a direction as shown by their effect on a compass needle.

Flux Density The more flux lines, the stronger the magnetic field at that point. Increasing current will increase **flux density**. Also, two conducting wires lying side-by-side carrying equal currents in the same direction create a magnetic field equal in strength to one conductor carrying twice the current. Therefore, adding more wires increases the magnetic field **(Figure 18–4)**.

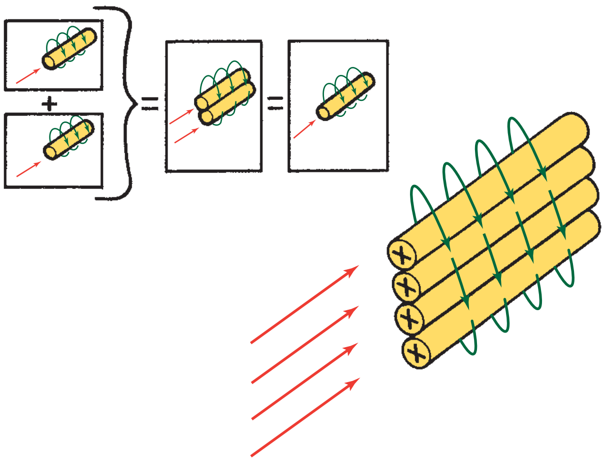


FIGURE 18–4 Increasing the number of conductors carrying current in the same direction increases the strength of the magnetic field around them.

Coils Looping a wire into a coil concentrates the lines of flux inside the coil. The resulting magnetic field is the sum of the single-loop magnetic fields **(Figure 18–5)**. The overall effect is the same as placing many wires side-by-side, each carrying current in the same direction.

Magnetic Circuits and Reluctance

Just as current can only flow through a complete circuit, the lines of flux created by a magnet can only occupy a closed magnetic circuit. The resistance

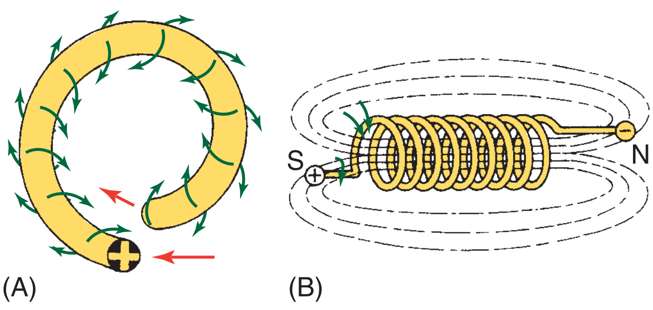


FIGURE 18–5 (A) Forming a wire loop concentrates the lines of force inside the loop. (B) The magnetic field of a wire coil is the sum of all the single-loop magnetic fields.

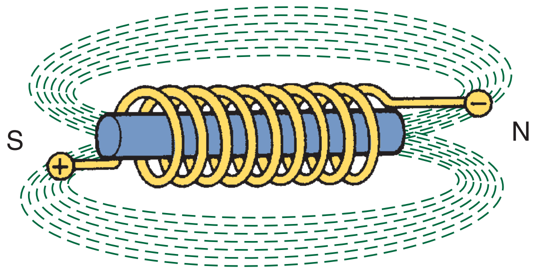


FIGURE 18–6 Placing a soft iron core inside a coil greatly reduces the reluctance of the coil and creates a usable electromagnet.

that a material offers to the passage of magnetic flux lines is called **reluctance**. Magnetic reluctance can be compared to electrical resistance.

Reconsider the coil of wire shown in Figure 18–5. The air inside the coil has very high reluctance and limits the magnetic strength produced. However, if an iron core is placed inside the coil, magnetic strength increases tremendously. This is because the iron core has a very low reluctance **(Figure 18–6)**.

When a coil of current-carrying wire is wound around an iron core, it becomes a usable electromagnet. The strength of an electromagnet's magnetic field is directly proportional to the number of turns of wire and the current flowing through them.

The equation for an electromagnetic circuit is similar to Ohm's law for electrical circuits. It states that the number of magnetic lines is proportional to the ampere-turns divided by the reluctance. To summarize:

- The magnetic polarity of the coil depends on the direction of current flow through the loop.
- Field strength increases if current through the coil increases.
- Field strength increases if the number of coil turns increases.
- If reluctance increases, field strength decreases.

Motors

An electric motor converts electric energy into mechanical energy. Through the years, electric motors have changed substantially in design; however, the basic operational principles have remained the same. That principle is easily observed by taking two bar magnets and placing them end-to-end with each other. If the ends have the same polarity, they will push away from each other. If the ends have the opposite polarity, they will move toward each other and form one magnet.

If we put a pivot through the center of one of the magnets to allow it to spin and moved the other magnet toward it, the first magnet will either rotate away from the second or move toward it **(Figure 18–7)**. This is basically how a motor works. Although we do not observe a complete rotation, we do see part of one, perhaps a half turn. If we could change the polarity of the second magnet, we would get another half turn. So in order to keep the first magnet spinning, we need to change the polarity immediately after it moves halfway. If we continued to do this, we would have a motor.

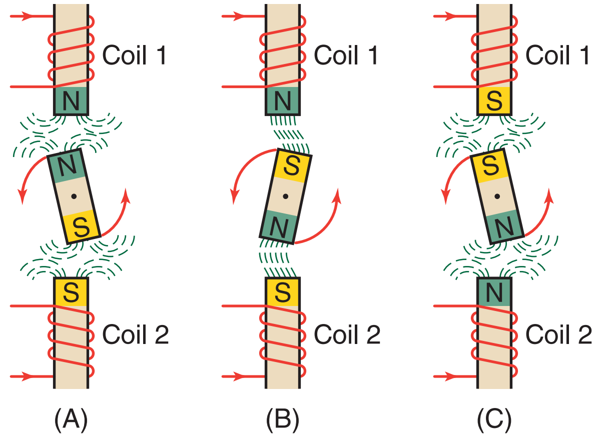


FIGURE 18–7 (A) Like poles repel. (B) Unlike poles are attracted to each other. Then if we change the polarity of the coils, (C) the like poles again repel.

In a real motor, an electromagnet is fitted on a shaft. The shaft is supported by bearings or bushings to allow it to spin and to keep it in the center of the motor. Surrounding, but not touching, this inner magnet is a stationary permanent magnet or an electromagnet. Actually, there is more than one magnet or magnetic field in both components. The polarity of these magnetic fields is quickly switched and we have a constant opposition and attraction of magnetic fields. Therefore, we have a constantly rotating inner magnetic field, the shaft of which can do work due to the forces causing it to rotate. The torque of a motor varies with rotational speed, motor design, and the amount of current draw the motor has. The rotational speed depends on the motor's current draw, the design of the motor, and the load on the motor's rotating shaft.

The basic components of a motor are the stator or field windings, which are the stationary parts of the motor, and the rotor or armature, which is the rotating part **(Figure 18–8)**. The field windings are comprised of slotted cores made of thin sections of soft iron wound with insulated copper wire to form one or more pairs of magnetic poles. Some motors have the field windings wound around iron anchors, called pole shoes. The armature is comprised of loops of current-carrying wire. The loops are formed around a metal with low reluctance to increase the magnetic field. The magnetic fields around the armature are pushed away by the magnetic field of the

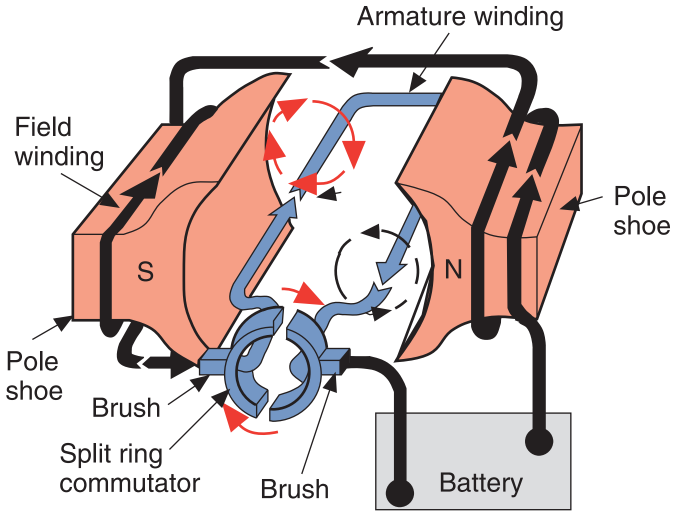


FIGURE 18–8 A simple electric motor.

field windings, causing the armature to rotate away from the windings' fields.

The field windings or the armature may be made with permanent magnets rather than electromagnets. Both cannot be permanent magnets. An electromagnet allows for a change in the polarity of the magnetic fields, which keeps the armature spinning. Changing the direction of current flow changes the magnetic polarities.

Starting Motors

The starting motor **(Figure 18–9)** is a special type of electric motor designed to operate under great electrical loads and to produce great amounts of torque for short periods.

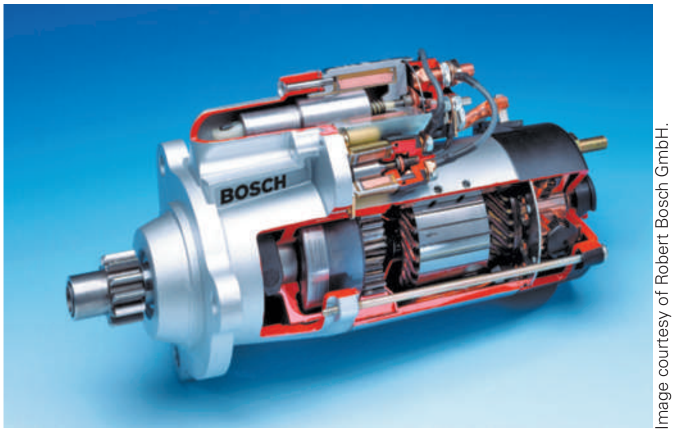


FIGURE 18–9 A cutaway of a starter motor.

All starting motors are generally the same in design and operation. Basically the starter motor consists of a housing, field coils (windings), an armature, a commutator with brushes, and end frames **(Figure 18–10)**.

The starter housing or **starter frame** encloses the internal parts and protects them from damage, moisture, and foreign materials. The housing also supports the field coils.

The **field coils** and their pole shoes **(Figure 18–11)** are securely attached to the inside of the housing. The field coils are insulated from the housing but are connected to a terminal that protrudes through the outer surface of the housing. This terminal connects to the solenoid.

The field coils and pole shoes are designed to produce strong stationary electromagnetic fields within the starter when current flows to it. The magnetic fields are concentrated at the pole shoe. The coils are

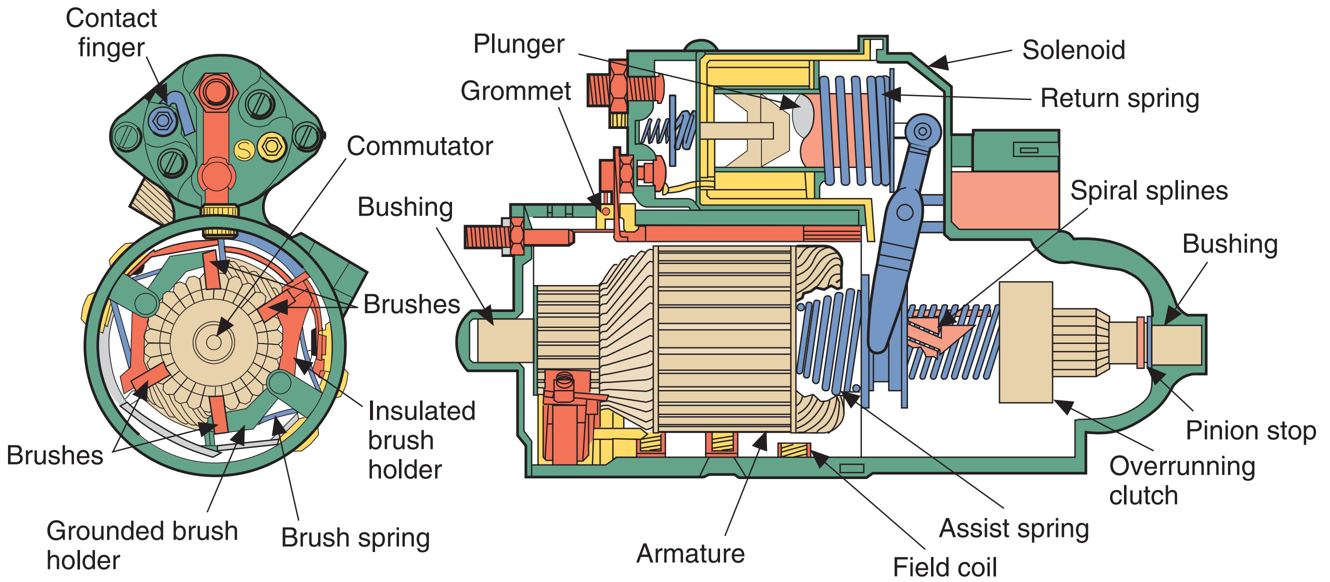


FIGURE 18–10 A typical starter motor assembly.

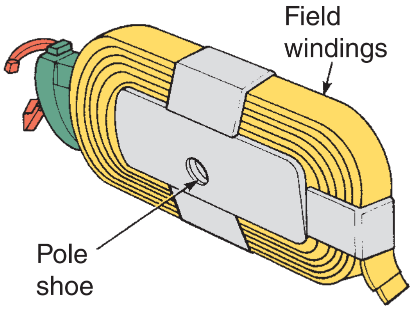


FIGURE 18–11 Example of a field coil and pole shoe.

wound around respective pole shoes in opposite directions to create opposing magnetic fields.

The field coils connect in series with the armature winding through the starter brushes. This permits all current passing through the field coil circuit to also pass through the armature windings.

The **armature** is the rotating part of a starter. It is located between the starter drive and commutator end frames and is enclosed by the field windings. Current passing through the armature produces a magnetic field in each of its conductors. The reaction between the armature's magnetic field and the magnetic fields produced by the field coils causes the armature to rotate **(Figure 18–12)**. This is the mechanical energy that is then used to crank the engine.

The armature assembly is made up of the armature windings, **commutator**, and the starter drive assembly **(Figure 18–13)**. The armature windings are made of heavy flat copper strips or wires that form a single loop and can handle the heavy current flow. The sides of these loops fit into slots in the armature core or shaft, but they are insulated from it.

The field coils connect to each other and current from the coils flows through all of the windings at the same time. This action generates a magnetic field around each armature winding, resulting in a repulsion force all around the conductor. This repulsion force causes the armature to turn.

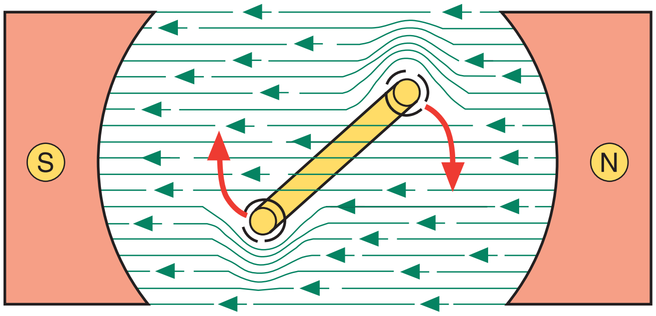


FIGURE 18–12 Rotation of the conductor is in the direction of the weaker magnetic field.

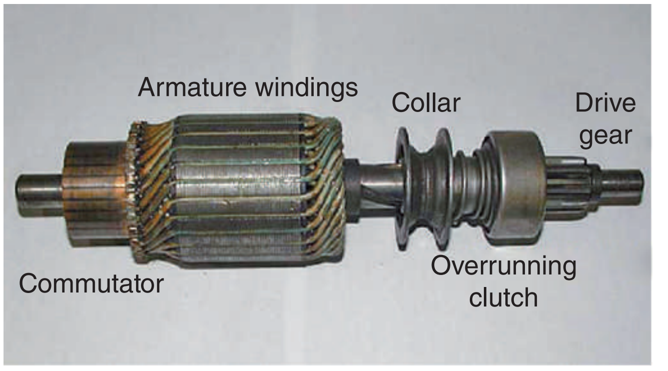


FIGURE 18–13 The armature of a starter motor.

The commutator assembly is made up of heavy copper segments separated from each other and the armature shaft by insulation. The commutator segments connect to the ends of the armature windings.

Starter motors have two to six brushes that ride on the commutator segments and carry the heavy current from the stationary field coils to the rotating armature windings. Each end of the armature windings is connected to one segment of the commutator. One set of carbon brushes is connected to one terminal of the power supply. The other set of brushes is connected to ground. The brushes contact the commutator segments conducting current to and from the armature coils.

The brushes mount on and operate in some type of holder, which may be a pivoting arm design inside the starter housing or frame (see **Figure 18–13**). However, in many starters the brush holders are secured to the starter's end frame. Springs hold the brushes against the commutator with the correct pressure. Finally, alternate brush holders are insulated from the housing or end frame. Those between the insulated holders are grounded.

The end frame is a metal plate that bolts to the commutator end of the starter housing. It supports the commutator end of the armature with a bushing or bearing.

Operating Principles

The starter motor converts current into torque through the interaction of magnetic fields. The magnetic field developed at the field windings and the armature have opposite polarities. When the armature windings are placed inside the field windings, part of the armature coil is pushed in one direction as the field opposes the field in the windings. This causes the armature to begin to rotate. As the armature moves, the contact between a brush and commutator

segment is broken and the brush contacts a new segment. This causes a reverse in the polarity of the magnetic field around the armature. The new opposition of magnetic fields causes the armature to rotate more. This process continues and the armature continues to rotate until current stops flowing to the armature.

Many armature segments are used. This provides for a uniform turning motion because as one segment rotates past a brush, another immediately takes its place. This also provides for constant torque.

The number of coils and brushes may differ among starter motor models. The armature may be wired in series with the field coils (**series motor**); the field coils may be wired parallel or shunted across the armature (shunt motors); or a combination of series and shunt wiring (**compound motors**) may be used **(Figure 18–14)**.

A series motor develops its maximum torque at startup and develops less torque as speed increases. It is ideal for applications involving heavy starting loads.

Shunt or parallel-wound motors develop considerably less startup torque but maintain a constant speed at all operating loads. Compound motors combine the characteristics of good starting torque with constant speed. This design is particularly useful for applications in which heavy loads are suddenly applied. In a starter motor, a shunt coil is frequently used to limit the maximum free speed at which the starter can operate.

Permanent Magnet Motors Many starter and accessory motors use permanent magnets instead of electromagnets as field coils. Electrically, this type of motor is simpler. It does not require current for the field coils. Current is delivered directly to the

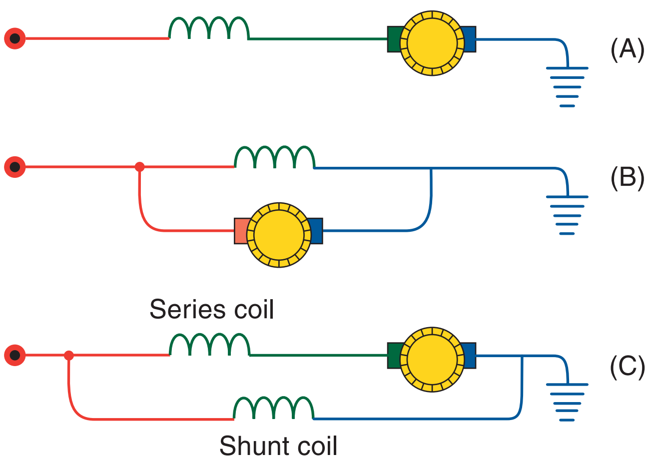
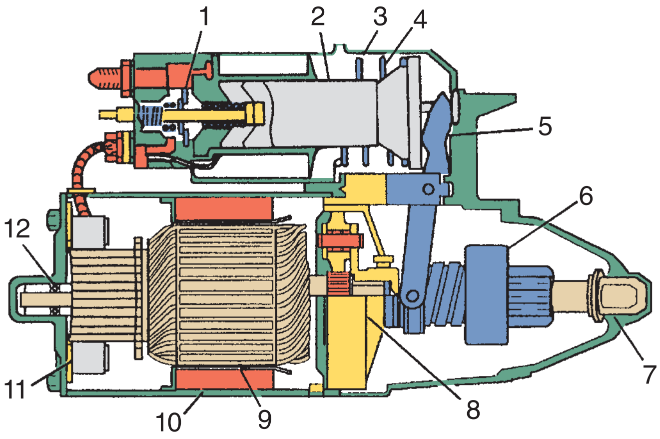


FIGURE 18–14 Starter motors are grouped according to how they are wired: (A) in series, (B) in parallel (shunt), or (C) a compound motor using both series and shunt coils.



1 Contact disc
2 Plunger
3 Solenoid
4 Return spring
5 Shift lever
6 Drive assembly
7 Roller bearing
8 Planetary gear reduction assembly
9 Armature
10 Permanent magnets
11 Brush
12 Ball bearings

FIGURE 18–15 Permanent magnet-type starter assembly.

armature through the commutator and brushes **(Figure 18–15)**. With the exception of no electromagnets in the fields, this functions exactly as the other motors.

Maintenance and testing procedures are the same as for other designs. Notice the use of a planetary gear reduction assembly on the front of the armature. This allows the armature to spin with increased torque, resulting in improved starter cold-cranking performance.

Warning! Permanent magnet motors require special handling because the permanent magnet material is quite brittle and can be destroyed with a sharp blow or if the motor is dropped.

Counter EMF The amount of torque from a starting motor depends on a number of things. One of the most important is current draw. The slower the motor turns, the more current it will draw. This is why a starter motor will draw large amounts of current when the engine is difficult to crank. A motor needs more torque to crank a difficult-to-start engine. The relationship between current draw and motor speed is explained by the principles of **counter EMF (CEMF)**. Electromotive force (EMF) is another name for voltage.

When the armature rotates within the field windings, conditions exist to induce a voltage in the

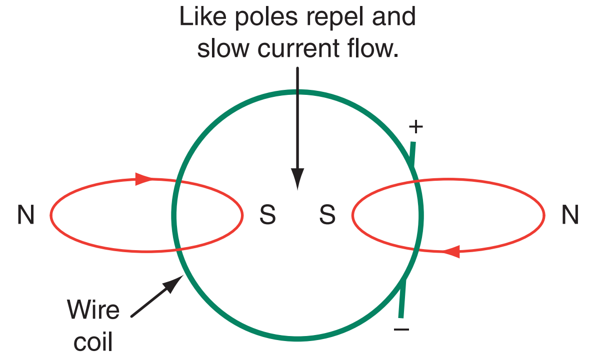


FIGURE 18–16 A magnetic field forms around a current-carrying conductor according to the direction of current flow. When a wire is formed into a coil, there are repelling poles that result in CEMF.

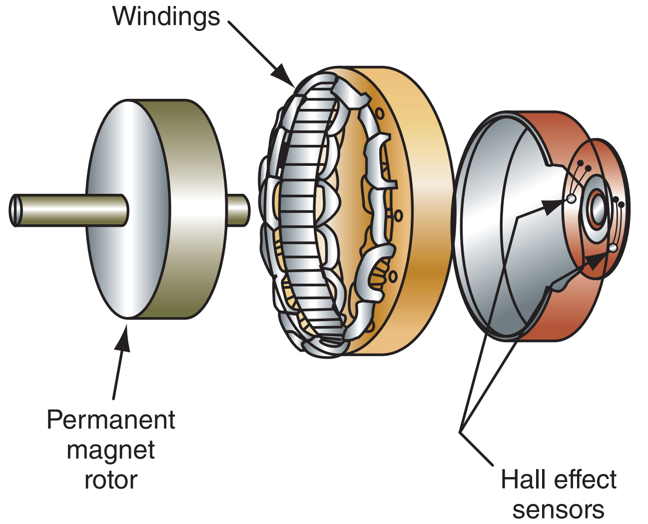


FIGURE 18–17 Parts of a brushless DC motor. The Hall-effect sensor monitors the position of the rotor.

armature. Voltage is induced anytime a wire is passed through a magnetic field. When the armature, which is a structure with many loops of wire, rotates past the field windings, a small amount of voltage is induced **(Figure 18–16)**. This voltage opposes the voltage supplied by the battery to energize the armature. As a result, less current is able to flow through the armature.

The faster the armature spins, the more induced voltage is present in the armature. The more voltage is induced in the armature, the more opposition there is to normal current flow to the armature. The induced voltage in the armature opposes or is counter to the battery's voltage. This is why the induced voltage is called CEMF.

The effects of CEMF are quite predictable. When the armature of the motor turns slowly, low amounts of voltage are induced and, therefore, low amounts of CEMF are present. The low CEMF permits higher current flow. In fact, the only time a starter motor draws its maximum amount of current is when the armature is not rotating.

Brushless Motors

Brushless motors use a permanent magnet motor and electromagnetic field windings. This design eliminates the arcing at the contact area between the brushes and commutator, which extends the service life of the motor. It also decreases EMI that can affect the operation of many electronic systems. High output brushless DC motors are used in some HEV-drive vehicles.

These motors operate through the control of the stator by an electronic circuit that switches current flow, as needed, to keep the rotor rotating. The key to this is the use of a Hall-effect sensor that monitors the position of the rotor **(Figure 18–17)**.

Starting System

The starting system is designed to turn or crank the engine until it can operate under its own power. To do this, the starter motor is engaged to the engine's flywheel. As it spins, it turns the engine's crankshaft. The sole purpose of the starting system is to crank the engine fast enough to run. The engine's ignition and fuel system provide the spark and fuel for engine operation, but they are not considered part of the starting system. However, they do affect how well an engine starts.

A typical starting system has six basic components and two distinct electrical circuits. The components are the battery, ignition switch, battery cables, magnetic switch (either an electrical relay or a solenoid), starter motor, and the starter safety switch.

The starter motor draws a great deal of current from the battery. A large starter motor might require 250 or more amperes of current. This current flows through the large cables that connect the battery to the starter and ground.

The driver controls the flow of this current using the ignition switch. The battery cables are not connected to the switch. Rather, the system has two separate circuits: the starter motor circuit and the control circuit **(Figure 18–18)**. The starter motor circuit carries the heavy current from the battery to the starter motor through a magnetic switch in a relay or solenoid. The control circuit connects battery power at the ignition switch to the magnetic switch, which controls the high current to the starter motor. In many late-model vehicles, the starter cir-

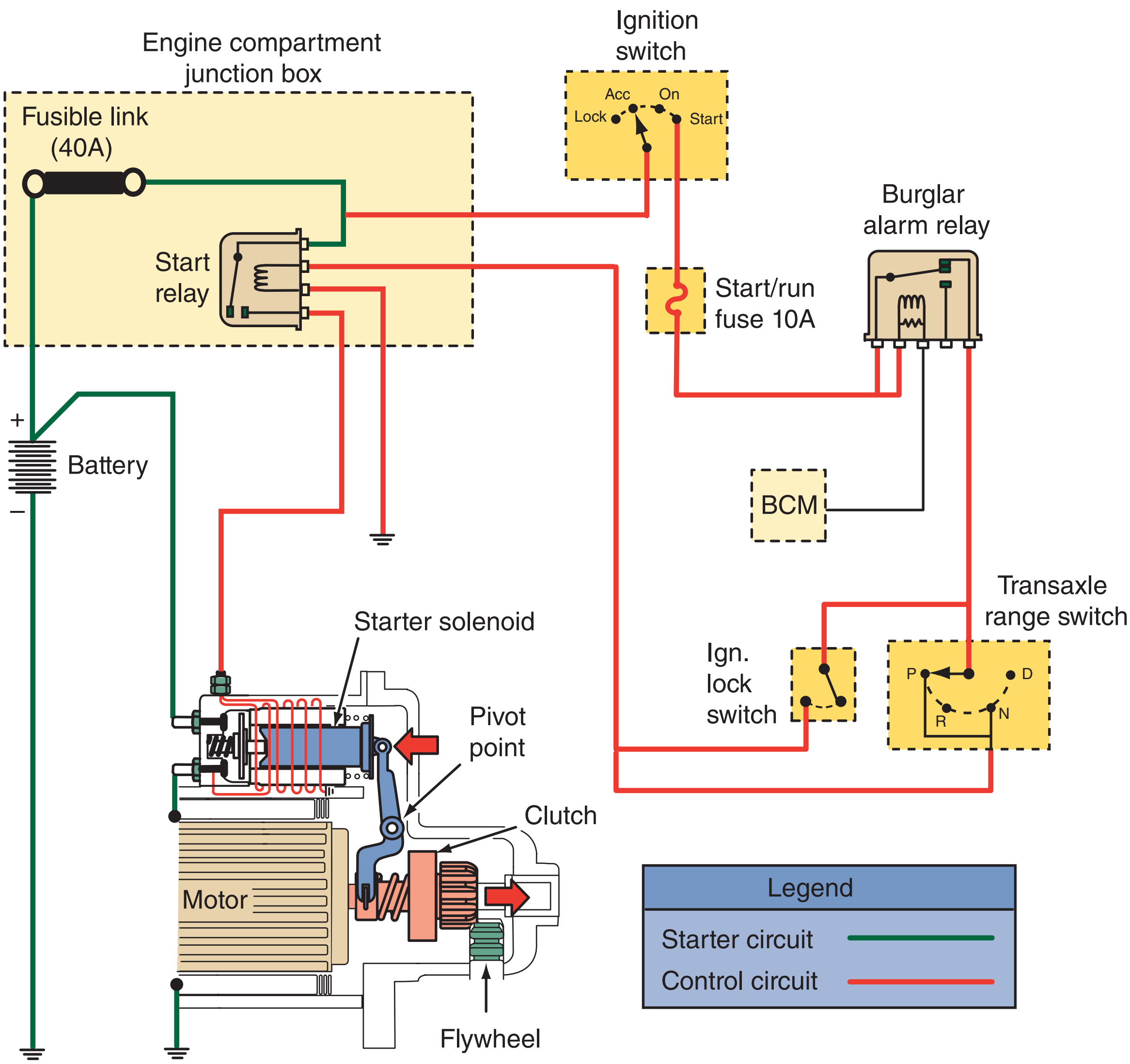


FIGURE 18–18 The starting system is made up of two separate systems: the starter and control systems.

cuit is controlled by the on-board computer system and the ignition switch is only used as an input for the system.

Starter Motor Circuit

The starter motor circuit carries the high current flow within the system and supplies power for the actual engine cranking. Components of the starter motor circuit are the battery, battery cables, magnetic switch or solenoid, and the starter motor.

Battery and Cables

The motor circuit requires two or more heavy-gauge cables. One of these cables connects between the battery's negative terminal and the engine block or transmission case. The other cable connects the battery's positive terminal with the solenoid **(Figure 18–19)**. On vehicles equipped with a **starter relay**, two positive cables are needed. One runs from the positive battery terminal to the relay and the second from the relay to the starter motor terminal. In any case, these cables carry the required heavy current from the battery to the starter and from the starter back to the battery.

Cables must be heavy enough to comfortably carry the required current load. Cranking problems can be created when undersized cables are installed. With undersized cables, the starter motor does not develop its greatest turning effort and even a fully charged battery might be unable to start the engine.

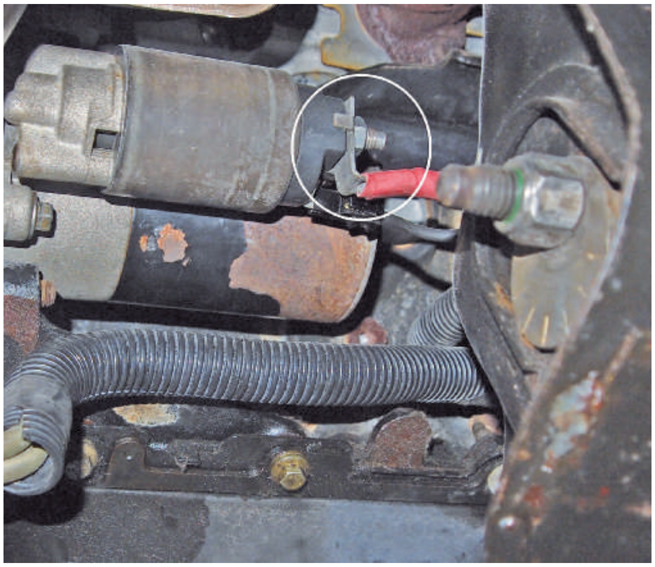


FIGURE 18-19 The battery cable is connected to the starter solenoid.

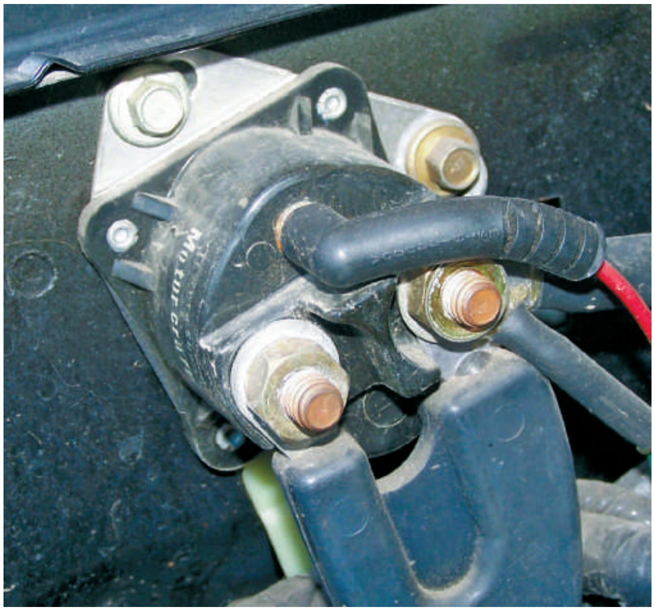


FIGURE 18-20 This starter relay (solenoid) is remotely mounted away from the starter motor.

Magnetic Switches

Every starting system contains some type of magnetic switch that enables the control circuit to open and close the starter circuit. This magnetic switch can be one of several designs.

Solenoid The solenoid-actuated starter is by far the most common starter system used. A solenoid is an electromechanical device that uses the movement of a plunger to exert a pulling or holding force. As shown in **Figure 18–20**, the solenoid is mounted in the engine compartment or directly on top of the starter motor.

In this type of starting system, the solenoid uses the electromagnetic field generated by its coil to perform two distinct jobs. The first is to push the drive pinion of the starter motor into mesh with the engine's flywheel. This is the solenoid's mechanical function. The second job is to act as an electrical relay switch to energize the motor once the drive pinion is engaged. Once the contact points of the solenoid are closed, full battery current flows to the starter motor.

The solenoid assembly has two separate windings: a pull-in winding and a hold-in winding. The two windings have approximately the same number of turns but are wound from different size wire **(Figure 18–21)**. Together these windings produce the electromagnetic force needed to pull the plunger into the solenoid coil. The heavier pull-in windings draw the plunger into the solenoid, while the lighter-gauge windings produce enough magnetic force to hold the plunger in this position.

Both windings are energized when the ignition switch is in the start position. When the plunger disc makes contact with this solenoid terminal, the pull-in winding is deactivated. At the same time, the plunger contact disc completes the motor feed connection between the battery and the starting motor, directing current to the field coils and starter motor armature for cranking power.

As the solenoid plunger moves, the shift fork also pivots on the pivot pin and pushes the starter drive pinion into mesh with the flywheel ring gear. When the starter motor receives current, its armature starts to turn. This motion is transferred through an overrunning clutch and pinion gear to the engine flywheel and the engine is cranked.

With this type of solenoid-actuated direct drive starting system, teeth on the **pinion gear** may not immediately mesh with the flywheel ring gear. If this occurs, a spring located behind the pinion compresses so the solenoid plunger can complete its stroke. When the starter motor armature begins to turn, the pinion teeth quickly line up with the flywheel teeth and the spring pressure forces them to mesh.

Auto Start-Stop Solenoid

In order to reduce fuel consumption, many late-model engines are equipped with auto start-stop or

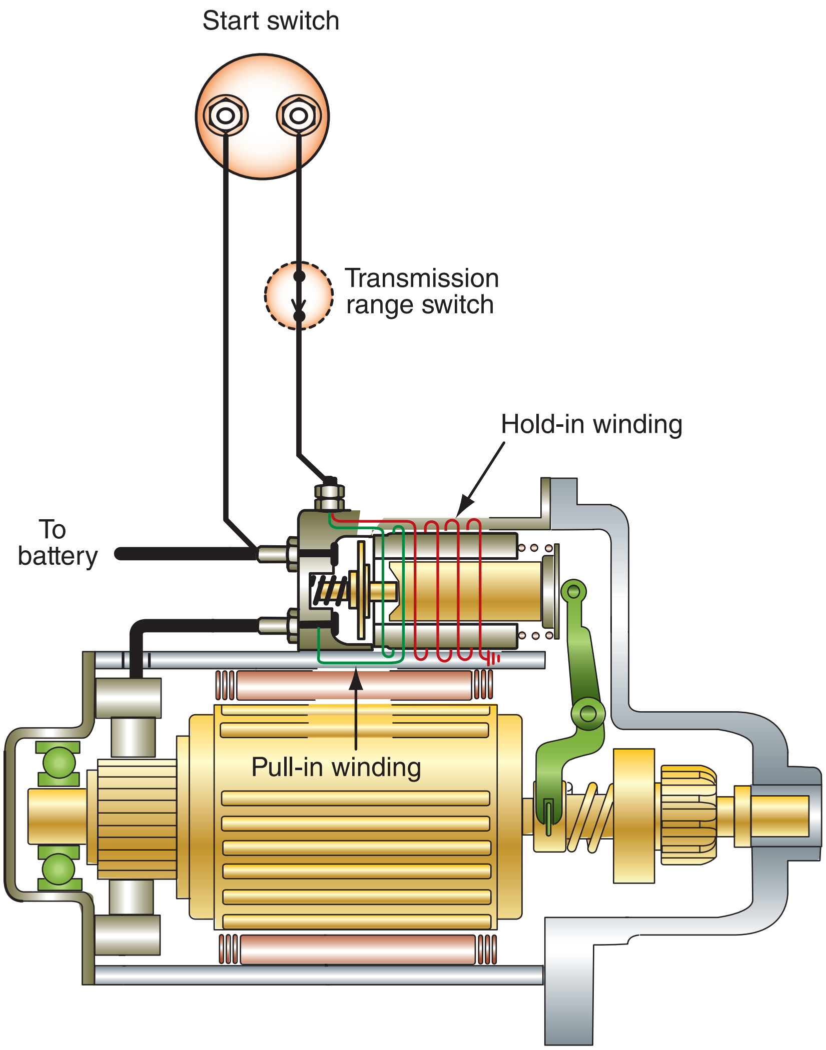


FIGURE 18–21 A starter solenoid has two windings; the pull-in and hold-in.

idle-stop systems. These systems shut the engine off when idling and very quickly restart it when the driver lifts off the brake pedal or presses the accelerator pedal. To accomplish rapid restarts, which may include re-engaging the starter drive even before the engine stops spinning, a new type of solenoid is needed **(Figure 18–22)**. Tandem solenoid starters can operate the starter drive gear separately from spinning the armature. This allows the system to engage the drive gear even with the engine spinning. The armature can then be activated through the rear section of the solenoid to crank the engine.

Another feature of this type of solenoid is that it allows much faster engine restarting. With the system active, engine restarts typically require less than ½ second, compared to two seconds or more during normal cranking.

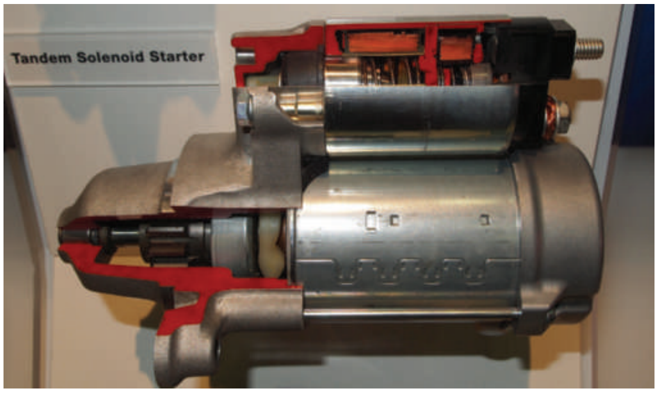


FIGURE 18–22 A tandem solenoid starter for auto start/stop operation.

To utilize auto start-stop capability, both the starter motor and battery are more robust to handle the much greater number of engine starts. The feature

is often able to be turned off by the driver or it may automatically turn off if certain operating conditions are not met or by driver preference.

Starter Relay Starter relays are similar to starter solenoids. However, they are not used to move the drive pinion into mesh. They are used as an electrical relay or switch. When current from the ignition switch arrives at the relay, a strong magnetic field is generated in the relay's coil. This magnetic force pulls the plunger contact disc up against the battery terminal and the starter terminal of the relay, allowing full current flow to the starter motor.

Positive Engagement Movable Pole Shoe Drive Positive engagement movable pole shoe drive starters **(Figure 18–23)** are found mostly on older Ford products. In this design, the drive mechanism is an integral part of the motor, and the drive pinion is engaged with the flywheel before the motor is energized.

When the ignition switch is moved to the start position, the starter relay closes, and full battery current is delivered to the starter. This current runs through the winding of the movable pole shoe and through a set of contacts to ground. This generates a magnetic force that pulls down the movable pole shoe. It also forces the drive pinion to engage the flywheel ring gear using a lever action and opens the contacts. A small holding coil keeps the movable shoe and lever assembly engaged during cranking. When the engine starts, an overrunning clutch prevents the flywheel from spinning the armature.

All positive engagement starters use a relay in series with the battery cables to deliver current through the shortest possible battery cables. Some vehicles use both a starter relay and a starter motor-mounted solenoid. The relay controls current flow to the solenoid, which in turn controls current flow to the starter motor. This reduces the amount of current flowing through the ignition switch. In other words, it takes less current to activate the relay than to activate the solenoid.

When the ignition switch is released from the start position, both the pole shoe and lever return to their original positions.

Starter Drives

The starter drive is the device that couples the armature with the flywheel. A pinion gear at one end of the armature meshes with the teeth on the outside of the flywheel **(Figure 18–24)**. The spinning armature then turns the flywheel. To prevent damage to the pinion gear or the ring gear on the flywheel, the pinion must mesh with the ring gear before the armature begins to spin. To help ensure smooth engagement, the end of the pinion gear is tapered **(Figure 18–25)**. To disengage the

FIGURE 18–23 A positive engagement starter.

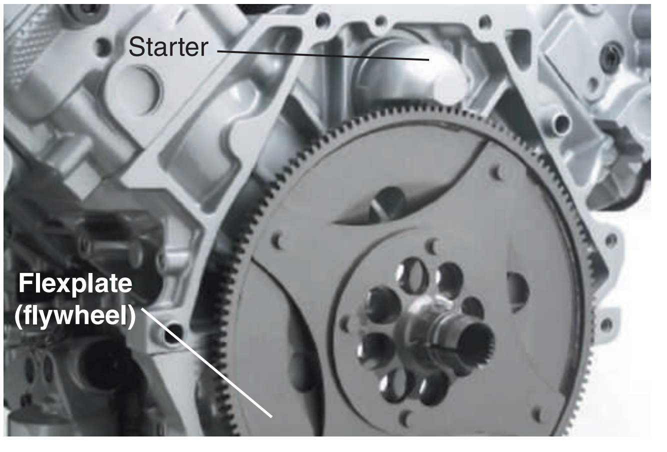


FIGURE 18–24 Starter drive pinion gear is used to turn the engine's flywheel.

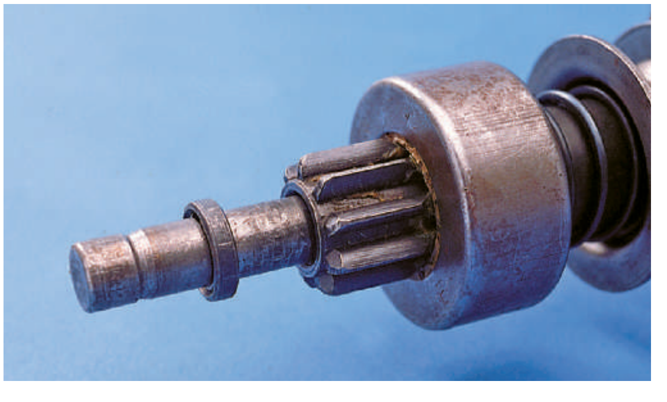


FIGURE 18–25 The pinion gear teeth are tapered to allow for smooth engagement.

pinion from the flywheel, the pinion is mounted to the armature via an overrunning clutch.

Overrunning Clutch Once the engine starts, its speed increases. If the starter motor remains connected to the engine through the flywheel, it will spin at very high speeds, destroying the armature and other parts.

To prevent this, the starter drive must be disengaged as soon as the engine turns faster than the starter. In most cases, the pinion remains engaged until current stops flowing to the starter. To prevent the armature from spinning at engine speed, an overrunning clutch is used.

The clutch housing is internally splined to the armature shaft. The drive pinion turns freely on the armature shaft within the clutch housing. When the clutch housing is driven by the armature, the spring-loaded rollers are forced into the small ends of their tapered slots and wedged tightly against the pinion barrel. This locks the pinion and clutch housing solidly together, permitting the pinion to turn the flywheel and, thus, crank the engine.

When the engine starts **(Figure 18–26)**, the flywheel spins the pinion faster than the armature. This releases the rollers, unlocking the pinion gear from the armature shaft. The pinion then freely spins on the armature shaft. Once current flow through the solenoid stops, the pinion is pulled away from the flywheel as the solenoid spring pushes the plunger back to its unenergized position.

Gear Reduction Drive The armature of some starter motors does not directly drive the starter drive gear. Rather it drives a small gear that is permanently meshed with a larger gear or a planetary gearset **(Figure 18–27)**. This provides for a gear reduction and allows a small, high-speed motor to provide high torque at a satisfactory cranking speed **(Figure 18–28)**. This starter design also tends to require lower current during engine startup.

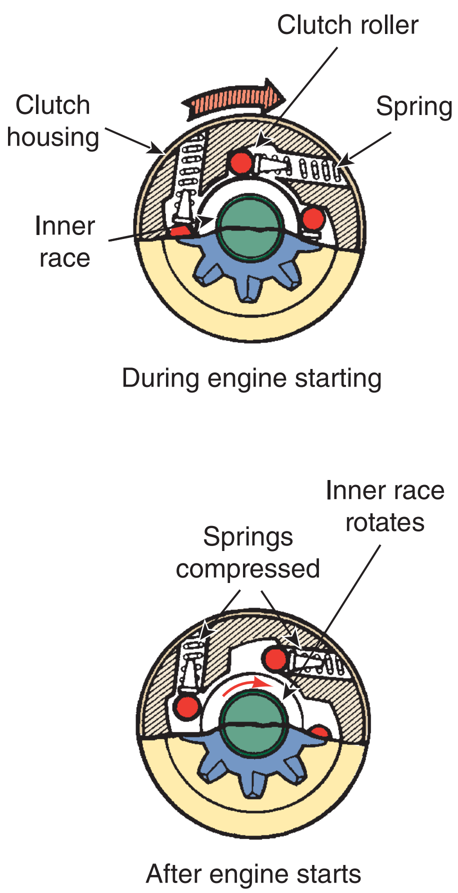


FIGURE 18–26 When the engine starts, the flywheel spins the pinion gear faster, which releases the rollers from the wedge.

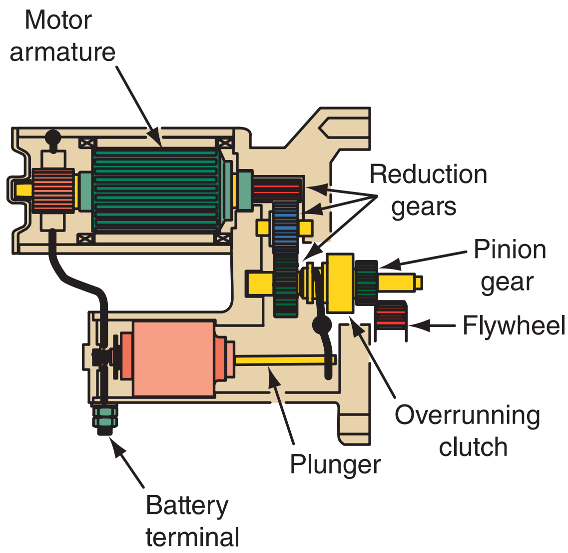


FIGURE 18–27 A gear reduction-drive starter.

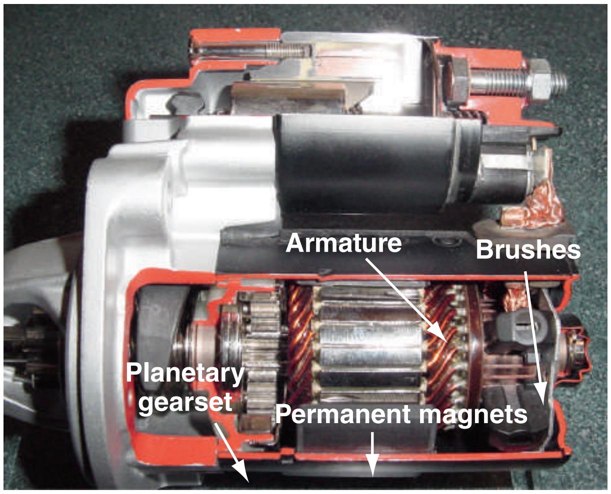


FIGURE 18–28 A cutaway of a gear reduction, permanent magnet starter motor.

Control Circuit

The control circuit allows a small amount of current to control the flow of a large amount of current in the starting circuit.

The entire circuit usually consists of an ignition switch connected through normal-gauge wire to the battery and the magnetic switch (solenoid or relay). When the ignition switch is turned to the start position, a small amount of current flows through the coil of the magnetic switch, closing it and allowing full current to flow directly to the starter motor. The ignition switch performs other jobs besides controlling the starting circuit. It normally has at least four separate positions: accessory, off, on (run), and start.

The ignition switch on some newer vehicles does not directly control starter operation **(Figure 18–29)**. Instead, the switch is an input for the onboard computer system. When the key is turned to the crank position, the body control module (BCM) signals the powertrain control module (PCM) to activate the crank relay. Current then passes through the crank relay to the starter solenoid. This arrangement is common on vehicles with factory installed anti-theft systems. A benefit of this system is the ability to add remote start capability from the vehicle's key fob.

Many newer vehicles have eliminated the traditional key and ignition switch and instead use push button start and a smart key **(Figure 18–30)**. The start button is simply an input for the onboard computer system. The starter circuit is controlled based on inputs from the anti-theft, body, and powertrain computers. Typically, the vehicle must detect the presence of the correct smart key. Next, the driver presses on the brake pedal and then presses the start button once to power-up the vehicle. Pressing the start button again activates the starter circuit. Pressing the start button when the engine is running shuts the engine off.

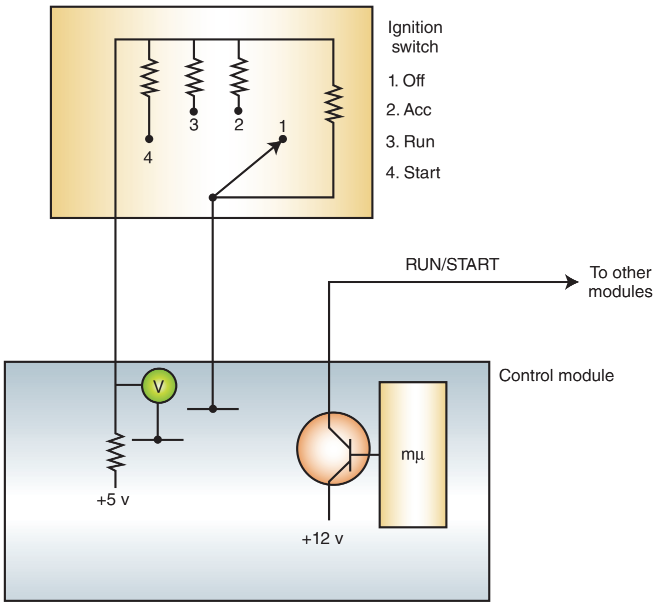


FIGURE 18–29 The ignition switch for a computer controlled starting system.

FIGURE 18–30 A start button.

Starting Safety Switch

The starting safety switch, often called the **neutral safety switch**, is a normally open switch that prevents the starting system from operating when the transmission is in gear. Starting safety switches can be located between the ignition switch and the relay or solenoid or the relay and ground. In computer controlled starting systems, the safety switch may be used as an input for the PCM and not be wired directly into the starter control circuit.

The safety switch used with an automatic transmission is normally called a park/neutral position switch **(Figure 18–31)**. The switch contacts are wired in series with the control circuit so that no current can flow through the relay or solenoid unless the shift lever is in neutral or park. The switch is normally mounted on the transmission housing.

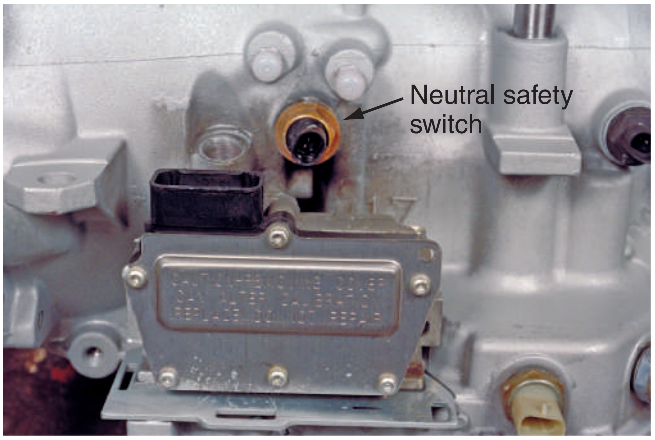


FIGURE 18-31 Neutral safety switch attached to an automatic transmission.

Mechanical safety switches for automatic transmissions physically block the movement of the ignition key when the transmission is in a gear. The ignition key can only be turned when the shift selector is in park or neutral. These are called interlock systems.

The safety switches used with manual transmissions are usually controlled by the clutch pedal. The clutch start switch serves the same purpose as a park/neutral position switch. The clutch start switch keeps the starter control circuit open until the clutch pedal is depressed **(Figure 18–32)**.

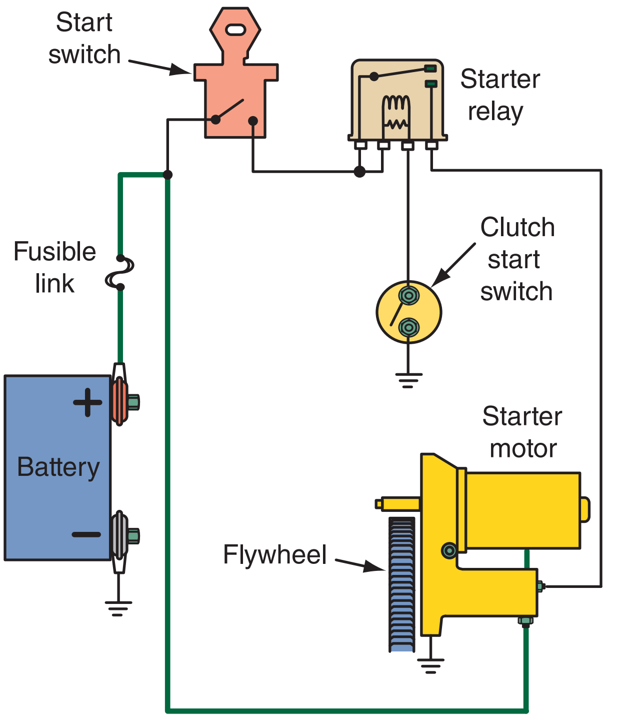


FIGURE 18-32 The clutch pedal must be fully depressed to close the clutch switch and complete the control circuit.

Starting System Testing

As mentioned earlier, the starter motor is a special type of electrical motor designed for intermittent use only. During testing, it should never be operated for more than 15 seconds without resting for 2 minutes in between operation cycles to allow it to cool.

Preliminary Checks

The cranking output of the motor is affected by the condition and charge of the battery, the circuit's wiring, and the engine's cranking requirement.

The battery should be checked and charged as needed before testing the starting system. Many of the problems associated with the starting system can be solved by troubleshooting the battery and its related components.

Check the wiring and cables for clean, tight connections **(Figure 18–33)**. Loose or dirty connections will cause excessive voltage drops. Cables can be corroded by battery acid, and contact with engine parts and other metal surfaces can fray the cable insulation. Frayed insulation can cause a dead short that can seriously damage some of the electrical units of the vehicle.

Cables should also be checked to make sure they are not undersized or too long. When checking cables and wiring, always check the maxi-fuses and/or fusible links for the system. When one has failed, always troubleshoot the system and locate the cause before replacing the fuse or link.

Make certain that the engine is filled with proper weight oil as recommended by the vehicle manufacturer. Heavier-than-specified oil when coupled with low operating temperatures can drastically lower cranking speed to the point where the engine does not start and excessively high current is drawn by the starter.

Safety Precautions

Almost all starting system tests must be performed while the starter motor is cranking the engine. However, the engine must not start and run during the test or the readings will be inaccurate.

To prevent the engine from starting, the ignition switch can be bypassed with a remote starter switch that allows current to flow to the starting system but not to the rest of the electrical system. During testing, be sure the transmission is out of gear during cranking and the parking brake is set.

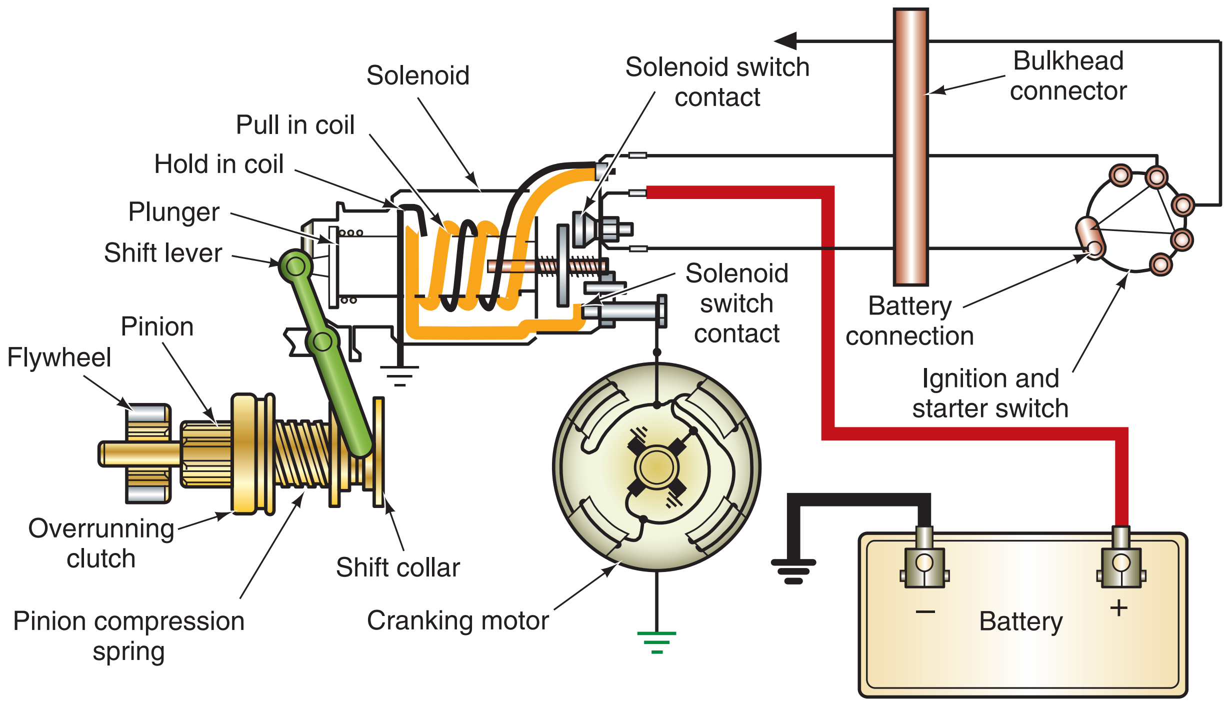


FIGURE 18-33 Excessive wear, loose connections, or unwanted resistance in any of these parts can cause slow or no cranking.

> **SHOP TALK**
> Always approach starting system diagnosis in a logical way. This is the only way to identify the exact cause of a problem. Nearly 80 percent of starters returned as defective on warranty claims work perfectly when tested. This is often caused by poor or incomplete diagnosis of the starting and related charging systems.

No-Crank Problems

A common problem is a no-crank, no-start condition. This means that when the key is turned or start button depressed to the start position, the starter motor does not engage. Use a testlight or voltmeter to check for battery voltage at the control circuit terminal on the starter solenoid during cranking. If voltage is present and the power and ground circuits to the motor are good, the solenoid or starter motor is faulty. If voltage is not present or if the voltage is low, you need to diagnose the control circuit.

Vehicles equipped with computer controlled starting systems and/or anti-theft systems may require the use of a scan tool to check the starter motor command. A no-crank condition may be the result of the anti-theft system disabling the starter motor. Ensure the safety switches are closing and note the starter command while attempting to crank the engine. If the starter is commanded ON but does not operate, check to see if voltage is supplied to the solenoid during cranking. If the starter is commanded off while attempting to crank, you need to determine why the starter is being disabled. Check the input data from the clutch, transmission range, and ignition switches to see if one is staying open.

Though not as common, it is possible that the engine won't crank because it is seized. The starter may click or clunk and try to turn the flywheel but cannot. Turn on the headlights while attempting to crank the engine. If the lights dim significantly or go out, check starter current draw or try to turn the engine with hand tools.

Starter Solenoid Problems

A typical symptom of solenoid problems is a clicking noise when the ignition switch is turned to the start position. The noise is caused by the solenoid's plunger moving back and forth. Normally the plunger moves to the battery contacts and is held there by a magnetic field until the ignition switch is moved from the start position.

In order for the solenoid's plunger to move enough to complete the starter motor circuit and remain in that position, a strong magnetic field must be present around the solenoid's windings. The strength of the magnetic field depends on the current flowing

through the windings. Therefore, anything that would reduce current flow would affect the operation of the solenoid. Common causes of the clicking are low battery voltage, low voltage available to the solenoid, or an open in the hold-in winding.

Checking voltage at the battery and to the solenoid will help you identify the cause of the problem. If the solenoid is bad, it can be replaced as a unit or with the starter motor.

Starting Safety Switches

Safety switches can be checked with a voltmeter or an ohmmeter. When the transmission is placed in park or neutral or when the clutch pedal is depressed, the switch should be closed. In other gear positions and when the clutch pedal is released, the switch should be open. On many vehicles, safety switch operation is checked with a scan tool. Locate the switch input data and check to see if the input changes as different gears are selected or the clutch pedal is depressed. Often these switches just need to be properly adjusted to correct their action. This is not possible on all vehicles. If adjustment does not correct the problem, the switch should be replaced.

Battery Load Test

A slow cranking engine is often caused by insufficient current from the battery. The battery must be able to crank the engine under all load conditions while maintaining enough voltage to supply the ignition for starting. Perform a battery load test before checking the starting systems.

GO TO Chapter 17 for the correct procedures for conducting a battery load and other battery tests.

Cranking Voltage Test

The cranking voltage test measures the available voltage to the starter during cranking. To perform the test, disable the ignition or use a remote starter switch to bypass the ignition switch. Normally, the remote starter switch leads are connected to the positive terminal of the battery and the starter or S terminal of the solenoid or relay **(Figure 18–34)**. Refer to the service information for specific instructions on the vehicle being tested. Connect the voltmeter's negative lead to a good chassis ground. Connect the positive lead to the starter motor feed at the starter relay or solenoid. Activate the starter motor and observe the voltage reading. Compare the reading to the specifications. Normally, 9.6 volts is the minimum required.

Test Conclusions If the reading is above specifications but the starter motor still cranks poorly, the starter motor may be faulty, or there may be high resistance in the motor's ground circuit. If the voltage reading is lower than specifications, a cranking current test and circuit resistance test should be performed to determine if the problem is caused by high resistance in the starter circuit or an engine problem.

Cranking Current Test

The cranking current test measures the amount of current the starter circuit draws to crank the engine. This

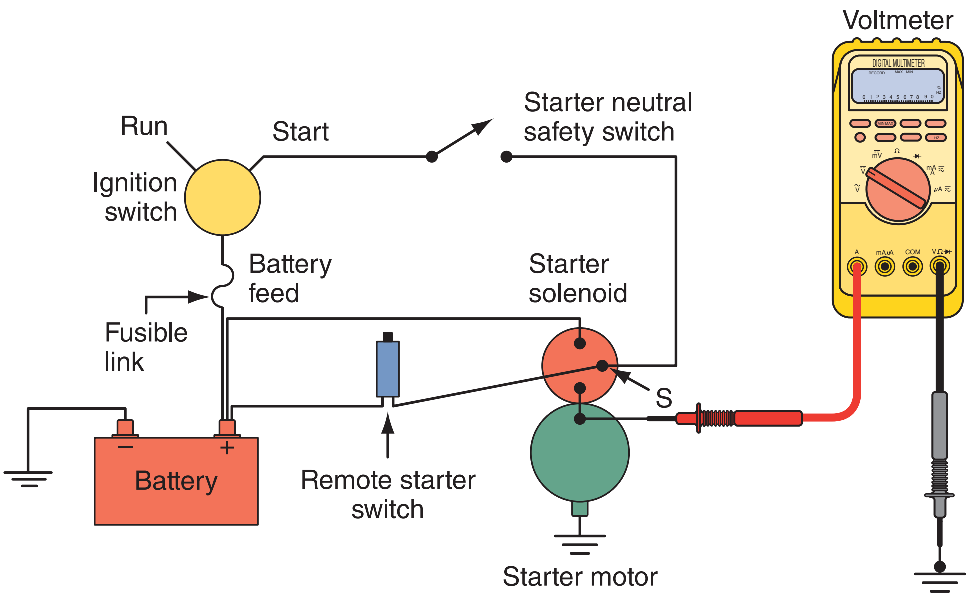


FIGURE 18–34 Using a remote starter switch to bypass the control circuit and ignition system.

SHOP TALK

Although most literatures state that cranking voltage should be at least 9.6 volts, some engines will have a difficult time starting with voltages lower than 10.2 volts. Always check the manufacturer's specifications before coming to conclusions from this test.

can be done with a VAT-type tester, DMM and current clamp, or a scope with a current clamp **(Figure 18–35)** to measure the current draw.

To conduct the cranking current test, connect a remote starter switch or disable the ignition prior to testing. Follow the instructions given with the tester when connecting the test leads. Crank the engine for no more than 15 seconds. Observe the voltmeter. If the voltage drops below 9.6 volts, a problem is indicated. Also, watch the ammeter and compare the reading to specifications. In general, cranking amperage for gasoline engines will range between 130 to 250 amps depending on engine size. Cranking current for diesel engines may reach 350 amps or more.

Table 18–1 summarizes the most probable causes of too low or high starter motor current draw. If the problem appears to be caused by excessive resistance in the system, conduct an insulated circuit resistance test.

Insulated Circuit Resistance Test

The starter circuit is made up of the insulated circuit and the ground circuit. The insulated circuit includes all of the high current cables and connections from the battery to the starter motor.

To test the insulated circuit for high resistance, disable the ignition or bypass the ignition switch with a remote starter switch. Connect the positive (+) lead of the voltmeter to the battery's positive (+) terminal post or nut. Connect the negative (–) lead of the voltmeter to the starter motor or M terminal at the solenoid or relay. Crank the engine and record the voltmeter reading. If the voltage drop is within specifications (usually 0.2 to 0.6 volts), the insulated circuit does not have excessive resistance. Proceed to the ground circuit resistance test. If the reading indicates a voltage loss above specifications, move the negative lead of the tester progressively closer to the battery, cranking the engine at each test point. Normally, a voltage drop of 0.1 volt is the maximum allowed across a length of cable.

Photo Sequence 17 goes through the correct procedure for conducting a voltage drop test on a typical starter circuit.

Test Conclusions When excessive voltage drop is observed, the trouble is located between that point and the preceding point tested. It is either a damaged cable or poor connection, an undersized wire, or possibly a bad contact assembly within the solenoid. Repair or replace any damaged wiring or faulty connections.

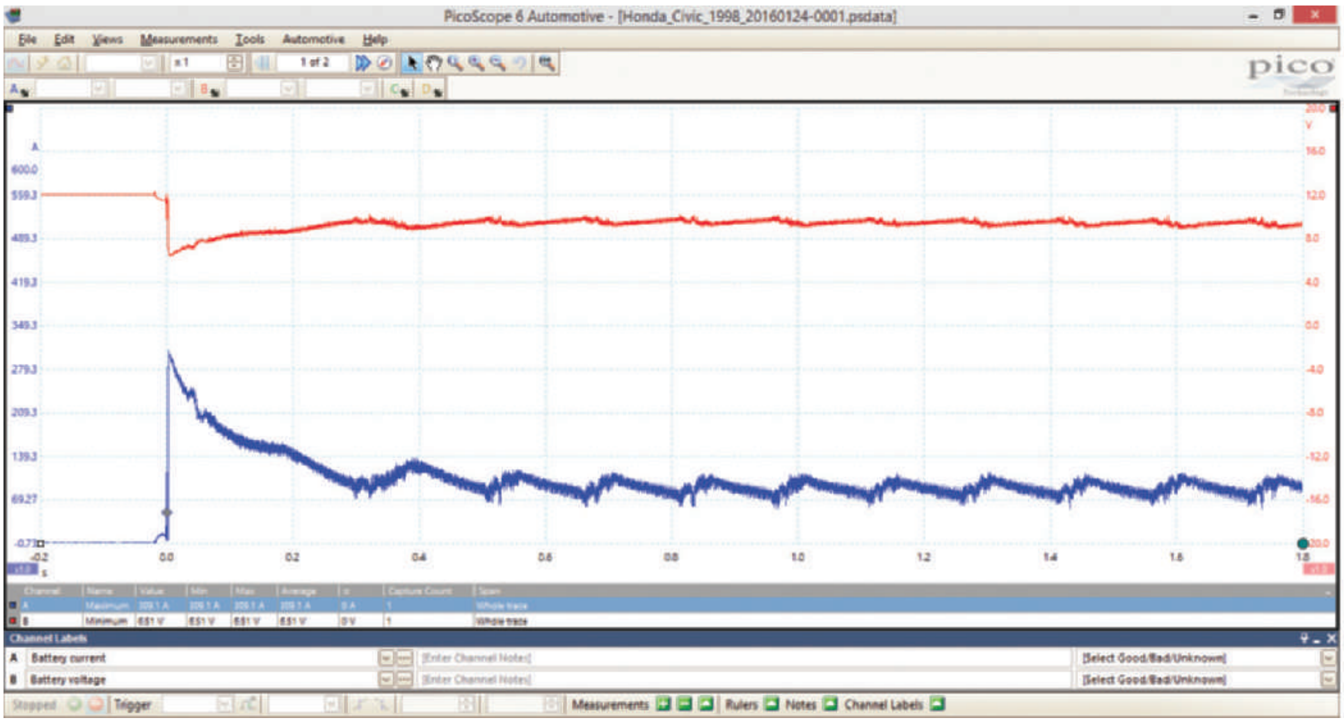


FIGURE 18-35 Using a lab scope to test cranking current and voltage.

TABLE 18–1 AVERAGE CURRENT DRAW

Engine	12-Volt Current
Four-cylinders	125 – 175 amps
Six-cylinders	150 – 200 amps
Eight-cylinders	175 – 250 amps

Concern	Probable Cause
Low current draw and low voltage	Undercharged or bad battery
Low current draw, voltage normal	Excessive resistance in the starter circuit
Low current draw, voltage normal	Excessive resistance in the starter or solenoid
Low current draw, voltage normal	Excessive resistance at the various connections to the starter and/or solenoid
High current draw, voltage normal	The starter motor is shorted
High current draw, voltage normal	A short-to-ground in the starter circuit
High current draw, voltage normal	High mechanical resistance due to engine problems
High current draw, voltage normal	Misalignment of starter drive
High current draw, voltage normal	High viscosity motor oil
High current draw, voltage normal	Cold weather

Caution! Make sure the vehicle's transmission is in park or neutral before doing this test. The starter motor can move the vehicle, which could injure you and others around you.

Starter Relay By-Pass Test

The starter relay by-pass test is a simple way to determine if the relay is operational. First, disable the ignition. Connect a heavy jumper cable between the battery's positive (+) terminal and the starter relay's starter terminal. This bypasses the relay. When the connection is made, the engine should crank.

Test Conclusions If the engine cranks with the jumper installed and did not before the relay was bypassed, the starter relay is defective and should be replaced.

Ground Circuit Resistance Test

The ground circuit provides the return path to the battery for the current supplied to the starter by the insulated circuit. This circuit includes the starter-to-engine, engine-to-chassis, and chassis-to-battery ground terminal connections.

To test the ground circuit for high resistance, disable the ignition, or bypass the ignition switch with a remote starter switch. Refer to **Figure 18–36** for the proper test connection. Crank the engine and record the voltmeter reading.

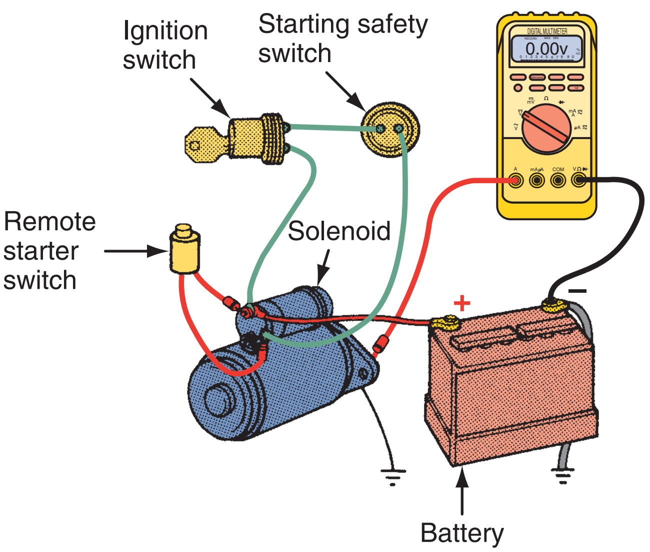


FIGURE 18–36 Setup for checking voltage drop across the ground circuit.

PHOTO SEQUENCE 17

Voltage Drop Testing of a Starter Circuit

P17-1 The tools required to measure voltage drop at various points within the starter circuit are fender covers, a DMM, and a remote starter switch. Make sure to apply the parking brake and set the transmission into neutral or park.

P17-2 Connect the meter's positive lead to the positive battery post. If at all possible, do not connect it to the battery clamp.

P17-3 Connect the negative lead to the battery connection at the starter.

P17-4 Set the voltmeter to the scale that is close to, but greater than, battery voltage.

P17-5 Disable the ignition and fuel injection and/or connect a remote starter switch.

P17-6 Crank the engine and read the voltmeter. This reading shows the voltage drop on the positive side of the starter circuit.

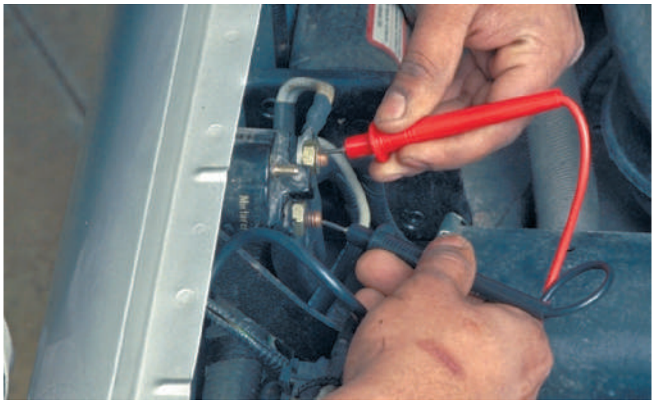
P17-7 This reading shows excessive resistance. To locate the resistance, move the meter's negative lead to the next location toward the battery. In this case it is the starter side of the starter relay.

Voltage Drop Testing of a Starter Circuit *(continued)*

P17-8 Crank the engine and observe the reading on the meter. This is the voltage drop across the positive circuit from the battery to the output of the relay.

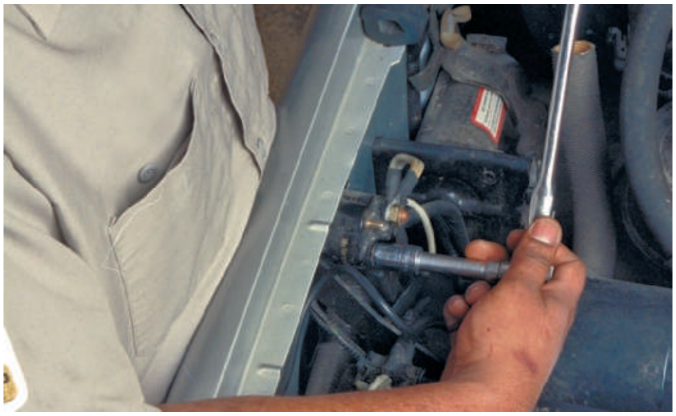
P17-9 There is still too much voltage drop; continue the test by moving the negative lead to the battery side of the relay.

P17-10 Crank the engine and observe the reading on the meter. This is the voltage drop across the cable from the battery to the relay. Notice that hardly any voltage was dropped. The cable is okay.



P17-11 Now connect the meter across the relay; the red lead on the battery side and the black lead on the starter side.

P17-12 Crank the engine and observe the reading on the meter. This is the voltage drop across the contacts inside the relay.



P17-13 The reading is higher than normal; therefore, the starter relay has high resistance and needs to be replaced.

Test Conclusions Good results would be less than a 0.2 volt drop for a 12-volt system. A voltage drop in excess of this indicates the presence of a poor ground circuit connection, resulting from a loose starter motor bolt, a poor battery ground terminal post connector, or a damaged or undersized ground system wire from the battery to the engine block. Isolate the cause of excessive voltage drop in the same manner as recommended in the insulated circuit resistance test by moving the positive (+) voltmeter lead progressively closer to the battery. If the ground circuit tests out satisfactorily and a starter problem exists, move on to the control circuit test.

Voltage Drop Test of the Control Circuit

The control circuit test examines all the wiring and components used to control the magnetic switch, whether it is a relay, a solenoid acting as a relay, or a starter motor-mounted solenoid.

High resistance in the solenoid switch circuit reduces current flow through the solenoid windings, which can cause improper functioning of the solenoid. In some cases of high resistance, it may not function at all. Improper functioning of the solenoid switch generally results in the burning of the solenoid switch contacts, causing high resistance in the starter motor circuit.

Check the vehicle wiring diagram, if possible, to identify all control circuit components. These normally include the ignition switch, safety switch, the starter solenoid winding, or a separate relay.

To perform the test, disable the ignition and/or fuel system. Connect the positive meter lead to the battery's positive terminal and the negative meter lead to the starter switch (S) terminal on the solenoid or relay. Crank the engine and record the voltmeter reading.

Test Conclusions Generally, good results would be less than 0.5 volt, indicating that the circuit condition is good. If the voltage reading exceeds 0.5 volt, it is usually an indication of excessive resistance. However, on certain vehicles, a slightly higher voltage loss may be normal.

Identify the point of high resistance by moving the negative test lead back toward the battery's positive terminal, eliminating one wire or component at a time.

A reading of more than 0.1 volt across any one wire, connector, or switch is usually an indication of trouble. If a high reading is obtained across the safety switch used on an automatic transmission, check the adjustment of the switch according to the manufacturer's service information. Most clutch-operated safety switches cannot be adjusted. They must be replaced.

Test Starter Drive Components

This test detects a slipping starter drive without removing the starter from the vehicle. First, disable the ignition system or bypass the ignition switch with a remote starter switch. Turn the ignition switch to start and hold it in this position for several seconds. Repeat the procedure at least three times to detect an intermittent condition.

Test Conclusions If the starter cranks the engine smoothly, that is an indication that the starter drive is functioning properly. If the engine stops cranking and the starter spins noisily at high speed, the drive is slipping and should be replaced.

If the drive is not slipping, but the engine is not being cranked, inspect the flywheel for missing or damaged teeth. Remove the starter from the vehicle and check its drive components. Inspect the pinion gear teeth for wear and damage. Test the overrunning clutch mechanism. If good, the overrunning clutch should turn freely in one direction but not in the other. A bad clutch will turn freely in the overrun direction or not at all. If a drive locks up, it can destroy the starter by allowing the starter to spin at more than 15 times engine speed.

Removing the Starter Motor

If your testing indicates that the starter must be removed, the first step is to disconnect the negative cable at the battery and wrap the clamp with electrical tape. It may be necessary to place the vehicle on a lift to gain access to the starter. Before lifting the vehicle, disconnect all wires, fasteners, and so on that can be reached from under the hood.

Disconnect the wires leading to the solenoid terminals. To avoid confusion when reinstalling the starter, it is wise to mark the wires so they can be reinstalled on their correct terminals.

On some vehicles you may need to disconnect the exhaust system to be able to remove the starter. Loosen the starter mounting bolts and remove all but one. Support the starter while removing the remaining bolt. Then pull the starter out and away from the flywheel. Once the starter is free, remove the last bolt and the starter.

You may need to remove the intake manifold to replace the starter. On some four-cylinder engines, the intake can be unbolted and moved out of the way to gain access to the starter motor. On some V-type engines, the intake manifolds must be removed.

Once the starter is out, inspect the starter drive pinion gear and the flywheel ring gear **(Figure 18–37)**. When the teeth of the starter drive are abnormally worn, make sure you inspect the entire circumference of the flywheel. If the starter drive or the flywheel ring gear show signs of wear or damage, they must be replaced.

Free Speed (No-Load) Test

Many manufacturers do not provide in-vehicle cranking amperage specifications, only no-load specifications. This is because in-vehicle current draw is affected by the battery, battery cables and connections, and engine condition. To accurately test starter motor current draw, the starter is removed and bench tested. No-load current draw is typically between 60 and 80 amps, though refer to the manufacturers' service information for actual specifications.

Every starter should be bench tested after it is removed and before it is installed. To conduct a free speed or no-load test on a starter **(Figure 18–38)**, follow these steps:

If the current draw was excessive or the motor speed too low, there is excessive physical resistance—which can be caused by worn bushings or bearings—or a bent armature. Excessive current draw can also be caused by a shorted armature or shorted field windings.

If there was no current draw and the starter did not rotate, the problem could be caused by a faulty solenoid, open field windings, open armature coils, broken brushes, or broken brush springs.

Low armature speed with low current draw indicates excessive resistance. There may be a poor connection between the commutator and the brushes, or the connections to the starter are bad. If the speed and current draw are both high, check for a shorted field winding.

Installation

When installing a new or remanufactured starter, sand away the paint at the mounting points before installing it. Also, make sure you have a good hold on the starter while installing it. Tighten the retaining bolts to the specified torque and make sure the starter is fully

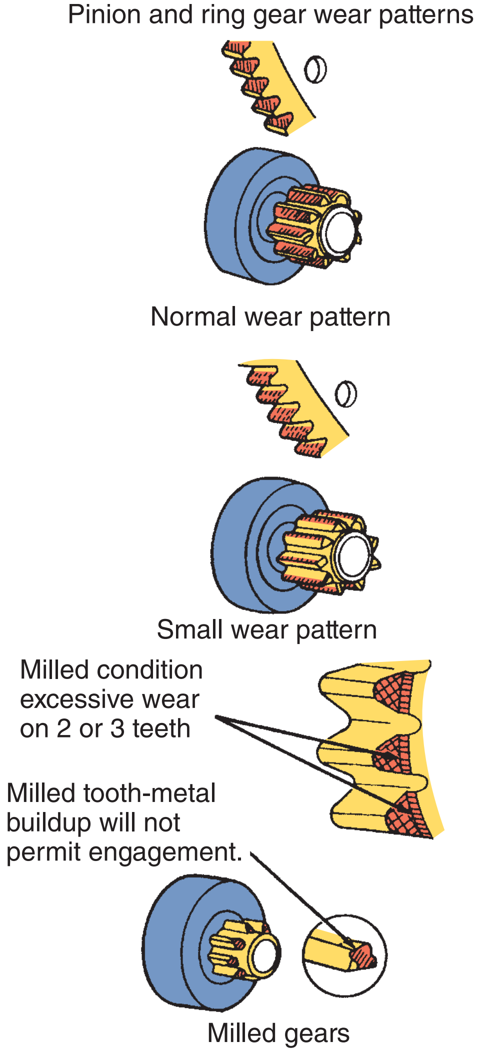


FIGURE 18–37 Starter drive and flywheel ring gear wear patterns.

PROCEDURE

Free Speed or No-Load Test

STEP 1 Clamp the starter firmly in a bench vise.

STEP 2 Connect an ammeter to the battery cable and the starter to a battery. This should cause the motor to run.

STEP 3 Check current draw and motor speed and compare them to specifications. If they meet specifications when the battery has at least 11.5 volts, the starter is working properly.

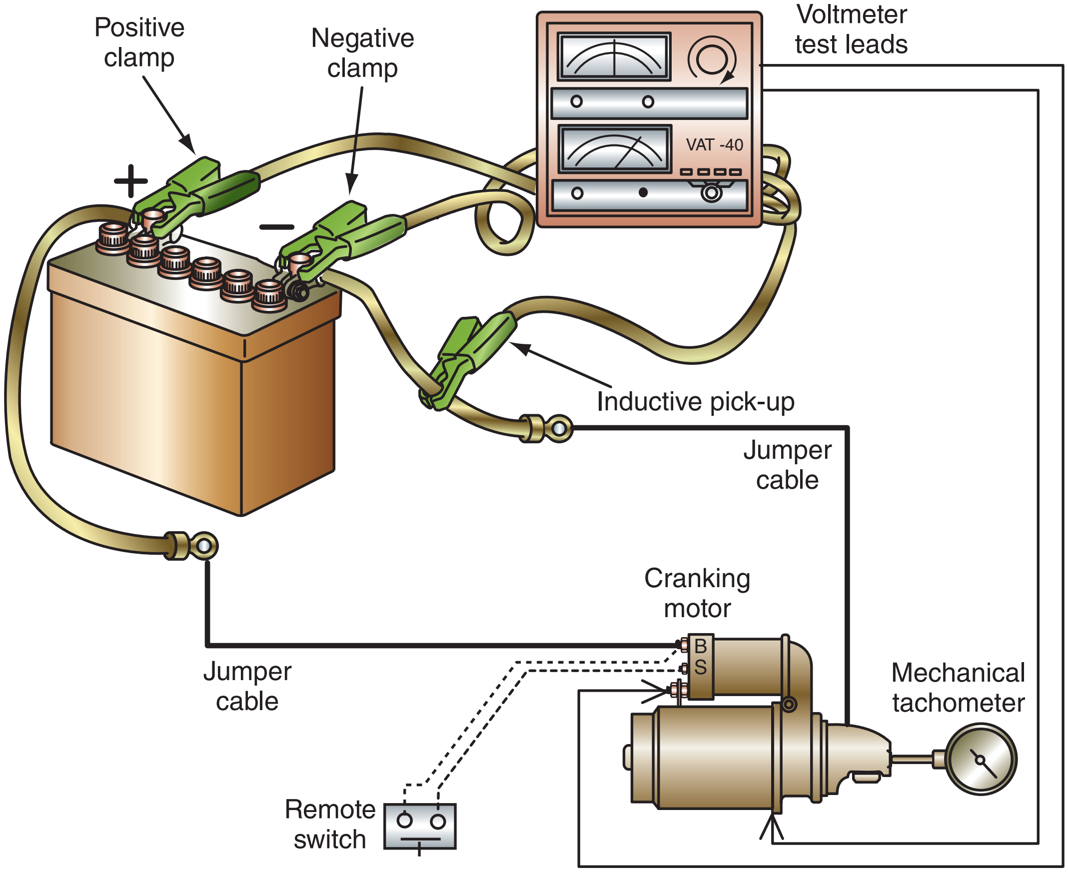


FIGURE 18–38 Basic setup for conducting a no-load test on a starter motor.

seated before final tightening. Undertorquing the starter may allow the bolts to work loose, which can cause the starter nose to crack and break. Also, make sure that all electrical connections are tight. If the starter was installed with heat shields, make sure they are in place before tightening the bolts.

Some starters use shims between the starter and the mounting pad **(Figure 18–39)**. To check this clearance, install the starter and insert a flat blade screwdriver into the access slot on the side of the drive housing. Pry the drive pinion gear into the engaged position. Use a wire feeler gauge or a piece of 0.020–inch diameter wire to check the clearance between the gears **(Figure 18–40)**.

If the clearance between the two gears is incorrect, shims will need to be added or subtracted to bring the clearance within specs. If the clearance is excessive, the starter will produce a high-pitched whine while it is cranking the engine. If the clearance is too small, the starter will make a high-pitched whine after the engine starts and the ignition switch is returned to the RUN position.

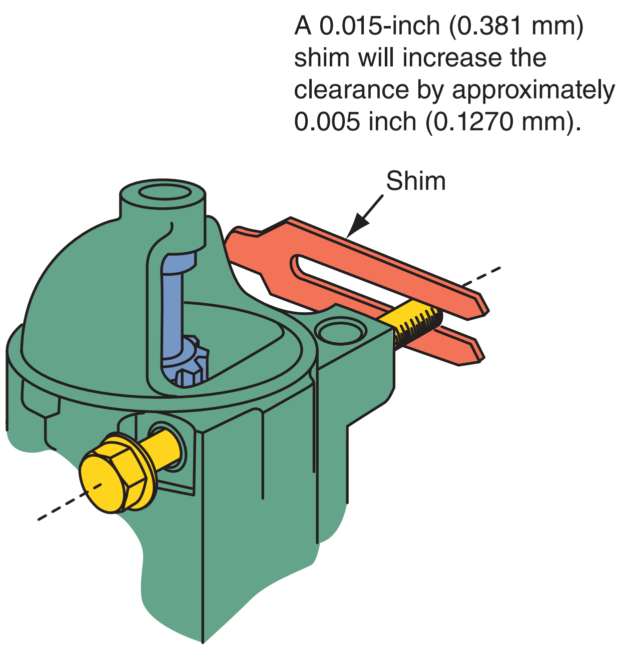


FIGURE 18–39 Shimming the starter to obtain proper pinion-to-ring gear clearance.

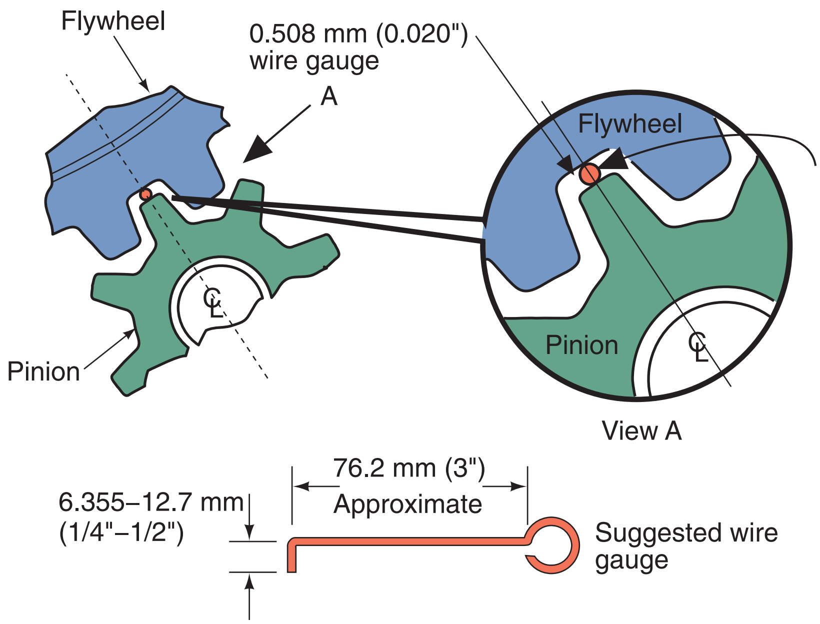


FIGURE 18–40 Checking the clearance between the pinion gear and the ring gear.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2008	**Make:** Toyota	**Model:** Corolla	**Mileage:** 149,051	**RO:** 16225
Concern:	Car towed-in. Customer states engine doesn't crank when key is turned.			
The technician confirms the engine does not crank when the key is in the START position. The battery passes a load test and battery voltage is present at the starter's M terminal when attempting to crank the engine.				
Cause:	Found starter motor not functioning.			
Correction:	Replaced starter motor and solenoid. Starting system operating normally.			

KEY TERMS

Armature
Commutator
Compound motors
Counter EMF (CEMF)
Field coils
Flux density
Flux field
Neutral safety switch
Pinion gear
Reluctance
Series motor
Starter frame
Starter relay

SUMMARY

- Current flowing through a wire creates a magnetic field around the wire. Moving a wire through a magnetic field creates current flow in the wire.
- A magnetic field, called a flux field, exists around every magnet.
- The magnetic polarity of an electromagnet depends on the direction of current flow through the loop.
- The strength of the field around an electromagnet increases if current through the coil increases, the number of coil turns increases, and the reluctance decreases.
- The basic parts of a motor are the stator or field windings, which are the stationary parts of the

motor, and the rotor or armature, which is the rotating part.

- A starting motor is a special type of electric motor designed to operate under great electrical loads and to produce great amounts of torque for short periods.
- All starting motors have a housing, field coils (windings), an armature, a commutator with brushes, and end frames.
- The amount of torque from a starting motor depends on its current draw, which is controlled by CEMF.
- The starting system has two distinct electrical circuits: the starter motor circuit and the control circuit.
- The starter circuit carries high current flow from the battery through heavy cables to the starter motor.
- The control circuit uses a small amount of current to operate a magnetic switch that opens and closes the starter circuit.
- The ignition switch is used to control current flow in the control circuit.
- Solenoids and relays are the two types of magnetic switches used in starting systems. Solenoids use electromagnetic force to pull a plunger into a coil to close the contact points. Relays use a hinged armature to open and close the circuit.
- The drive mechanism of the starter motor engages and turns the flywheel to crank the engine for starting.
- An overrunning clutch protects the starter motor from spinning too fast once the vehicle engine starts.
- Starting safety switches prevent the starting system from operating when the transmission is engaged.
- Battery load, cranking voltage, cranking current, insulated circuit resistance, starter relay bypass, ground circuit resistance, control circuit, and drive component tests are all used to troubleshoot the starting system.
- With the starter removed, inspect the starter drive pinion gear and the flywheel ring gear.

REVIEW QUESTIONS

Short Answer

1. Explain the purpose of the field windings in an electric motor.
2. Briefly explain counter EMF and how it relates to motor operation.
3. The part of the armature that the brushes ride on is called the ___.
4. Describe how to perform a starter bench test.

True or False

1. *True or False?* The strength of the magnetic field in an electromagnet increases with an increase in the number of turns of wire and the current flowing through them.
2. *True or False?* Worn armature bearings can result in higher than normal starter cranking current draw.

Multiple Choice

1. Which of the following is *not* part of the starter motor circuit?
   a. Battery
   b. Starting safety switch
   c. Starter motor
   d. Relay solenoid
2. Which of the following tests would *not* be performed to check for high resistance in the battery cables?
   a. Cranking voltage test
   b. Insulated circuit resistance test
   c. Starter relay by-pass test
   d. Ground circuit resistance test
3. When the starter spins but does not crank the engine, which of the following may be true?
   a. Defective starter relay
   b. Damaged flywheel teeth
   c. A faulty starter solenoid
   d. All of the above
4. If the solenoid just clicks while trying to crank the engine with the starter, which of the following is *not* a probable cause?
   a. A faulty neutral safety switch
   b. Low battery voltage
   c. Low voltage available to the solenoid
   d. An open in the hold-in winding
5. The normal minimal cranking voltage specification is approximately ___.
   a. 9.6 volts
   b. 10.5 volts
   c. 11.0 volts
   d. 12.65 volts

6. If a ground circuit test reveals a voltage drop of more than 0.2 volt, the problem may be ___.
   a. a loose starter motor mounting bolt
   b. a poor battery ground terminal post connector
   c. a damaged battery ground cable
   d. all of the above
7. Which of the following would *not* cause excessive current draw by the starter motor?
   a. A short in the motor
   b. High resistance in the armature
   c. Using oil that is too heavy in the engine
   d. Very cold weather
8. The device that prevents the engine from turning the armature of the starter motor is the ___.
   a. overrunning clutch
   b. pinion gear
   c. flywheel
   d. pole shoe
9. A control circuit voltage drop test shows a 1.1 volt drop at the starter S terminal. Which of the following could be the cause?
   a. High resistance in the solenoid switch circuit
   b. High resistance in the clutch safety switch
   c. Loose battery cable connection
   d. Short in the starter armature windings

ASE-STYLE REVIEW QUESTIONS

1. An engine cranks slowly: Technician A says that a possible cause of the problem is poor starter circuit connections. Technician B says that an engine problem could be the cause. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. While discussing auto start-stop systems: Technician A says special starters are used that allow for quicker engine restarts. Technician B says both the starters and generators are different on vehicles with this system. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. Pinion gear-to-flywheel ring gear clearance is being discussed: Technician A says that if there is too much clearance, there will be a high pitch whine while the engine cranks. Technician B says that if there is too little clearance, there will be a high pitch noise after the engine is started. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. Technician A says that a starter no-load test is conducted with the starter in a bench vise. Technician B says that the no-load test is used to determine starter motor circuit voltage drop. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Cranking current is excessive but is normal when the starter is bench tested: Technician A says the problem could be with the positive battery connection to the solenoid. Technician B says there could be an engine mechanical problem. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. Technician A says that the purpose of the starter relay is to complete the circuit from the battery to the starter motor. Technician B says that the purpose of the solenoid is to complete the circuit from the battery to the starter motor. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. When diagnosing a no-crank no-start condition, no voltage is present at the S terminal of the solenoid while attempting to crank the engine. Technician A says a faulty starter motor is the cause. Technician B says a shorted safety switch is the cause. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

8. While discussing a no-crank condition: Technician A says to verify the condition of the battery before testing the starter motor. Technician B says a scan tool may be used to check starter control circuit operation. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. While discussing DC starting motors: Technician A says that the armature may be wired in series with the field coils. Technician B says that the field coils may be wired parallel with the armature. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While discussing electric motors: Technician A says that when there is high CEMF, there will be high current flow. Technician B says that if the reluctance of an electromagnet increases, its field strength increases. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER 19

CHARGING SYSTEMS

OBJECTIVES

- Explain the purpose of the charging system.
- Identify the major components of the charging system.
- Explain the purposes of the major parts of an AC generator.
- Explain half- and full-wave rectification and how they relate to AC generator operation.
- Identify the different types of AC voltage regulators.
- Describe the two types of stator windings.
- Explain the features enabled by the use of a starter/generator unit.
- Perform charging system inspection and testing procedures using electrical test equipment.

The primary purpose of a charging system is to recharge the battery. After the battery has supplied the high current needed to start the engine, the battery, even a good battery, has a low charge. The charging system recharges the battery by supplying a constant and relatively low charge to the battery. Charging systems work on the principles of magnetism and change mechanical energy into electrical energy. This is done by inducing voltage.

Voltage is induced in a wire when it moves through a magnetic field. The wire or conductor becomes a source of electricity and has a polarity or distinct positive and negative ends. However, this polarity can be switched depending on the relative direction of movement between the wire and magnetic field **(Figure 19–1)**. This is why an AC generator produces alternating current **(Figure 19–2)**.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2007	**Make:** Toyota	**Model:** Camry	**Mileage:** 113,874	**RO:** 17401
Concern:	Customer had to jump start engine and the car is making strange, loud, howling sounds with the engine running.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

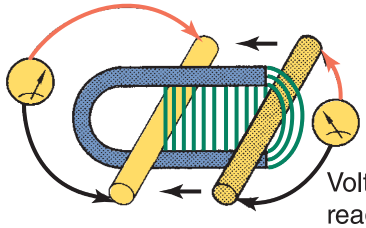


FIGURE 19–1 Moving a conductor so it cuts across the magnetic lines of force induces a voltage in the conductor.

FIGURE 19–2 An AC generator.

Alternating Current Charging Systems

During cranking, the battery supplies all of the vehicle's electrical power. However, once the engine is running, the charging system is responsible for producing enough energy to meet the demands of the loads in the electrical system while also recharging the battery.

Several decades ago the charging system depended on a DC generator. The DC generator **(Figure 19–3)** provided direct current (DC) and was similar to an electric motor in construction. The biggest difference between a generator and a motor is the wiring to the armature. In a motor, the armature receives current from the battery. This creates the magnetic field that opposes the magnetic fields in the motor's coils, which causes the armature to rotate. The armature in a DC generator is driven by the engine. It is not magnetized and the windings simply rotate through the stationary magnetic field of the field windings, inducing a voltage in the conductors inside the armature. A motor can become a generator by allowing current to flow from the armature instead of to it. In a DC generator, the placement of the brushes on the commutator changes the induced AC voltage to a DC voltage output.

> **SHOP TALK**
>
> With the implementation of OBD II, new terminology was given to many parts of an automobile. Prior to that law, an AC generator was called an **alternator.** In fact, in many cases an AC generator is still referred to as an alternator. To avoid confusion, just remember that an alternator is an AC generator and vice versa.

DC generators had a very limited current output, especially at low speeds and were replaced by AC generators. AC generators are capable of providing high current output even at low engine speeds.

In an AC generator **(Figure 19–4)**, a spinning magnetic field (called the rotor) rotates inside an assembly of stationary conductors (called the stator). As the spinning north and south poles of the magnetic field pass the conductors, they induce a voltage that first flows in one direction and then in the opposite direction (AC voltage). Because automobiles use DC voltage, the AC must be changed or rectified into DC. This is done through an arrangement of diodes that are placed between the output of the windings and the output to the battery.

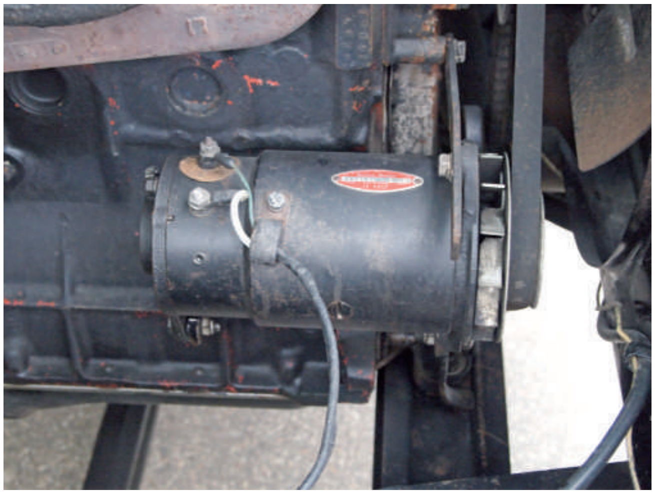


FIGURE 19–3 A DC generator.

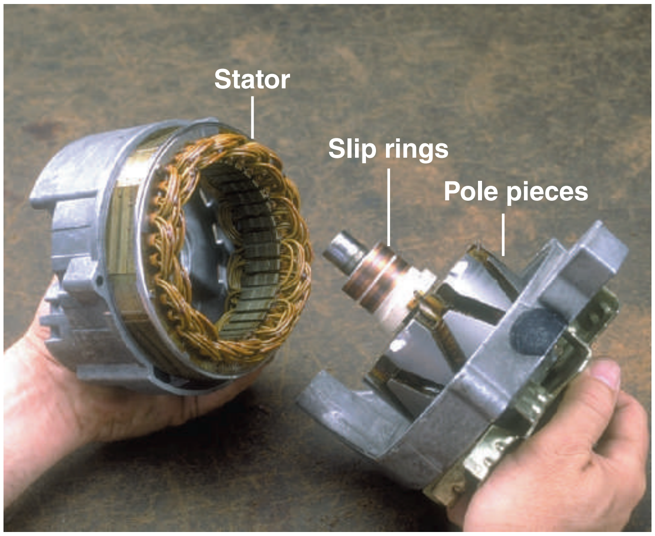


FIGURE 19-4 The pole pieces of the rotor rotate within the stator.

AC Generator Construction

Rotor The rotor assembly is a shaft with a coil and two pole pieces **(Figure 19–5)**. A pulley mounted on one end of the shaft allows the rotor to be spun by a belt driven by the engine.

The **rotor** is a rotating magnetic field inside the alternator. The field coil is simply a long length of insulated wire wrapped around an iron core. The core is located between the two sets of pole pieces. A magnetic field is formed by a small amount (4.0 to 6.5 amperes) of current passing through the coil winding. As current flows through the coil, the core is magnetized and the pole pieces assume the magnetic polarity of the end of the core that they touch. Thus, one pole piece has a north polarity and the other has a south polarity. The extensions of the pole pieces, known as fingers, form the actual magnetic poles. A typical rotor has fourteen poles, seven north and seven south, with the magnetic field between the pole pieces moving from the N poles to the adjacent S poles **(Figure 19–6)**.

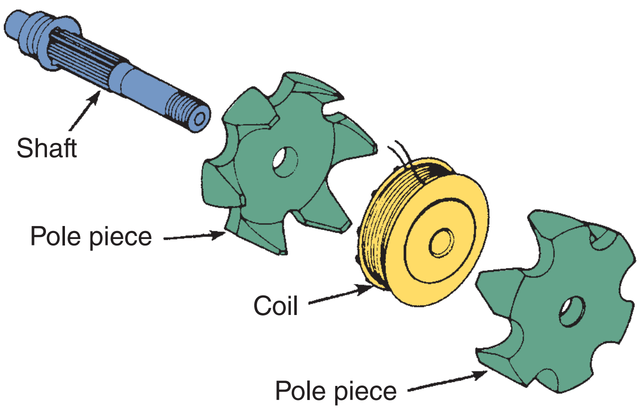


FIGURE 19-5 The rotor is made up of a coil, pole pieces, and a shaft.

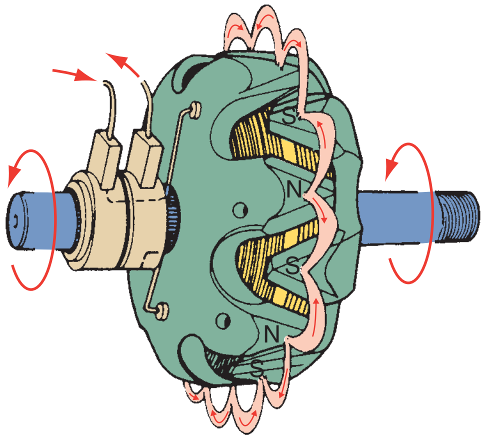


FIGURE 19-6 The magnetic field moves from the N poles, or fingers, to the S poles.

Overrunning and Decoupling Alternator Pulleys

Many late-model vehicles have generators equipped with an overrunning clutch pulley. Overrunning alternator pulleys (OAPs), also called overrunning clutch pulleys, were developed to reduce the noise and vibrations caused by the conventional belt and pulley drive system for a generator (alternator). With solid drive pulleys, changes in engine speed are absorbed by the drive belt and tensioning pulley. This causes increased wear on both the belt and tensioner and causes excessive vibration in the belt drive system. The use of an OAP allows the alternator to be driven normally and to coast when engine speed decreases. This reduces the load on the drive belt and tensioner.

Decoupling pulleys, also called alternator decoupler pulleys or overrunning alternator decoupler (OAD) pulleys, have an additional spring in addition to using a one-way clutch. The spring allows the pulley to absorb torsional vibrations in the pulley and not affect the speed of the driveshaft in the alternator. The clutch allows the pulley to rotate in only one direction. With a solid drive pulley, as the engine's speed is quickly increasing and decreasing, the generator's rotational inertia works against the drive belt. This increases the load on the belt and increases vibration and wear on the system. By using an OAD, under engine acceleration and cruising conditions, the alternator is driven by the belt and OAD. When the engine decelerates, the alternator can freewheel. This reduces the forces against the drive belt and tensioner. The use of the additional spring reduces or eliminates vibrations caused by the accelerating and decelerating crankshaft.

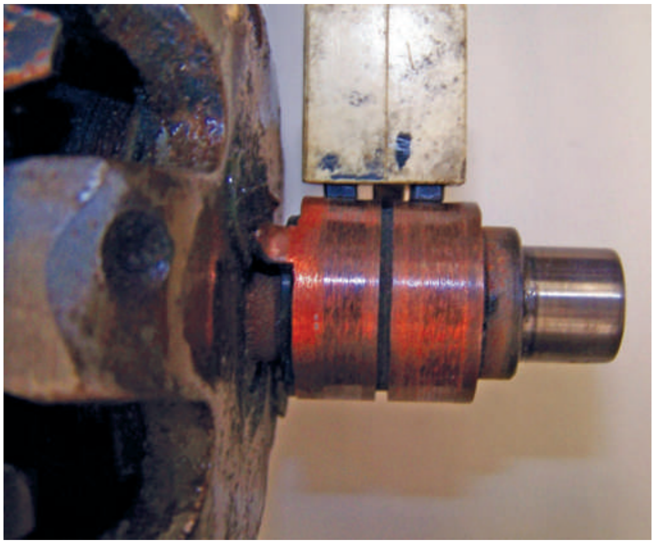


FIGURE 19–7 The brushes ride on the slip rings.

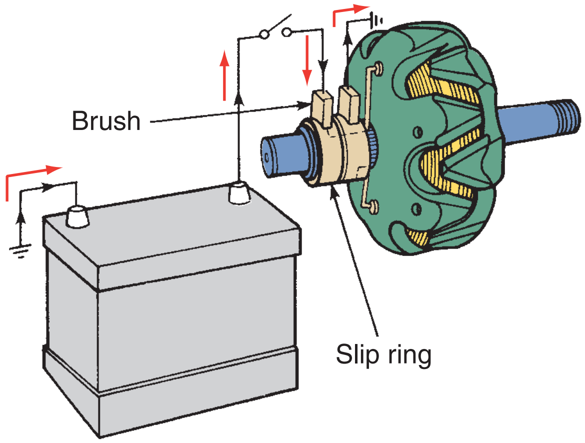


FIGURE 19–8 Current is carried by the brushes to the rotor windings via the slip rings.

Slip Rings and Brushes The **slip rings** and brushes **(Figure 19–7)** conduct current to the spinning rotor. Most AC generators have two slip rings mounted directly on the rotor shaft. They are insulated from the shaft and each other. Each end of the **field coil** connects to one of the slip rings. A carbon brush located on each slip ring carries the current to the field coil. Current is transmitted from the field terminal of the voltage regulator through the first brush and slip ring to the field coil. Current passes through the field coil and the second slip ring and brush before returning to ground **(Figure 19–8)**.

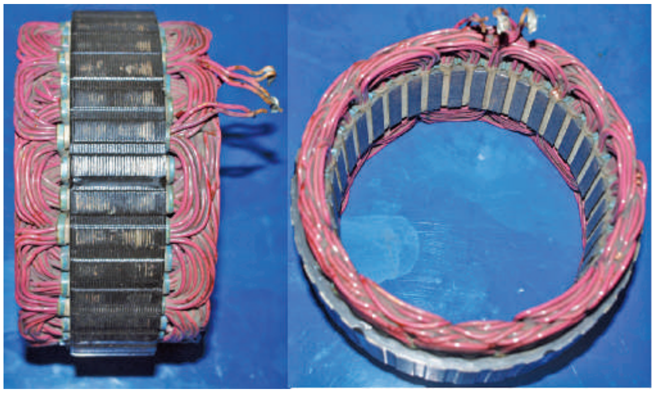


FIGURE 19–9 A typical stator winding.

Stator The **stator** is the stationary member of the generator **(Figure 19–9)**. It is made up of a number of conductors, or wires, into which the voltage is induced. Most AC generators use three windings to generate the required amperage output. Each stator winding acts as an individual generator and produces one-third of the total generator output. They can be arranged in either a delta configuration or a wye configuration **(Figure 19–10)**. The **delta**

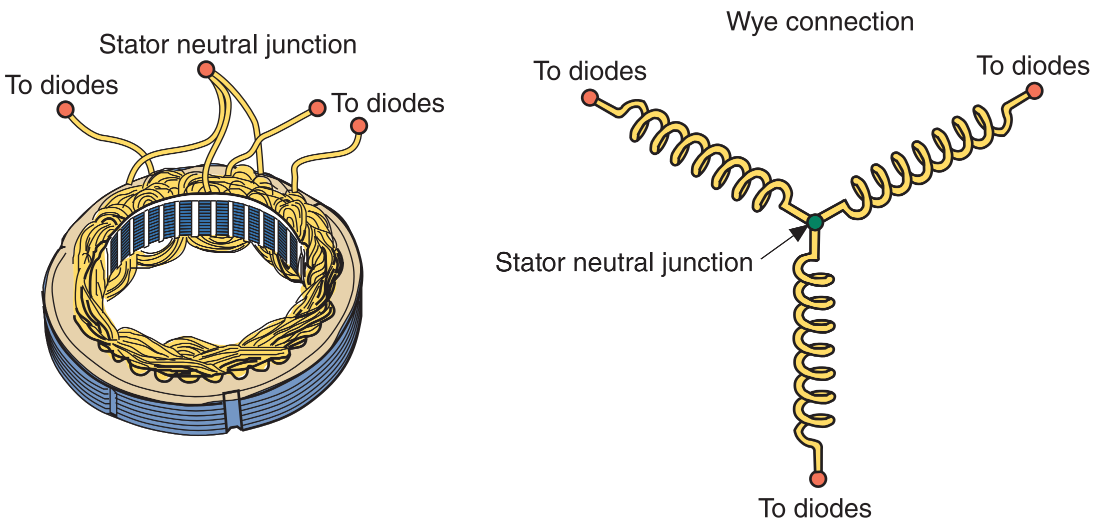


FIGURE 19–10 A wye-connected stator winding.

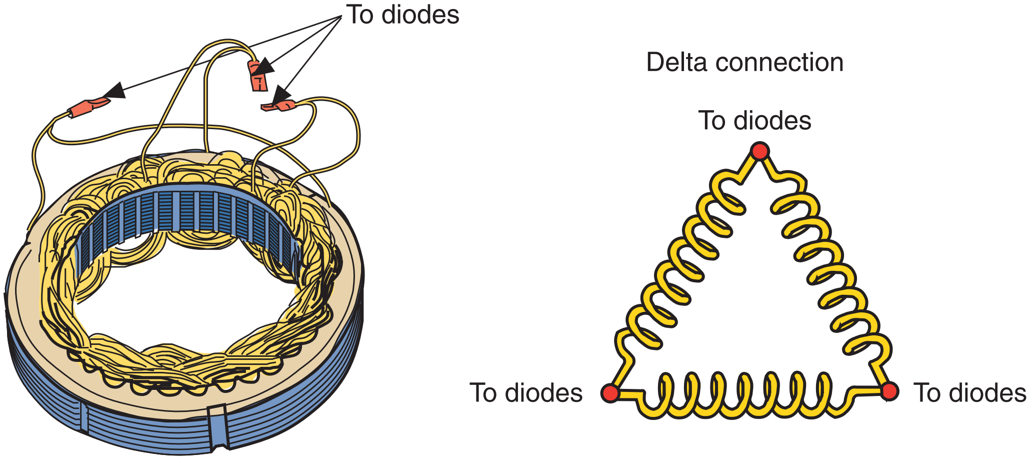


FIGURE 19–11 A delta-connected stator winding.

winding (Figure 19–11) received its name because its shape resembles the Greek letter delta, Δ. The **wye winding** resembles the letter *Y*. Normally, a wye winding is used in applications in which high charging voltage at low engine speeds is required. AC generators with delta windings are capable of putting out higher amperages at high speeds but low engine speed output is poor.

The rotor rotates inside the stator. A small air gap between the two allows the rotor to turn without making contact with the stator **(Figure 19–12)**.

Alternating current produces positive and negative pulses. The resultant waveform is a sine wave, which shows the voltage changing from positive to negative. Basically as the rotor spins inside the stator, the voltage starts at zero, goes positive, and then drops back to zero before turning negative. A single loop of wire energized by a single north then a south pole result in a single-phase voltage. Remember that there are three overlapping stator windings. This produces overlapping sine waves **(Figure 19–13)** or **three-phase voltage**.

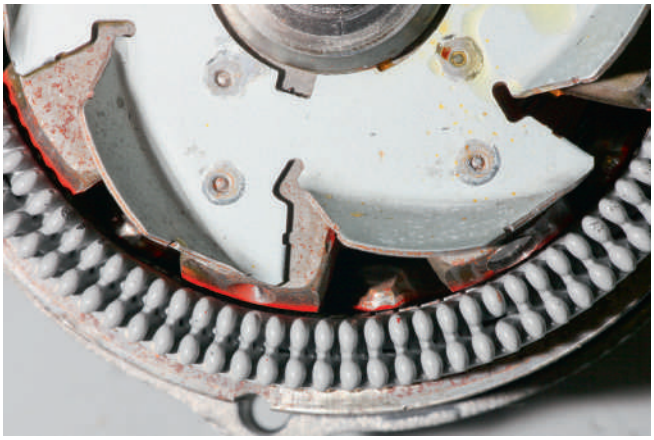


FIGURE 19–12 A small air gap exists between the rotor and the stator.

End Frame Assembly The end frame assembly, or housing, contains the bearings for the rotor shaft. Each end frame also has built-in ducts so the air from the rotor shaft fan can pass through the AC generator. Normally, a heat sink containing three positive rectifier diodes is attached to the rear end frame. Heat can pass easily from these diodes to the moving air **(Figure 19–14)**. The housing may also contain the voltage regulator. The end frames are bolted together and then bolted directly to the engine, therefore the end frame assembly is part of the ground. This means that anything connected to the housing that is not insulated from the housing is grounded.

Cooling Fans

Behind the drive pulley on most AC generators is a cooling fan that rotates with the rotor. This cooling fan draws air into the housing through the openings at the rear of the housing. The air leaves through openings behind the cooling fan **(Figure 19–15)**. The moving air pulls heat from the diodes and their heat decreases.

Cooling the diodes is important for the efficiency and durability of an AC generator. Several generator designs have been introduced recently that increase the cooling efficiency of a generator. One of these is the AD-series generator from General Motors. The "A" stands for air cooled and the "D" means dual fans. This series is lighter than most other generators but capable of very high outputs. This type of generator does not have an external fan; instead, it has two internal fans.

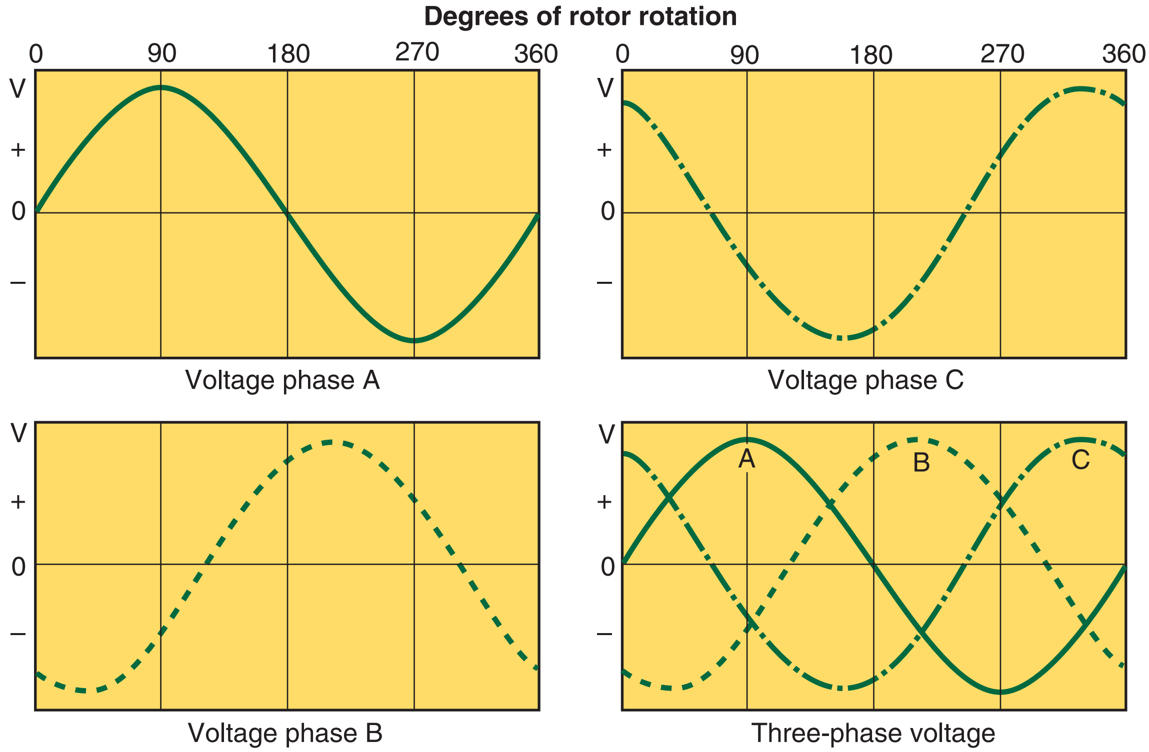


FIGURE 19–13 The voltage produced in each stator winding is added together to create a three-phase voltage.

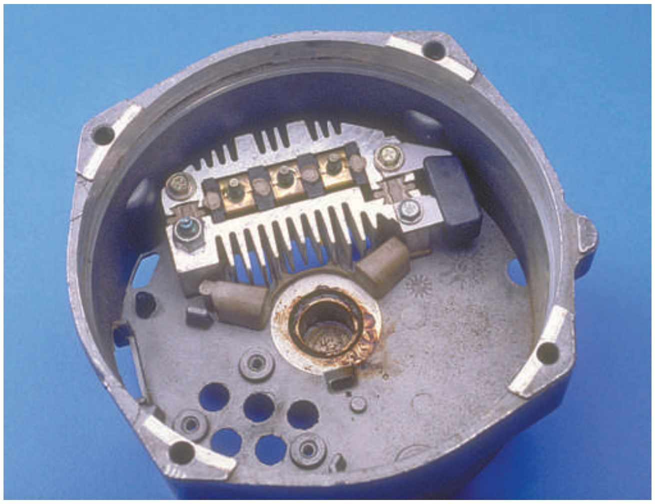


FIGURE 19–14 A bridge rectifier mounted in the end frame.

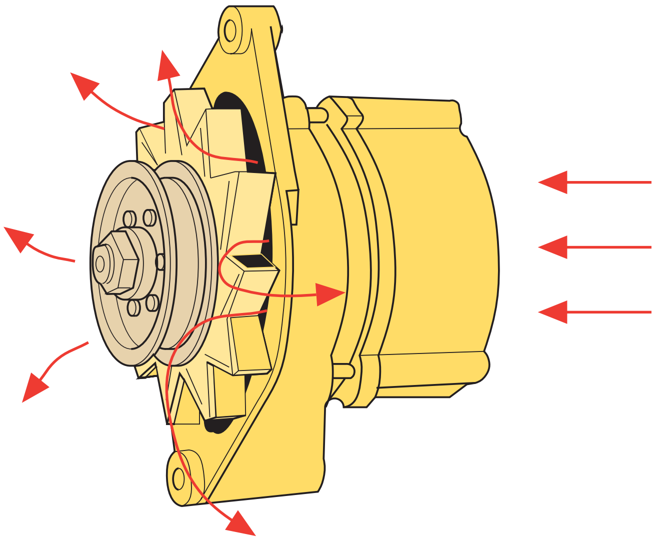


FIGURE 19–15 The cooling fan draws air in from the rear of the generator to keep the diodes cool.

Liquid-Cooled Generators Another recent design uses liquid cooling **(Figure 19–16)**. Using water or coolant to cool a generator is a very efficient way to keep the temperatures of the generator and its sensitive electronics down. But the primary reason for eliminating the fan and using liquid to cool the generator is to reduce noise. The rotating fan is a source of underhood noise that some automobile manufacturers want to eliminate. Also at higher outputs, the rotating fan is a load on the engine as it moves the surrounding air. These generators have water jackets cast into the housing. Hoses connect the housing to the engine's cooling system. Not only do these generators make less noise, they have higher power output and should last longer in the high-temperature environment of the engine compartment.

Liquid cooled generators may have a static field coil that eliminates the need for brushes and slip rings. The field coil is set in the center of the generator. The pole fingers, driven by the pulley, rotate

FIGURE 19–16 A water-cooled AC generator.

between the stationary field coil and the stationary stator winding. The fingers of rotor cut through the magnetic field of the field coil and the stator. This induces a voltage in the stator.

AC Generator Operation

AC generators produce alternating current that must be converted, or rectified, to DC. This is accomplished by passing the AC through diodes.

Diodes

A **diode** allows current to flow in one direction but not in the opposite direction. Current flow is in the direction indicated by the triangle in its schematical drawing. Therefore, it can function as a switch, acting as either conductor or insulator, depending on the direction of current flow. In an AC generator, current is rectified (changed from AC to DC) through the use of diodes. The diodes are arranged so that current can leave the generator in one direction only (as DC).

A variation of the diode is the zener diode. This device functions like a standard diode until a certain voltage is reached. When the voltage level reaches this point, the zener diode allows current to flow in the reverse direction. Zener diodes are often used in electronic voltage regulators.

DC Rectification

Figure 19–17 shows that when AC passes through a diode, the negative pulses are blocked off to produce the scope pattern shown. Because the diode is wired so that the positive side of the diode is connected to the positive side of the load, the negative

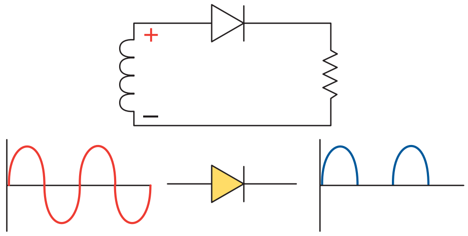


FIGURE 19–17 Half-wave rectification, diode positively biased.

AC pulses are blocked. If the diode is reversed, it blocks off current during the positive pulse and allows the negative pulse to flow **(Figure 19–18)**. Because only half of the AC current pulses (either the positive or the negative) is able to pass, this is called **half-wave rectification**.

By adding more diodes to the circuit, more of the AC is rectified. When all of the AC is rectified, **full-wave rectification** occurs.

Full-wave rectification requires another circuit with similar characteristics. **Figure 19–19** shows a wye stator with two diodes attached to each winding. One diode is insulated, or positive, and the other is grounded, or negative. The center of the Y contains a common point for all windings. It can have a connection attached to it. It is called the stator neutral junction. At any time during the rotor movement,

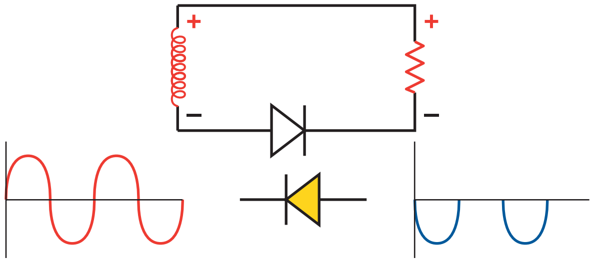


FIGURE 19–18 Half-wave rectification, diode negatively biased.

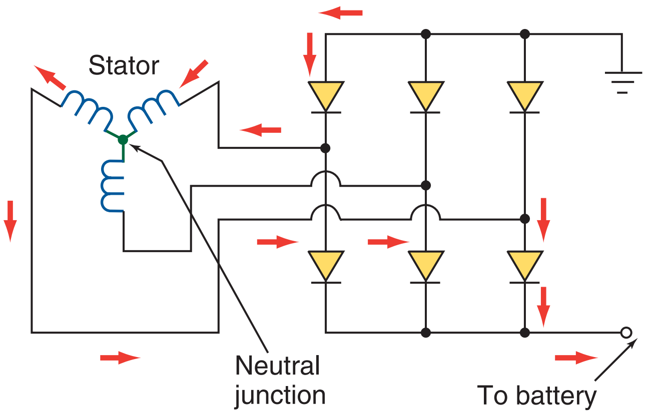


FIGURE 19–19 A wye stator wired to six diodes.

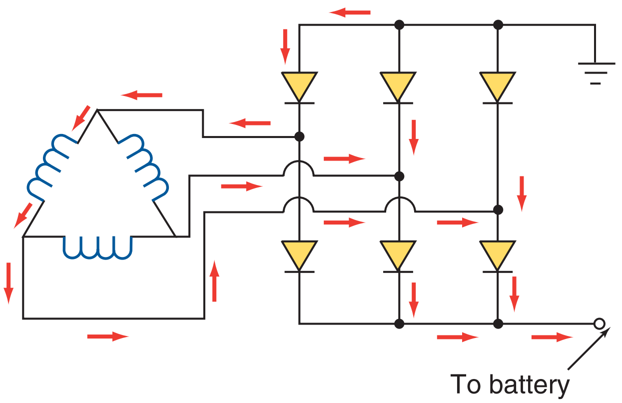


FIGURE 19-20 A delta stator wired to six diodes.

two windings are in series and the third coil is neutral and inactive. As the rotor revolves, it energizes the different sets of windings in different directions.

The diode action does not change when the stator and diodes are wired in a delta pattern. **Figure 19–20** shows the major difference. Instead of having two windings in series, the windings are in parallel. Thus, more current is available because the parallel paths allow more current to flow through the diodes. Nevertheless, the action of the diodes remains the same.

Many AC generators have an additional set of three diodes called the diode trio. The diode trio is used to rectify current from the stator so that it can be used to create the magnetic field in the rotor. Using the diode trio eliminates extra wiring. To control generator output, a voltage regulator regulates the current from the diode trio and to the rotor **(Figure 19–21)**.

Factors Controlling Generator Output

Several factors determine the total output available from a generator other than the type of stator winding. These include:

- The rotational speed of the rotor. Higher speeds can lead to higher output.
- The number of windings in the rotor. Increased windings will increase output.
- The current flow through the rotor windings. Increased current through the rotor will increase output.
- The number of windings in the stator. An increase in the number of windings will increase output.

Voltage Regulation

Current to create the magnetic field is supplied to the rotor winding from one of two sources: the battery or the AC generator itself. In either case, the current is passed through the AC generator's voltage regulator before it is applied to the winding. The **voltage regulator** varies the amount of current supplied. By controlling the amount of resistance in series with the field coil, control of the field current and voltage output is obtained.

Increasing field current through the rotor winding increases the strength of the magnetic field. This, in turn, increases AC generator voltage output. Decreasing the field current to the winding has the opposite effect. Output voltage decreases.

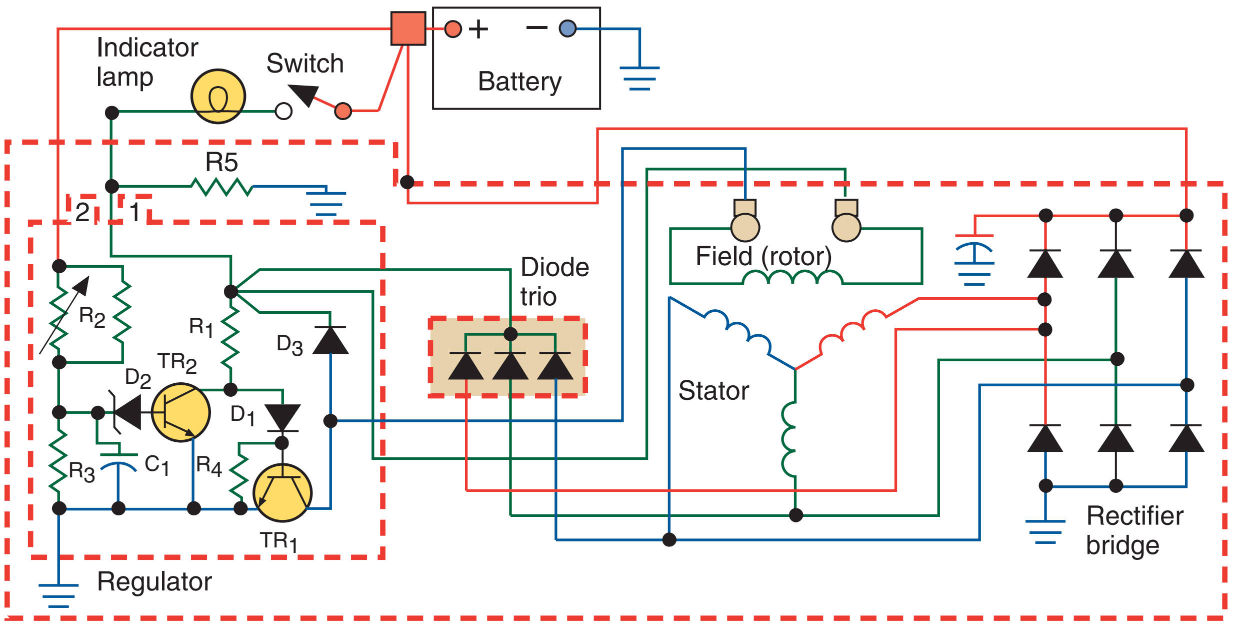


FIGURE 19-21 Wiring diagram of a charging circuit with a diode trio.

Performance TIP

Often owners will change the size of the generator's pulley to decrease the drag on the engine and, therefore, increase the engine's power output. Although the generator will spin at a lower speed, it also will have a lower output. Because the system will respond to the lower output by sending more current to the rotor, the magnetic field will be stronger and that alone will create more drag on the engine. Making the decision to change a generator pulley should be done only after much thought. If the battery is fully charged, there will be a net increase in engine output. If the battery is low on charge, there may be no gain at all.

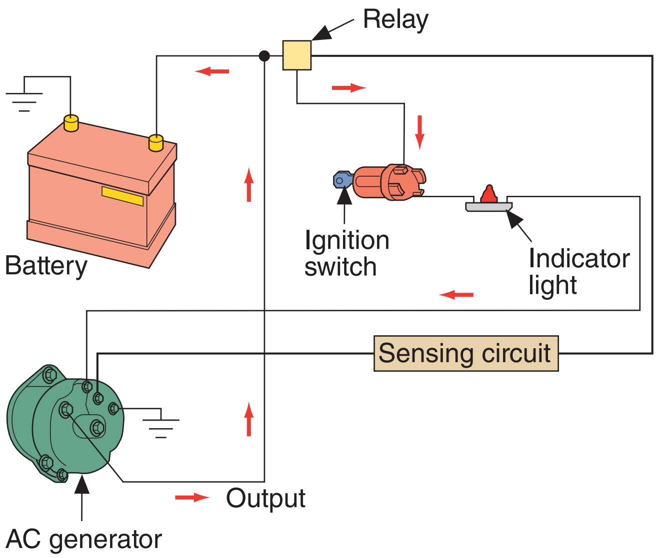


FIGURE 19–22 The voltage regulator adjusts the generator's output according to the voltage on the sensing circuit.

The output from an AC generator can reach as high as 250 volts if it is not controlled. The battery and the electrical system must be protected from this excessive voltage. Therefore, charging systems use a voltage regulator to control the generator's output. To ensure that the battery stays fully charged, most regulators are set for a system voltage between 14 and 14.5 volts.

Older vehicles were equipped with electromechanical regulators, whereas newer vehicles have an electronic regulator. Most newer vehicles do not have a separate voltage regulator; rather, they control charging system output through the PCM.

An input signal, called the **sensing voltage**, allows the regulator to monitor system voltage **(Figure 19–22)**. If the sensing voltage is below the regulator setting, an increase in field current is allowed, which causes an increase in voltage output. Higher sensing voltage will result in a decrease in field current and voltage output. The regulator will reduce the charging voltage until it is at a level to operate the various systems while putting a low charge on the battery. If a heavy load is turned on, such as the headlights, the additional draw will cause a decrease in battery voltage. The regulator will sense the low voltage and will increase current to the rotor. When the load is turned off, the regulator senses the rise in system voltage and reduces the field current.

Another input that affects voltage regulation is temperature. Because ambient temperature influences the rate of charge that a battery can accept, regulators are temperature compensated. Temperature compensation is required because the battery is more reluctant to accept a charge at lower ambient temperatures. The regulator will increase the voltage output to force a charge on the battery.

Field Circuits

A regulator controls field current and is connected in one of three ways to the rotor. These are called field circuits. The A-circuit has the regulator on the ground side of the field coil. The battery feed (B+) for the field coil is picked up inside the AC generator. By placing the regulator on the ground side of the field coil, the regulator controls field current by varying the current flow to ground.

The second type of field circuit is the B-circuit. The voltage regulator controls the power side of the field circuit. The field coil is grounded inside the AC generator. Normally the B-circuit regulator is mounted outside the generator.

The third type of field circuit is called the isolated field. This generator has two field wires attached to the outside of the case. One wire is the ground; the other is the B+. The voltage regulator can be placed on the ground or the B+ side of the circuit.

The relationship between the field current, rotor speed, and regulated voltage is shown in **Figure 19–23**.

Electronic Regulators

Electronic regulators can be mounted outside the generator or be an integral part of the AC generator **(Figure 19–24)**. Voltage output is controlled through the ground side of the field circuit (A-circuit control). Most electronic regulators have a zener diode that

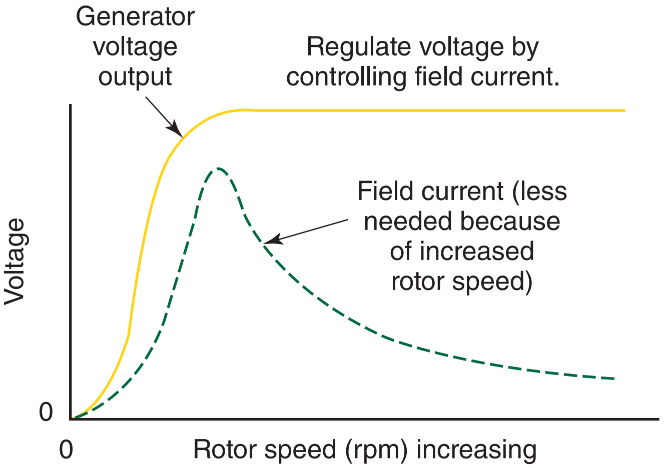


FIGURE 19–23 A graph showing the relationship between field current, rotor speed, and regulated voltage.

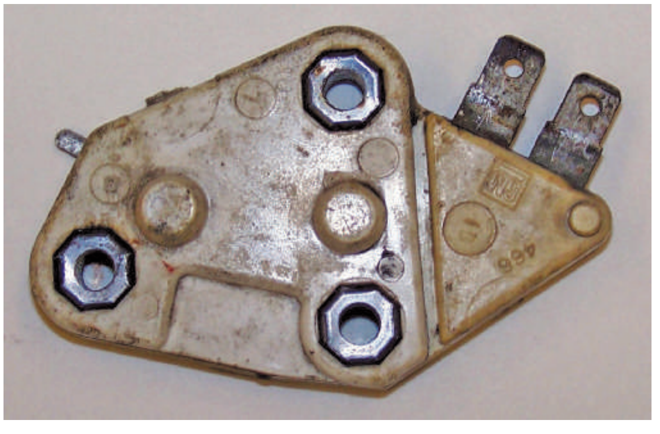


FIGURE 19–24 An integrated voltage regulator.

blocks current flow until a specific voltage is obtained, at which point it allows the current to flow. The schematic for an electronic voltage regulator with a zener diode is shown in **Figure 19–25**.

The generator's output is controlled by pulse width modulation. This varies the amount of time the field

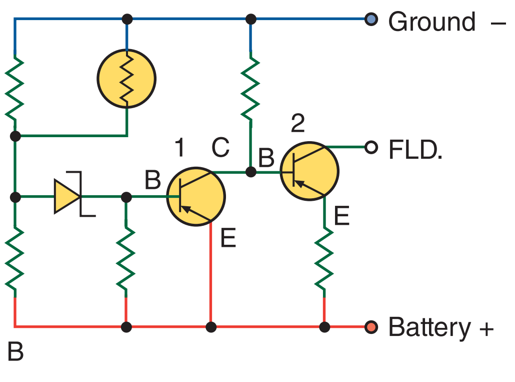


FIGURE 19–25 A simplified circuit of an electronic regulator with a zener diode.

coil is energized in response to the vehicle's needs. For example, assume that a vehicle is equipped with a 100-ampere generator. If the electrical demand placed on the charging system requires 50 amps, the regulator would energize the field coil for 50 percent of the time. If the electrical system's demand were increased to 75 amps, the regulator would energize the field coil 75 percent of the cycle time.

Integrated circuit voltage regulators are used in many vehicles. These compact units are mounted either inside or on the back of the AC generator. Integrated circuit regulators are nonserviceable and must be replaced if defective.

Fail-Safe Circuits To prevent simple electrical problems from causing high-voltage outputs that can damage delicate electronic components, many voltage regulators have **fail-safe circuits**.

If connections to the AC generator become corroded or accidentally disconnected, the regulator's fail-safe circuits may limit voltage output to prevent high-charging voltages. Under certain conditions, the fail-safe circuit may prevent the AC generator from charging at all. A fusible link or maxi-fuse in the fail-safe circuitry prevents high current from leaving the charging system and damaging the delicate electronic components in other vehicle systems.

Computer Regulation

Late-model vehicles do not have a separate voltage regulator. Instead voltage regulation is one of the many functions of the vehicle's PCM. The computer is used to control current to the field windings in the rotor. The PCM looks at the input from several sensors in order to provide the correct charging output **(Figure 19–26)**.

This type of system switches or pulses field current on and off at a fixed frequency of about 400 cycles per second. A significant feature of this system is its ability to vary the amount of voltage according to vehicle requirements and ambient temperatures. This precise control allows the use of smaller, lighter storage batteries. It also reduces the magnetic drag of the AC generator, increasing engine output by several horsepower. Precise management of the charging rate also results in increased gas mileage.

The part of the PCM that controls charging output is typically called the power management system **(Figure 19–27)**. This system not only controls the field current, it also causes the engine's idle speed to increase when the battery is low and sends diagnostic messages to alert the driver of possible

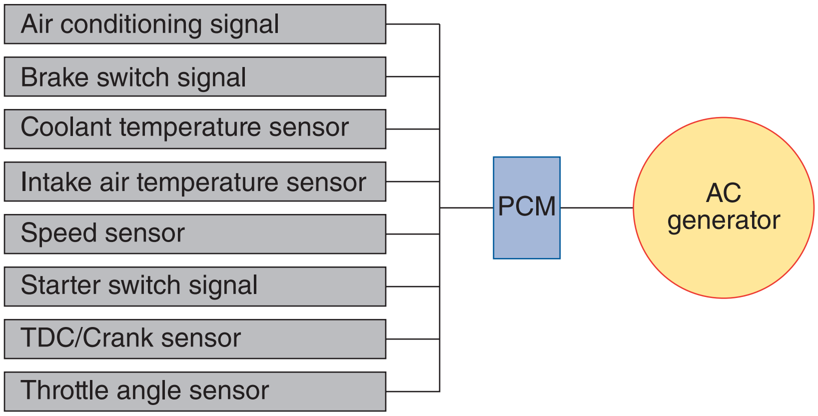


FIGURE 19-26 The PCM uses various inputs to regulate the output of an AC generator.

battery and generator problems. The condition of the battery is monitored with the ignition off and when it is on.

When the ignition is off, the battery's state-of-charge (SOC) is monitored by open-circuit voltage. Engine-off SOC is used as an indicator of the battery's condition. When the engine is running, the system continuously estimates SOC based on temperature, battery capacity, the initial SOC, and the charging system's output.

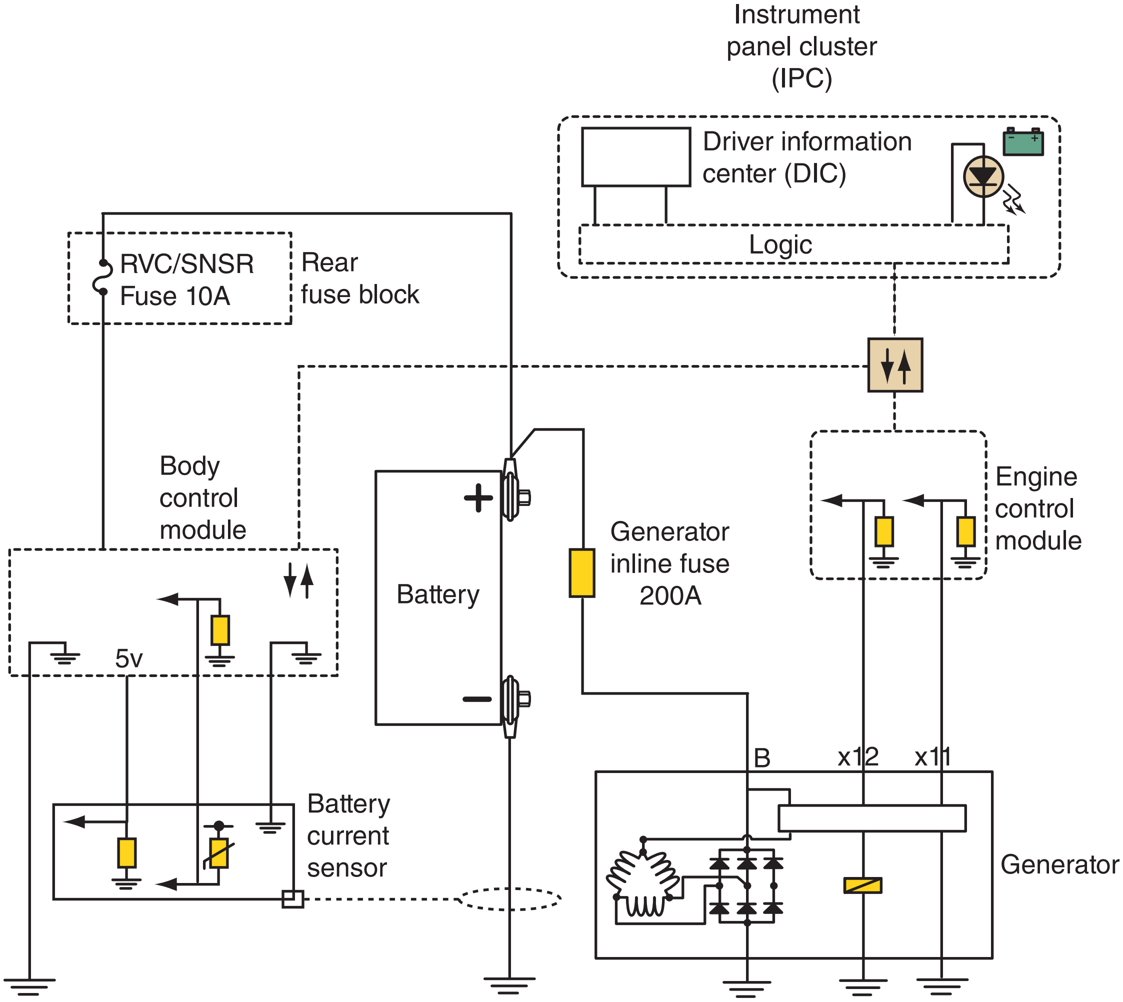


FIGURE 19-27 The main circuit for a PCM-controlled charging system.

Current Trends

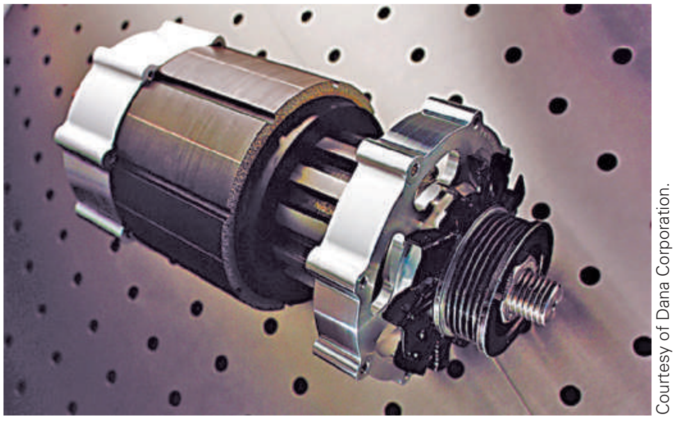
In the quest to improve fuel economy, decrease emission levels, and make vehicles more reliable, engineers have applied advanced electronics to starters and generators.

Motor/Generators

Keep in mind that the main difference between a generator and a motor is that a motor has two magnetic fields that oppose each other, whereas a generator has one magnetic field and wires are moved through that field. Using electronics to control the current to and from the battery, a generator can also work as a motor. These units are called starter/generators or motor/generators. The construction of a motor/generator may be based on two sets of windings and brushes, a brushless design with a permanent magnet, or switched reluctance **(Figure 19–28)**.

SHOP TALK

Although not commonly used today in automobiles, switched reluctance motors are common in other industries. Without going into great detail into their operation, the basics should be understood for the future. This design has a toothed stator and rotor and the rotor has no windings or magnets. The stator has slots containing a series of coil windings. A controller establishes a rotating magnetic field around the stator as it activates one coil set in the stator at one time. The timing of this activation is based on the position of the rotor. When one coil is energized, a magnetic field is formed around it. The rotor tooth that is closest to the magnetic field moves toward that field. When the tooth is close, current is switched to another stator winding and the tooth moves to it. As the current is sent to the consecutively placed windings, the rotor rotates.



Courtesy of Dana Corporation.

FIGURE 19–28 A switched reluctance motor/generator. Note the design of the rotor.

A motor/generator can be mounted externally to the engine and connected to the crankshaft by a drive belt. Belt-driven motor/generators have a belt tensioner that is mechanically or electrically controlled to allow it to drive or be driven by the engine's crankshaft **(Figure 19–29)**. One system uses an electromagnetic clutch fitted to the crankshaft pulley. The clutch is engaged to allow the motor/generator to work as a generator or as a starter

FIGURE 19–29 A belt-driven alternator starter (BAS) assembly.

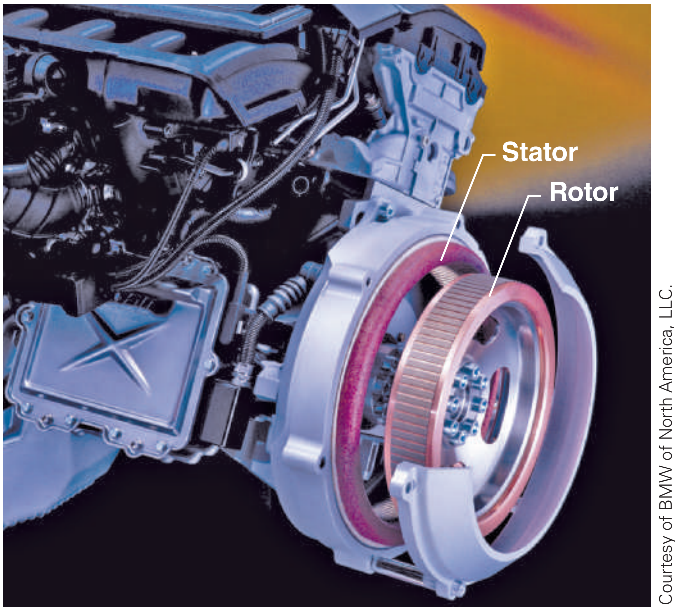


FIGURE 19–30 An integrated motor/generator assembly built into the flywheel.

motor. When the engine is stopped, the crank pulley clutch disengages. Motor/generators can also be directly mounted to the crankshaft between the engine and transmission or integrated into the flywheel **(Figure 19–30)**. The most common hybrid vehicles have two motor/generators: one that serves as the engine starting motor and a generator and the other as a traction motor and generator.

Motor/generators are capable of high charging outputs and can crank the engine at high speeds. They also allow for other features that make the vehicle more efficient (Figure 19–30):

- Stop-start
- Regenerative braking
- Electrical assist

Caution! Always adhere to the precautions given by the manufacturer when working on or near high-voltage motor/generators and their related systems. Being careless can cause serious injuries, including death.

Regenerative Braking

When the brakes are applied in a conventional vehicle, friction at the wheel brakes converts the vehicle's kinetic energy into heat. With regenerative braking, that energy is used to recharge the batteries. The vehicle's kinetic energy is changed to electrical energy until the vehicle is stopped **(Figure 19–31)**. At that point, there is no kinetic energy. Through electronic controls, the motor/generator functions as a generator. The rotor is driven by the engine, which is driven by the vehicle's wheels, as the vehicle is slowing down. The amount of energy captured by regenerative braking depends on many things, such as the SOC of the battery and the speed at which the generator's rotor is spinning.

Regenerative braking not only recharges the battery pack, but the load of turning the generator's rotor helps slow and stop the vehicle. Regenerative braking is not used to completely stop the vehicle. A combination of conventional hydraulic brakes and regenerative braking is used. Hydraulic, friction-based brakes must be used when sudden and hard braking is needed. Regenerative braking systems are not a physical part of the brake system.

The system's controller regulates how fast the kinetic energy is converted, and thus regulates how fast braking will occur. The controller receives a signal from the brake pedal and other sensors. Based on programs, the controller determines the amount

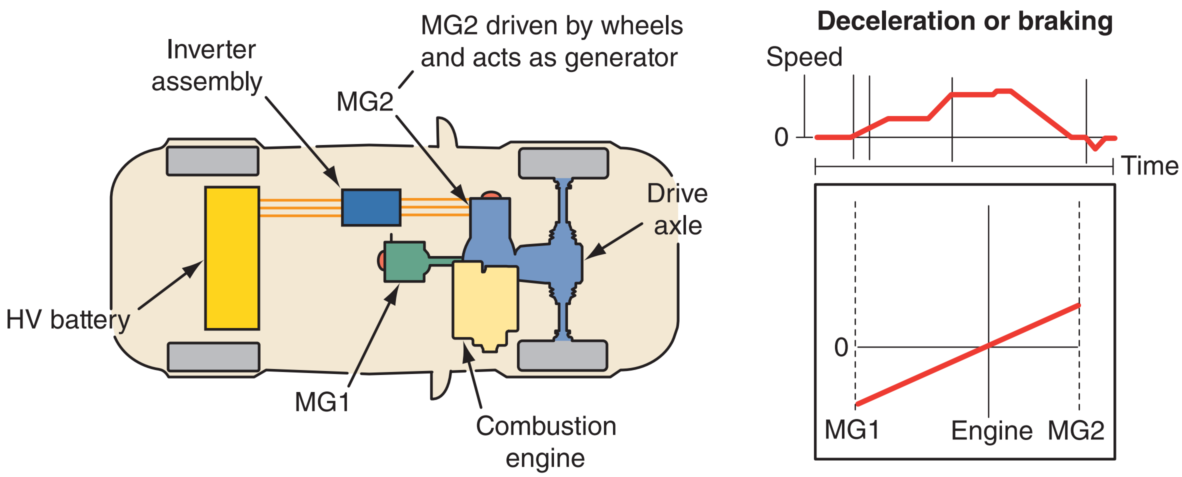


FIGURE 19–31 The power flow for a hybrid with two motors/generators during brake regeneration.

of regenerative and hydraulic braking needed. Regenerative braking works better when the generator's rotor spins fast. It works poorly at low speed; therefore, the controller must base the amount of regenerative braking on the vehicle's speed and the pressure applied to the brake pedal. The controller must also apply the regenerative braking smoothly so the vehicle does not jerk when it is engaged.

Regenerative braking is found on all hybrid vehicles. It can capture approximately 30 percent of the energy normally lost during braking in conventional vehicles. It is claimed that the electric energy resulting from regenerative braking supplies 20 percent of the energy used by a Toyota Prius. Regenerative braking also decreases brake wear and reduces maintenance costs.

Non-hybrid vehicles are also utilizing regenerative braking. Mazda's i-ELOOP system uses a large capacitor to store energy to run the electrical system. During normal driving, the generator freewheels and does not power the electrical system. When the driver lifts off the accelerator pedal, the generator turns on. Because of the constant surging of generator output, the electricity is stored in a capacitor. The electricity is then used to power the vehicle's electrical system. Generator output can vary between 12 volts and 25 volts depending on conditions.

Suspension Movement AC Generation

Recently many developments have been made to generate electricity from other systems that automobiles and trucks are equipped with. Regenerative braking is quite common in hybrid and electrical vehicles; but another source of electricity is the movement of the suspension. The motion of the car moving up and down can be used to generate electricity. This technology relies on electromechanical shock absorbers replacing the hydraulic units used in nearly all suspensions.

To accomplish AC generation, the wheel support is fitted with an arm that is connected to a gear assembly that changes the up and down movement of the wheel into a rotating motion, which in turn drives a generator.

Electric Vehicle and Plug-In Hybrid Electric Vehicles

Charging an electric vehicle (EV) or a plug-in hybrid electric vehicle (PHEV) requires a charging station. Dealerships that sell EVs or PHEVs often have at least one charging station **(Figure 19–32)**. A 2017

FIGURE 19–32 An EV charging station at a new car dealership.

study estimates that there are over 16,000 public charging stations in the United States. Tesla currently owns and operates over 1000 Supercharger stations across the North America and thousands of stations are installed in private homes, many of which are available for shared use with the EV community.

There are several types of charging in use, which are as follows:

- Level 1 charging uses a standard 120-volt household wall outlet **(Figure 19–33)**. EVs and PHEVs come with the equipment to charge from

FIGURE 19–33 Level 1 charging can be done anywhere a 120-volt outlet is available.

a 120-volt source. To fully charge a battery it may take 8 to 12 hours or more depending on battery capacity.

- Level 2 charging requires 240-volt AC service **(Figure 19–34)**. These typically use a single-phase 30 or 40-amp circuit. Charging may take 4 to 6 hours.
- Level 3 CHAdeMO or DC fast charging uses 480-volt DC chargers that can provide an 80 percent charge in 30 minutes. Level 3 capability is not available for all vehicles.
- Level 3 Supercharger for Tesla vehicles are proprietary charging stations that use 480-volts. As of late 2017, Tesla has over 1,000 Supercharger stations across North America with more being added.

Regardless of the type of system used, the plug and charger work with the vehicle's onboard computer network to control charging. Communication between the charging station, the plug, and the onboard charger are required to initiate and maintain current flow. The Level 1 and 2 plugs have five pins, two for AC charging, one ground, and two for proximity detection and CAN communication. The CHAdeMO has 10 pins, two for carrying current, one ground, one not assigned, and six for communication **(Figure 19–35)**.

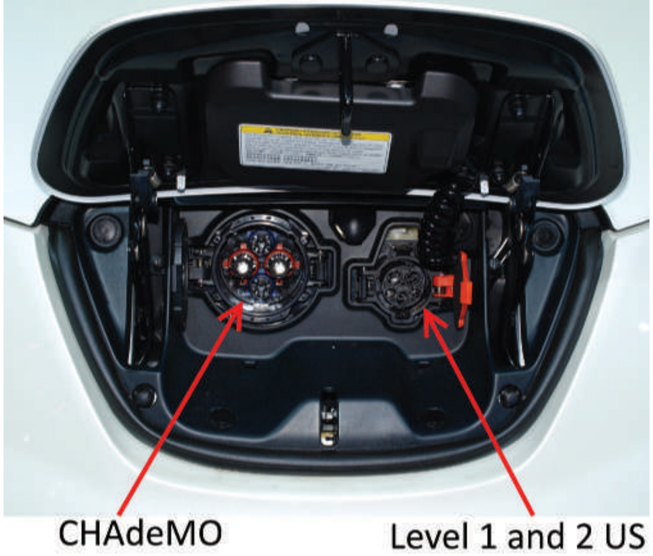


FIGURE 19–35 A CHAdeMO plug compared to a standard U.S. Level 1 and Level 2.

FIGURE 19–34 Level 2 charging requires a dedicated 240-volt supply.

Wireless Charging

Several aftermarket companies are working on wireless EV charging systems. These induction-based charging systems use a ground-based unit and a receiver in the vehicle. Magnetic fields produced by the unit are picked up and used to charge the high-voltage battery.

Small-scale induction charging is available in many vehicles to charge cell phones and other devices. One obstacle for induction charging is that the charger and battery need to be close to each other to work efficiently.

Preliminary Checks

The key to solving charging system problems is getting to the root of the trouble the first time. Once a customer drives away with the assurance that the problem is solved, another case of a dead battery is very costly—both in terms of a free service call and a damaged reputation. Add to this the many possible hours of labor trying to figure out why the initial repair failed, and the importance of a correct initial diagnosis becomes all too clear.

Safety Precautions

- Disconnect the battery ground cable before removing any leads from the system. Do not reconnect the battery ground cable until all wiring connections have been made.
- Avoid contact with the AC generator output terminal. This terminal is hot (has voltage present) at all times when the battery cables are connected.
- The AC generator is not made to withstand a lot of force. Only the front housing is relatively strong.
- When adjusting belt tension, apply pressure only to the front housing to avoid damaging the stator and rectifier.
- When installing a battery, be careful to observe the correct polarity. Reversing the cables destroys the diodes. Proper polarity must also be observed when connecting a booster battery, positive to positive and negative to ground.
- Keep the tester's carbon pile off at all times, except during actual test procedures.
- Make sure all hair, clothing, and jewelry are kept away from moving parts.

Indicators

Part of all charging circuits is some sort of charging system warning device or indicator. The sole purpose of these is to alert the driver when there is a problem. They are also one of the first things to check when a charging system problem is suspected. Vehicles have an indicator light, an ammeter, a voltmeter, and/or a message center in the instrument panel that allows the driver to monitor the charging system.

Indicator Light This is the simplest and most common method of monitoring charging system performance. When the system fails to supply sufficient current, the light turns on. However, when the ignition switch is first activated, the light also comes on **(Figure 19–36)**. This is due to the fact that the AC generator is not providing power to the battery and other electrical circuits. Thus, the only current path is through the ignition switch, indicator light, voltage regulator, part of the AC generator, and ground, and then back through the battery **(Figure 19–37)**. Once enough power is provided, the lamp should turn off.

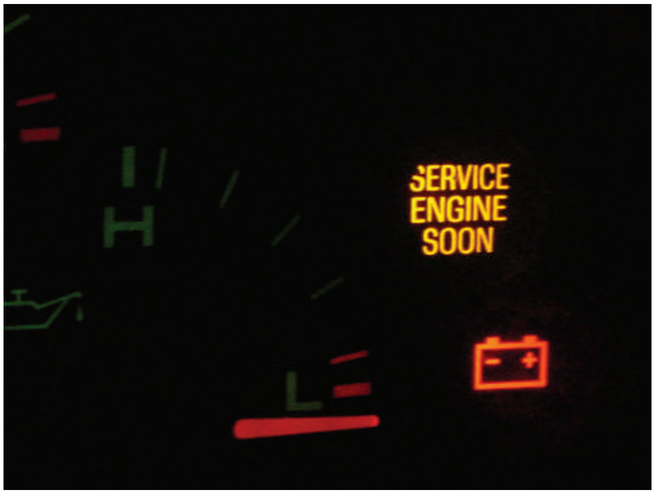


FIGURE 19-36 The charging warning indicator is shown in the right bottom of this display.

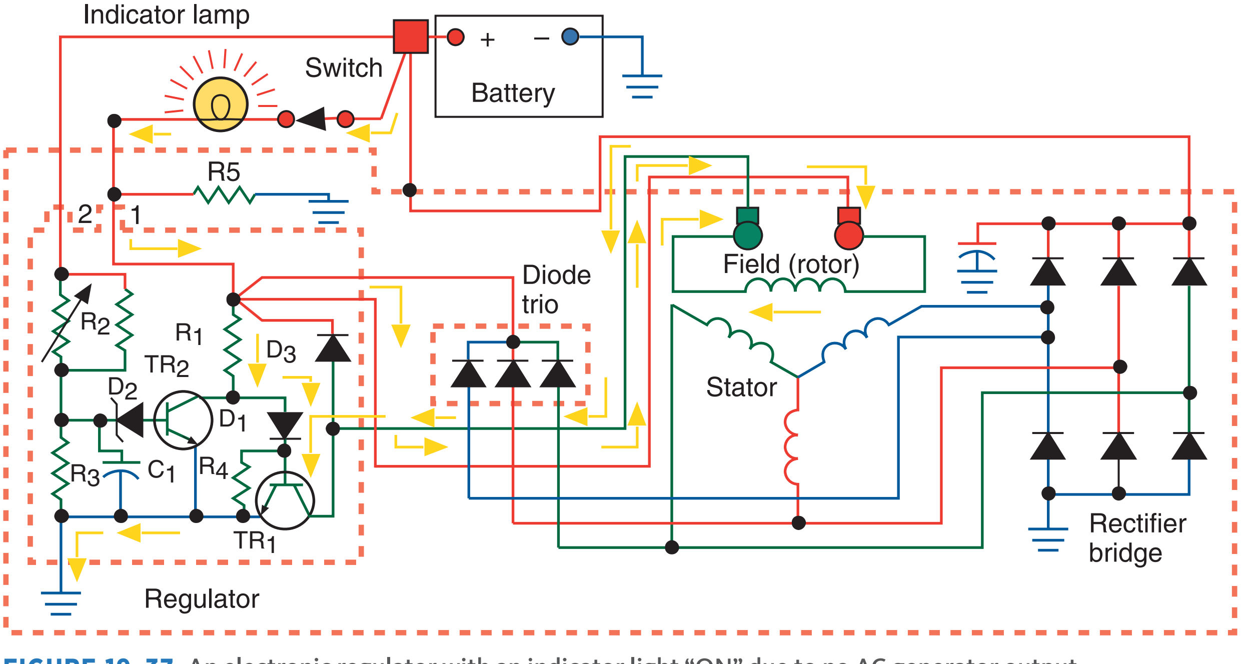


FIGURE 19-37 An electronic regulator with an indicator light "ON" due to no AC generator output.

SHOP TALK

On some late-model cars, the indicator light may be combined with the oil pressure warning light and is usually labeled "engine." If this light turns on while the engine is running, either the AC generator is not charging or the oil pressure is low—or both.

If, when the engine is running, the electrical load is greater than what can be handled by the charging system, the indicator light should turn on. This occasionally happens when the engine is idling. If there are no problems, the light should go out as the engine speed is increased. If it does not, either the AC generator or regulator is not working properly. If the lamp does not light when the ignition is placed in the on position, check the bulb and its circuitry.

Meters Some vehicles have an ammeter or voltmeter in their instrument cluster. The voltmeter displays the voltage at the battery. If the charging system is working fine, the voltmeter will read more than 12 volts. The ammeter monitors current flow in and out of the battery. When the generator is delivering current to the battery, the ammeter shows a positive (+) indication. When not enough current (or none at all) is being supplied, the result is a negative (–) indication. The latter situation indicates a problem with the charging system.

Warning Messages Warning messages are typically found on some vehicles with a PCM-controlled charging system. These messages are normally accompanied by the illumination of the charging system warning lamp. Like other warning lamp circuits, the lamp, along with a message, should be displayed when the ignition is first turned on. It should also turn off or clear once the engine is running, normally about 3 seconds. If the lamp and/or message remains on, the charging system needs to be diagnosed. If the lamp does not initially illuminate, that circuit needs to be diagnosed.

Normally the message center will display one of two messages when there is a faulty charging system. One message will say the battery is not being charged. An example for this would be: "Battery Not Charging Service Charging System." If the system senses a too low or too high charging voltage, the typical message will read: "Service Battery Charging System." Both of these messages will set a diagnostic trouble code that can be retrieved to help in diagnosis.

PROCEDURE

Follow these steps while inspecting a charging system:

1. Inspect the battery. It might be necessary to charge the battery to restore it to a fully charged state. If the battery cannot be charged, it must be replaced. Also, make sure that the posts and cable clamps are clean and tight, because a bad connection can cause reduced current flow.
2. Inspect all system wiring and connections **(Figure 19–38).** Many systems contain fusible links or maxi-fuses to protect against overloads; check them.
3. Inspect the generator and regulator mountings for loose or missing bolts. Replace or tighten as needed. Remember, most generators and regulators complete their ground through their mounting. If the mountings are not clean and tight, a high resistance ground will result.
4. Inspect the AC generator drive belt and tensioner. Loose drive belts are a major source of charging problems. The correct procedure for inspecting, removing, replacing, and adjusting a drive belt is shown in Photo Sequence 4.
5. Before adjusting belt tension, check for proper pulley alignment.

Inspection

Many charging system concerns are caused by easily repairable problems that reveal themselves during a visual inspection of the system. Remember to always

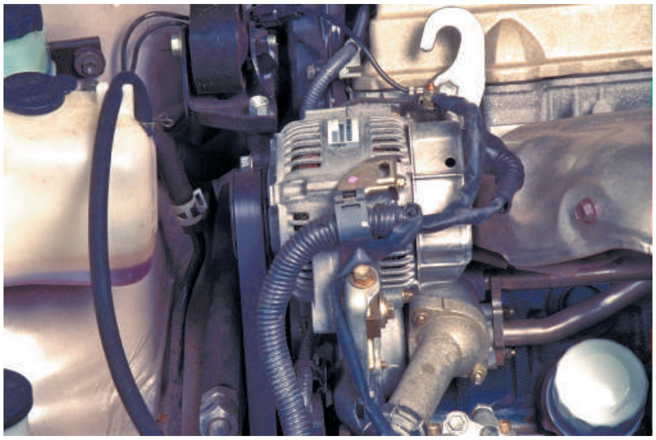


FIGURE 19–38 Start your diagnosis with an inspection of the generator and its drive belt and wires.

look for the simple solution before performing more involved diagnostic procedures. Use the following inspection procedure when a problem is suspected.

GO TO Chapter 8 for the procedures for checking and replacing drive belts and pulleys.

PCM-Controlled Systems

With PCM-controlled systems, diagnosis should continue with a check for diagnostic trouble codes (DTCs). Normally there are two possible types of charging system DTCs: generator related and battery current sensor related. Always refer to the manufacturer's DTC charts and follow its prescribed diagnostic steps for those codes. On most systems, the voltage output can be monitored with a scan tool. If the voltage is not within the range specified by the manufacturer, check all connections before continuing with other tests.

In a typical PCM-controlled charging system, the PCM controls the generator by controlling the duty cycle of the field current. The PCM will also change charging rates according to existing conditions **(Figure 19–39)**. The PCM monitors a battery current sensor, the battery voltage, and the estimated battery

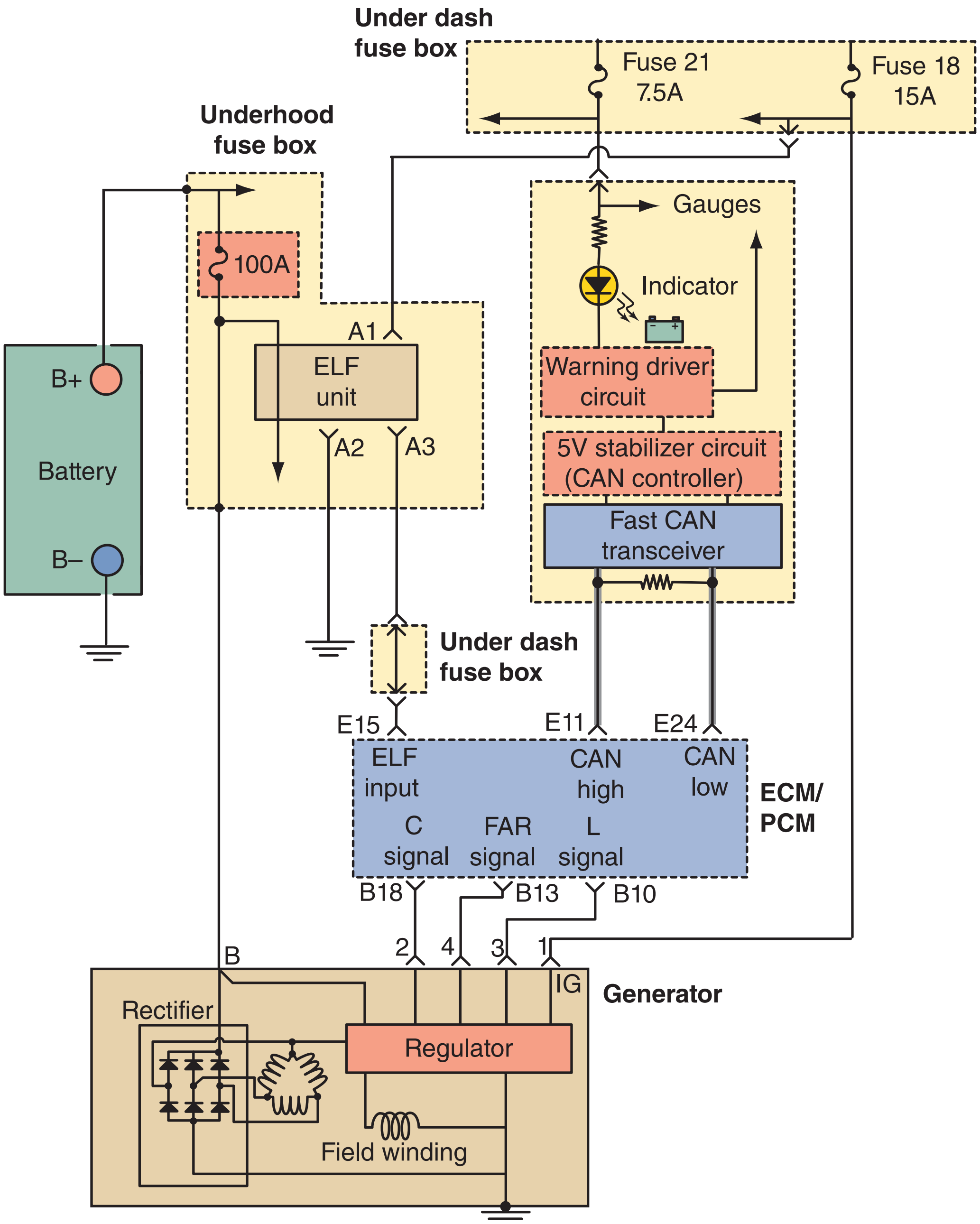


FIGURE 19–39 A schematic for a PCM-controlled charging system.

TABLE 19–1 THE RELATIONSHIP BETWEEN THE CONTROLLED OR COMMANDED FIELD CIRCUIT CURRENT DUTY CYCLE AND THE VOLTAGE OUTPUT OF THE GENERATOR

Commanded Duty Cycle	Output Voltage
10%	11V
20%	11.6V
30%	12.1V
40%	12.7V
50%	13.3V
60%	13.8V
70%	14.4V
80%	15V
90%	15.5V

temperature to determine the battery's SOC. The PCM can also increase the idle speed of the engine to raise charging rates in order to meet the current needs. The PCM sets a target charging output and adjusts the duty cycle of the field current to meet that target **(Table 19–1)** without overstressing the battery.

The battery current sensor is connected to the negative battery cable at the battery **(Figure 19–40)**. The current sensor is a three-wire, Hall-effect sensor that directly feeds the PCM with information. The actual voltage regulator may be connected internally to the generator but it is controlled externally by the PCM. If the voltage regulator detects a charging system problem, it grounds the sensor's circuit, which signals the PCM that a problem exists. The PCM then controls the duty cycle based on information in its memory.

Several conditions will cause the PCM to increase or decrease the target charging output. These include the current operation of some heavy current draw accessories, low current demand at constant vehicle speeds, low speed after initial engine startup, and low or high temperatures. When monitoring the performance of these systems, it is important to note the operational conditions because these do affect the output of the generator.

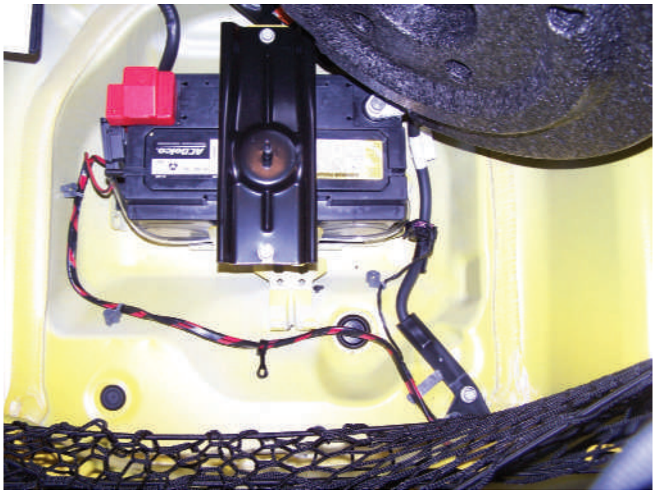


FIGURE 19–40 A battery current sensor.

Noise Diagnosis

Often a charging system concern is excessive noise. The cause of this noise can be something mechanical or electrical. Most often, electrical noise is normal and will vary with the load put on the charging system. However, a bad diode can cause an abnormal whirring noise and should be considered.

Most noises are caused by belts, bad bearings, or something rubbing against a pulley or belt. As with all problems, verify the noise and attempt to identify the area it is coming from. If a drive belt does not have the proper tension, it might produce a loud squealing sound. Check the condition and tension of the belt.

Check the mounting of the generator, its wiring harness, and all heater hoses, A/C lines, and other items that may be misrouted and making contact with belts or pulleys. If the cause of the noise is not identified, remove the drive belt. Spin the generator's pulley, idler pulley, and tensioner. If any of these do not spin freely, replace them. If no problem is found, check the tightness of the generator's mounting bolts and make sure the generator is mounted correctly. If no problem is found, replace the generator.

General Testing Procedures

Diagnosing a charging system is a straightforward task. Tests can be conducted with a VAT, current probe, DMM, or a lab scope. Charging system tests for all cars are basically the same; however, it is very important to refer to the manufacturer's specifications. Even the most accurate test results are no good if they are not matched against the correct specs.

Regulator Tests

If the concern is excessive charge resulting in battery or component failure, the most likely cause is

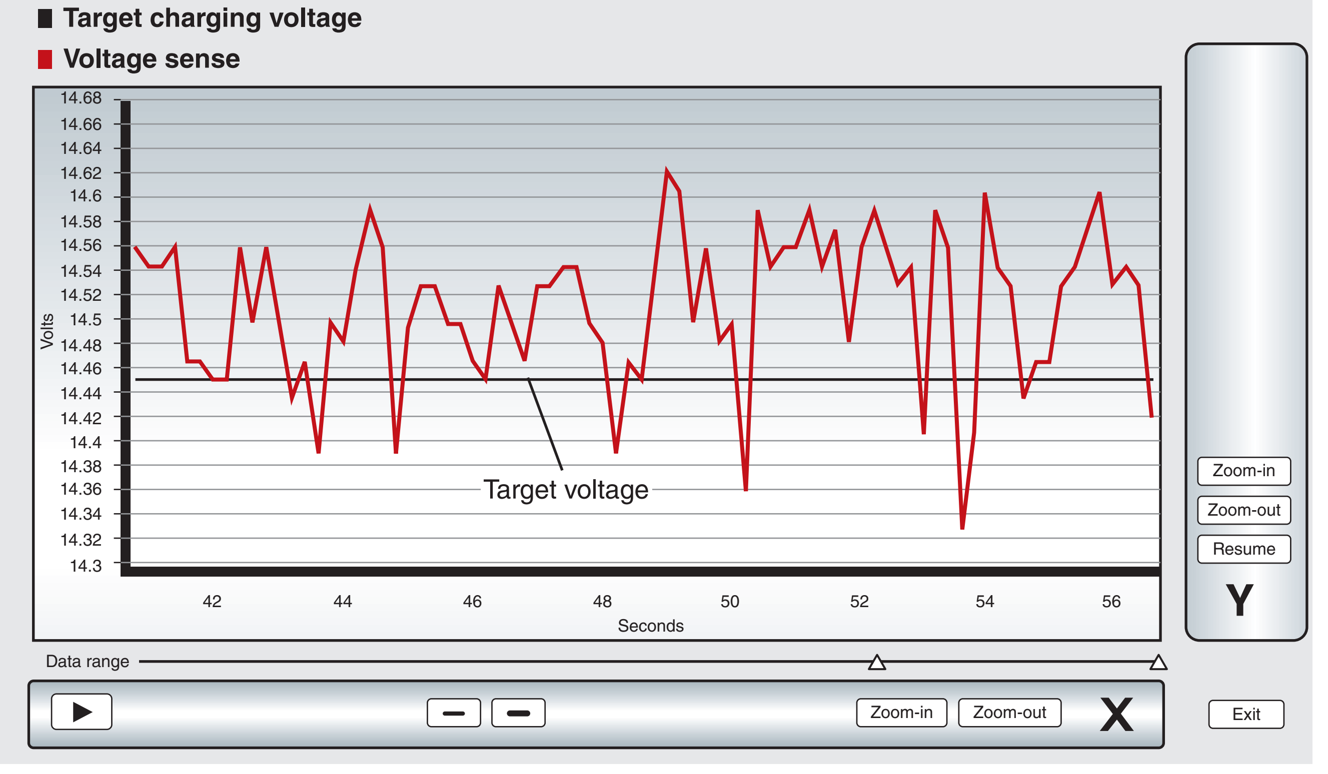


FIGURE 19–41 A graph comparing the target voltage to the sensed voltage.

the voltage regulator. Seldom does a bad regulator cause low output, but it can cause no output. To determine if the regulator was the cause on older generators, the regulator was bypassed or full-fielded. This is not done with today's generators.

This requires knowledge of the type of field circuit the generator has. Then the field windings are given full current and the generator's output observed. Some generators had a window with a grounding tab inside. By inserting a small screwdriver into the hole and grounding the tab, the regulator was bypassed. Also follow the manufacturer's procedures for full-fielding a generator.

Voltage Output Test

To check the charging system's voltage output, begin by measuring the battery's open circuit voltage. If the voltage is low, proceed to check the battery's condition. Then, start the engine and run it at the suggested rpm for this test (usually 1,500 rpm). With no electrical load, the voltage reading should be about 2 volts higher than the open circuit voltage.

A reading of less than 13 volts immediately after starting the engine indicates a charging problem. A reading of 16 or more volts indicates overcharging. A faulty voltage regulator or control voltage circuit is the most likely cause of overcharging. Voltage tests can be conducted with a voltmeter or graphing meter. With a GMM, you can observe changes in the sensed voltage to the desired charging voltage **(Figure 19–41)**.

If the unloaded charging system voltage is within specifications, test the output under a load. Increase the engine speed to about 2,000 rpm and turn on the headlights and other high current accessories. The voltage output while under heavy load should be about 0.5 volt above the battery's open circuit voltage.

Current Output Test

The output test looks at the current output of the system. A VAT can quickly check the amperage output. With the tester connected to the system **(Figure 19–42)**, the engine is run at a moderate speed (2,500 rpm) and the carbon pile adjusted to obtain maximum current output. This reading is compared against the rated output. Normally, readings that are more than 10 amperes out of specifications indicate a problem and the generator should be repaired or replaced.

Oscilloscope Checks

AC generator output can also be checked using an oscilloscope. **Figure 19–43** shows a good pattern

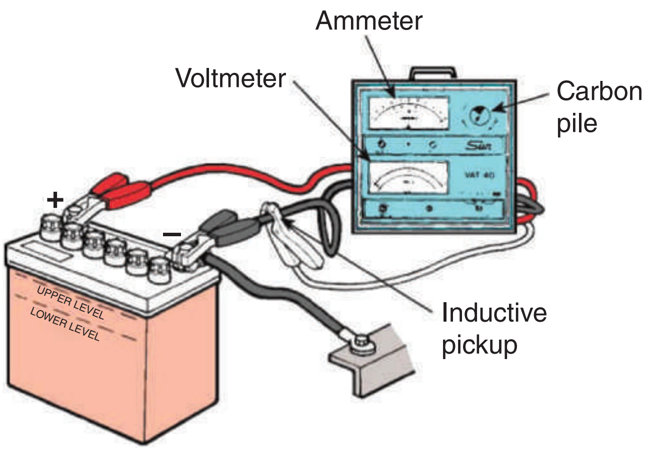


FIGURE 19–42 The lead connections for conducting a current output test with a VAT. Notice that the ammeter clamp is around the battery cable.

> **SHOP TALK**
>
> It is important to know the amperage rating of the generator before coming to any conclusions from the output test. The generator may have its rating stamped into its case, there may be a label on the case, and some have color markings that denote their rating. However, the appropriate service information is the best way to identify the rating.

for an AC generator operating under normal loads. The correct pattern looks like the rounded top of a picket fence. Note that a regular dip in the pattern normally indicates that one or more of the coil windings is grounded or open, or that a diode in the rectifier circuit of a diode trio circuit has failed. One or more bad or leaking diodes will decrease the output of a generator.

AC Leakage Test

It is important to remember that a battery cannot be charged with AC voltage. Therefore, it is important to make sure that no AC is leaking into the charging system from the AC generator. Leakage typically occurs at a faulty diode. To check for diode leakage, connect a DMM in series to the generator's output terminal while the engine is not running **(Figure 19–44)**. Set the meter to read milliamps. There should be no more than 0.5 milliamp. If there is more, check the diodes and/or replace the generator.

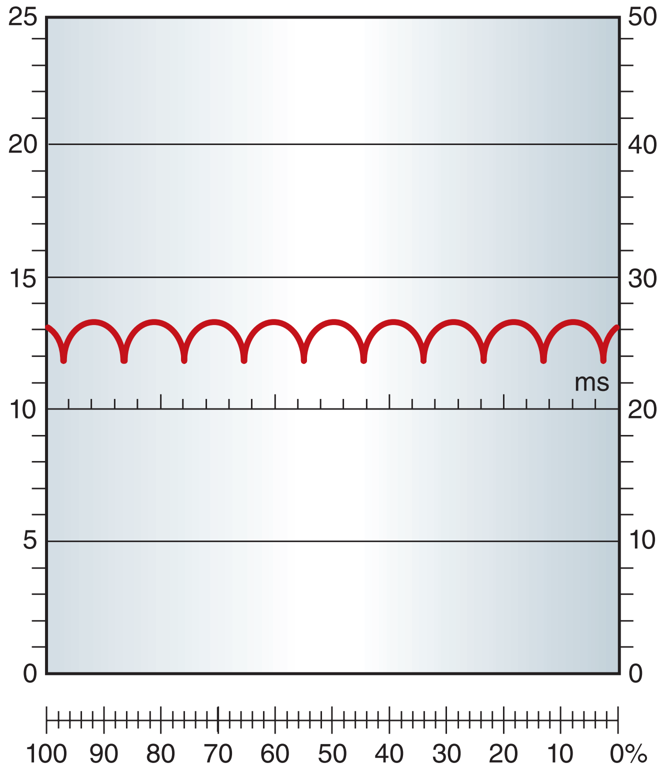


FIGURE 19–43 The waveform from a properly operating AC generator.

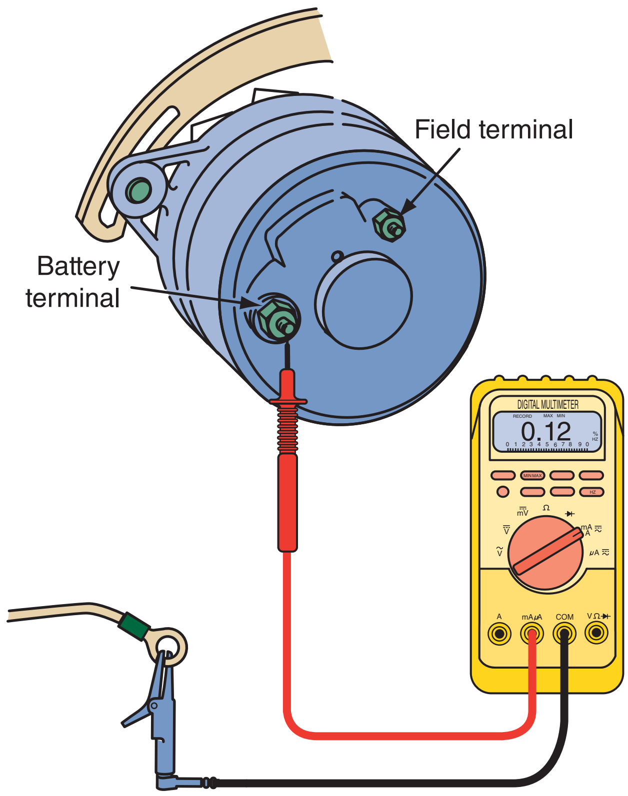


FIGURE 19–44 Setup for checking AC leakage.

Diode Checks

The output of a generator is highly dependent on the condition of the diodes. Not only do the diodes rectify AC voltage to DC, they also prevent AC voltage from being present in the output. Bad diodes are indicated by the presence of more than 0.5 AC volt in the output wire. To check this, set the DMM to measure AC volts. Then connect the black meter lead to a good ground and the red lead to the generator's battery terminal.

On a lab scope, the action of the diodes can be easily observed. Like all electrical problems, diodes can be open **(Figure 19–45)**. It is also common for a positive diode to short to ground **(Figure 19–46)** or that a rectifier have an open and shorted diode **(Figure 19–47)**. **Figure 19–48** shows what the output pattern would look like if there was high resistance in the rectifying circuit.

Another check of the diodes while they are still in the generator is done with the engine off and with a low-amperage current probe. Measure the current

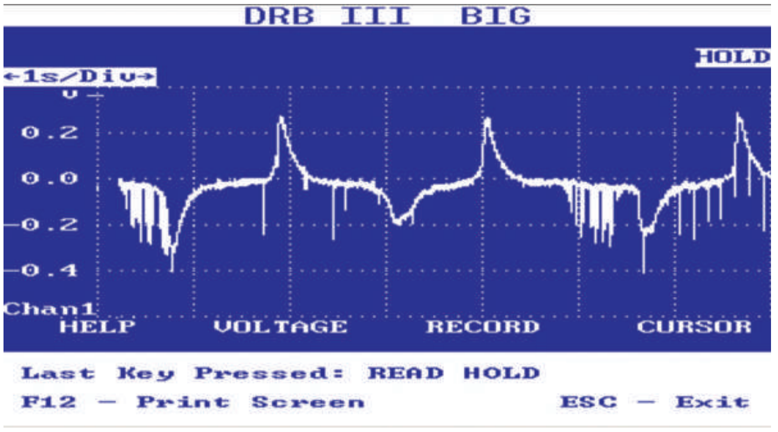


FIGURE 19–45 The waveform from an AC generator with an open diode.

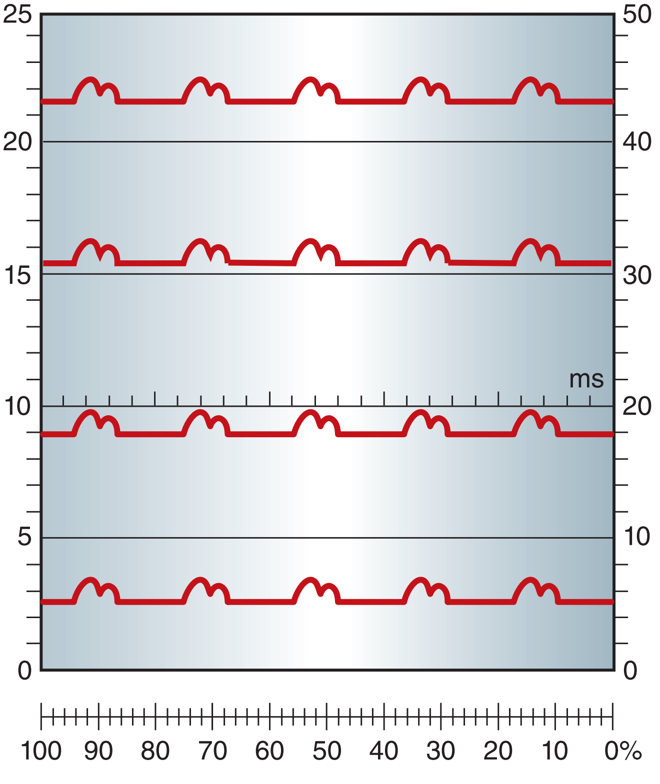


FIGURE 19–46 The waveform from an AC generator with a shorted diode or stator winding.

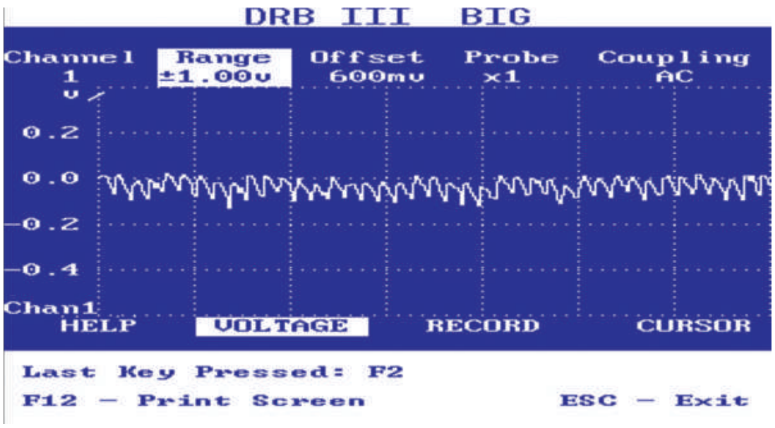


FIGURE 19–47 The waveform from an AC generator that has an open diode and a shorted diode.

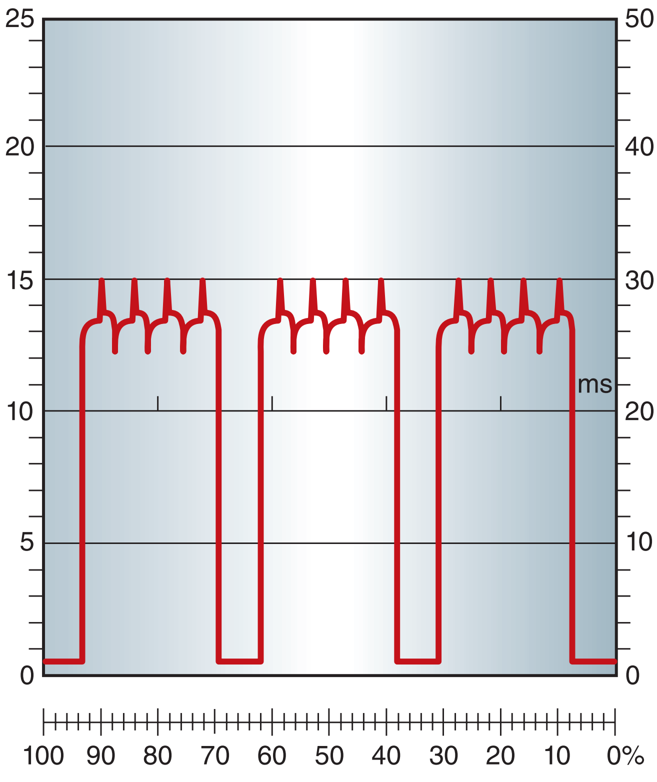


FIGURE 19–48 The waveform of a AC generator that has high resistance in its stator or diode circuit.

on the generator's output wire. Any measurement greater than 0.5 milliamp indicates that one or more diodes are leaking and the generator or diodes need to be replaced.

Generator Output and Generator Voltage Drop Tests These tests measure voltage drop within the system wiring. They help pinpoint corroded connections or loose or damaged wiring.

Circuit resistance is checked by connecting a voltmeter to the positive battery terminal and the output, or battery terminal of the AC generator. The positive lead of the meter should be connected to the AC generator output terminal and the negative lead to the positive battery terminal **(Figure 19–49)**. To check the voltage drops across the ground circuit, connect the positive lead to the generator housing and the negative meter lead to the battery negative terminal. When measuring the voltage drop in these circuits, a sufficient amount of current must be flowing through the circuit. Therefore, turn on the headlights and other accessories to ensure that the AC generator is putting out at least 20 amps. If a voltage drop of more than 0.5 volt is measured in either circuit, there is a high-resistance problem in that circuit.

AC Generator Control Circuit

If charging voltage is incorrect or the system is not charging at all, first verify the power and ground circuits for the generator. If power is present at the generator and the ground circuit voltage drop is acceptable, the control circuit should be inspected. For computer-controlled charging systems, a scan tool is often required. Begin by checking for any stored DTCs. If DTCs are stored for the charging system, you will need to follow the manufacturer's service information to diagnose the DTC. In general, locate the charging system PIDs and note the generator output command. Increase the electrical load and engine rpm and note the commanded output and actual generator output. Both should increase as electrical load increases. Depending on the vehicle, generator output may be controlled via the scan tool using bidirectional control. This feature can be helpful in verifying the integrity of the charging control circuit.

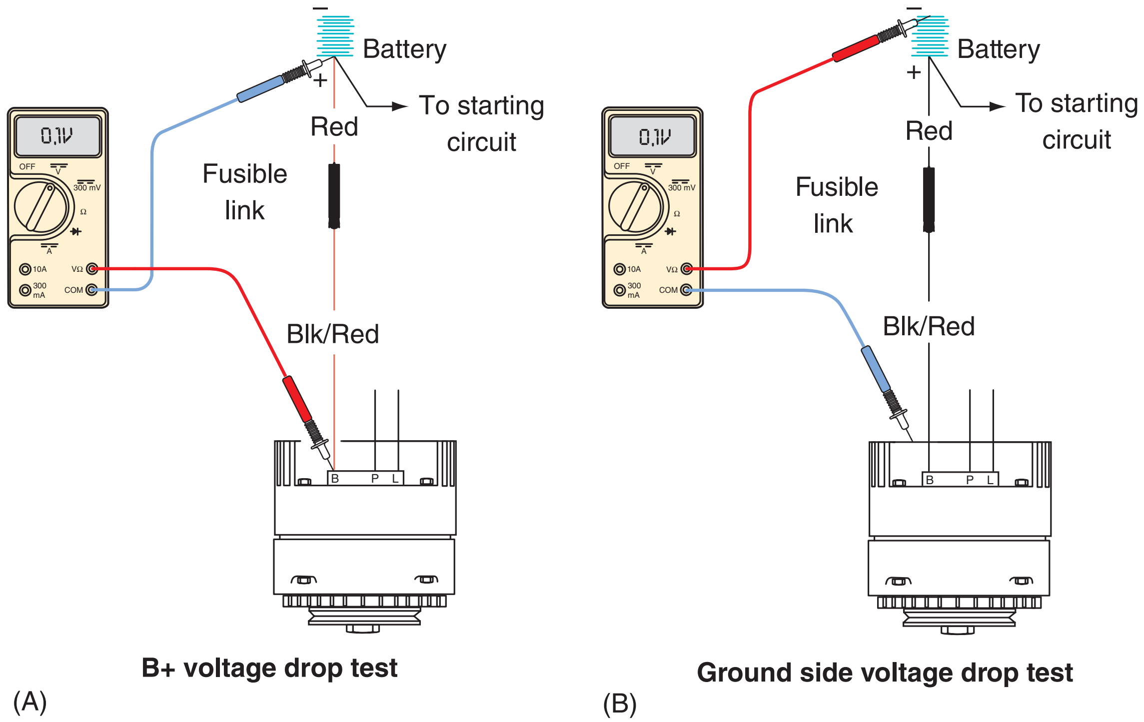


FIGURE 19-49 Voltage drop testing of the (A) generator output circuit and the (B) ground circuit.

Clutch Pulley Inspection

To check the pulley bearing, run the engine at 2,000 rpm and shut the engine off while at the increased speed. A worn alternator drive pulley bearing will make noise for 5 to 10 seconds after the engine is shut down.

Special tools are sometimes required to check clutch-type pulleys. To check the action of the overrunning clutch, rotate the pulley's outer ring while keeping the center stationary. The ring should rotate freely in the counterclockwise direction, and not rotate in the clockwise direction. If the pulley fails this check, replace it. A torque wrench may be required to check the amount of force necessary to turn the pulley. Refer to the manufacturer's service information for testing procedures for the specific vehicle.

AC Generator Service

When the cause of charging system failure is the AC generator, it should be removed and replaced, or rebuilt. Whether it is rebuilt or replaced depends on the type of generator it is, the time and cost required to rebuild it, your shop's policy, and your customer's desires. Most late-model AC generators are not rebuilt. They are traded in as a core toward the purchase of a new or remanufactured unit.

Replacing an AC Generator

Keep in mind that although some AC generators can be rebuilt, often the parts to do so are not readily available and the time spent doing so may not save the customer money. If the customer chooses to have the AC generator rebuilt, refer to the service information about the generator to see what should be done.

When replacing a generator, follow the correct procedures for removing and installing an AC generator. Remember, improper connections to an AC generator can destroy it. Begin by disconnecting the battery negative connection. Next, disconnect the wiring at the generator. Release the tension from the generator drive belt and remove the belt from the pulley. Locate and remove the fasteners holding the generator and then remove the generator. When replacing with a new or remanufactured unit, compare the wiring connections and mountings of the new and old unit before installing the new generator.

Install the generator and torque the fasteners to specifications. Reconnect the wiring and install the drive belt. If the old drive belt is being reused, use a belt tension gauge to check that the correct amount of tension is applied. A weak belt tensioner or stretched belt can reduce generator output. Reconnect the battery and perform charging system voltage and current tests to ensure the replacement generator is operating properly and verify the charging system warning light is off.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2007	**Make:** Toyota	**Model:** Camry	**Mileage:** 113,874	**RO:** 17401
Concern:	Customer had to jump start engine and the car is making strange, loud, howling sounds with the engine running.			
The technician confirms that the vehicle sounds loud and unusual when running. The noise, along with a lot of heat and a strange odor seem to be coming from the generator.				
Cause:	Found no generator output. Determined engine noise stopped when the generator is unplugged.			
Correction:	Replace generator and drive belt (original belt). Generator output 112 amps at 12.8 volts @ 2,000 rpm.			

KEY TERMS

Alternator
Delta winding
Diode
Fail-safe circuits
Field coil
Full-wave rectification
Half-wave rectification
Integrated circuit voltage regulators
Rotor
Sensing voltage
Slip rings
Stator
Three-phase voltage
Voltage regulator
Wye winding

SUMMARY

- Inducing a voltage requires a magnetic field producing lines of force, conductors that can be moved, and movement between the conductors and the magnetic field so the lines of force are cut.
- Modern vehicles use an AC generator to produce electrical current in the charging system. Diodes in the generator change or rectify the alternating current to direct current.
- A voltage regulator keeps charging system voltage above battery voltage. Keeping the AC generator charging voltage above the 12.6 volts of the battery ensures that current flows into, not out of, the battery.
- Modern voltage regulators are completely solid-state devices that can be an integral part of the AC generator or mounted to the back of the generator housing. In some vehicles, voltage regulation is the job of the computer control module.
- Voltage regulators work by controlling current flow to the AC generator field circuit. This varies the strength of the magnetic field, which in turn varies current output.
- The driver can monitor charging system operation with indicator lights, a voltmeter, or an ammeter.
- Using electronics to control the current to and from the battery, a generator can work as a motor or vice versa.
- Motor/generators are capable of high charging outputs. They can crank the engine at high speeds and allow for the stop-start feature and regenerative braking and may provide electrical assist to the engine.
- Regenerative braking captures some of the vehicle's kinetic energy to recharge the battery.
- Problems in the charging system can be as simple as worn or loose belts, faulty connections, or battery problems.
- Circuit resistance, current output, voltage output, field-current draw, and voltage regulator tests are all used to troubleshoot AC charging systems.

REVIEW QUESTIONS

Short Answer

1. To protect electronic circuits, some voltage regulators have a ___ circuit built into them.
2. What is the purpose of the diodes in the generator?
3. How does a voltage regulator regulate the voltage output of an AC generator?

4. Describe the differences between an overrunning alternator pulley and an alternator decoupler pulley.
5. What would happen to the output of an AC generator if one of the stator windings has an open?
6. Describe the basic difference between a DC motor and a DC generator.

True or False

1. *True or False?* A faulty voltage regulator can only cause a no-charge condition.
2. *True or False?* A generator that is not producing voltage or current may have an open stator winding.

Multiple Choice

1. A rotating magnetic field inside a set of conducting wires is a simple description of a ___.
   a. DC generator
   b. AC generator
   c. voltage regulator
   d. none of the above
2. What part of the AC generator is the rotating magnetic field?
   a. Stator
   b. Rotor
   c. Brushes
   d. Poles
3. Which type of stator winding has two windings in parallel?
   a. Wye
   b. Delta
   c. Trio
   d. Series
4. Slip rings and brushes ___.
   a. mount on the rotor shaft
   b. conduct current to the rotor field coils
   c. are insulated from each other and the rotor shaft
   d. all of the above
5. The alternating current produced by the AC generator is rectified into DC, or direct current, through the use of ___.
   a. transistors
   b. electromagnetic relays
   c. diodes
   d. capacitors
6. A voltage drop over ___ indicates high resistance in either the positive or ground circuit of the charging system.
   a. 0.1
   b. 0.2
   c. 0.5
   d. 1.0
7. Voltage regulation by a PCM is done by ___.
   a. using a variable resistor to vary current flow to the rotor field windings
   b. pulsing current flow to the rotor field windings on and off to create a correct average field current supply
   c. changing the duty cycle of a current sensor to control the field's path to ground
   d. none of the above

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that the waveform produced by an AC generator after rectification is called a sine wave. Technician B says that the waveform produced by the AC generator after the output moves through the diodes is a straight line because it is a constant DC voltage. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. While discussing what is indicated by a vehicle's charge indicator: Technician A says that any positive reading on an ammeter shows that the generator is in working condition. Technician B says that if the voltmeter reading does not increase immediately after starting the engine, the battery is bad. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. When checking the charging system on a late-model vehicle: Technician A connects a scan tool to monitor the system's voltage output. Technician B connects a scan tool to retrieve any DTCs that may be in the system. Who is correct?
   a. Technician A
   c. Both A and B
   b. Technician B
   d. Neither A nor B

4. While diagnosing the cause of a noise coming from a generator just after the engine shuts off: Technician A says that the noise can be caused by something mechanical or electrical. Technician B says that the whirring noise is probably caused by a diode or an overrunning clutch and it should be considered normal. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Technician A says generator output should be within 10 amps of the AC generator's rated output. Technician B says generator voltage output should not exceed 14.5 volts during voltage output test. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. Technician A says that many newer charging systems do not have a separate voltage regulator. Technician B says that most late-model charging systems are computer regulated through the ground of the field. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. While diagnosing rapid and severe belt wear after generator replacement: Technician A says that a defective drive belt tensioner may be the cause. Technician B says that the generator may have the wrong type of pulley installed. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. Technician A says that if there was no output from the charging system until the AC generator was full-fielded, the voltage regulator is faulty. Technician B says that this indicates one or more leaking diodes in the generator. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. When checking AC generator output on a late-model vehicle: Technician A tests the battery's open circuit voltage before testing the generator's output because the battery's SOC will affect the maximum output of the generator. Technician B checks the ambient temperature before performing any tests because the generator's output will be affected by temperature. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While testing a charging system: Technician A says that an overcharge condition is evident any time charging voltage is greater than 13 volts. Technician B says that the system should be able to supply its maximum current output when the engine is at idle and there is no load on the system. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER 20

LIGHTING SYSTEMS

OBJECTIVES

- Explain the operating principles of the various lighting systems.
- Describe the different types of headlights and how they are controlled.
- Explain the purpose of auxiliary automotive lighting.
- Describe the operation and construction of the various automotive lamps.
- Understand the functions of turn, stop, and hazard warning lights.
- Know how back-up lights operate.
- Replace headlights and other burned-out bulbs.
- Explain how to aim headlights.
- Diagnose lighting problems.

The lighting system provides power to both exterior and interior lights. It consists of the headlights, parking lights, marker lights, taillights, turn signals, hazard warning lights, back-up lights, stoplights, courtesy lights, dome/map lights, instrument illumination or dash lights, headlight switch, and various other control switches **(Figure 20–1)**. Other lights, such as vanity mirror lights, the underhood light, the glove box light, and the trunk compartment light, are used on some vehicles and are also part of the lighting system.

Automotive Lamps

A lamp is a device that provides light or illuminates something to make it visible. The term lamp is also given to light fixtures that provide light in a house, business, or outside. The most commonly used are

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2005	**Make:** Ford	**Model:** Focus	**Mileage:** 115,209	**RO:** 17947
Concern:	Turn signals are not working correctly. Customer installed new bulbs, lights blink very quickly.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

FIGURE 20-1 Automotive lighting systems.

SHOP TALK

Lighting systems are largely regulated by federal laws, so the systems are similar among the various manufacturers. However, there are many variations. Before attempting to do any repairs on an unfamiliar system, you should always refer to the manufacturer's service information.

the incandescent lamps, halogen lamps, high-intensity lamps, and light-emitting diodes.

Incandescent Lamps

Perhaps the most commonly used type of lamp today is the incandescent lamp **(Figure 20–2)**, though these are being phased out and replaced by other types. These lamps produce light when current passes through a filament made of tungsten. The filament wire is heated to a high temperature, causing it to glow and give off light. Basically electrical energy is changed to heat energy in the wire filament.

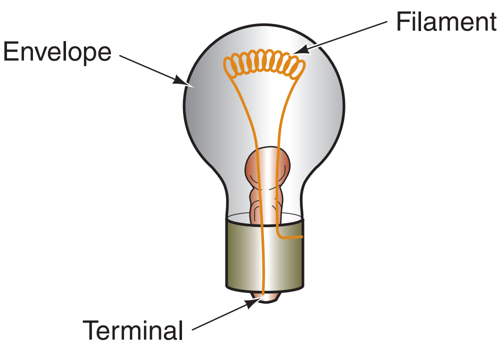


FIGURE 20-2 An incandescent lamp.

The filament is enclosed in a glass bulb that has been purged of air, therefore the filament "burns" in a vacuum. If air enters the bulb, the oxygen will allow the filament to oxidize and burn up. As the filament burns, blackish deposits are left on the glass bulb. The presence of this coating is an indication that the bulb is bad or has little life remaining in it.

Incandescent lamps use more energy to provide light than other types of lamps. In an incandescent lamp, about 95 percent of the energy it consumes is lost through heat. Today, these lamps are being replaced by a variety of fluorescent lamps (including cold cathode fluorescent lamps [CCFL] and compact fluorescent lamps [CFL]), light-emitting diodes (LEDs), and high-intensity discharge lamps.

Halogen Lamps

Halogen lamps are actually incandescent lamps. This lamp is comprised of a tungsten filament enclosed in a halogen-filled bulb made of high-temperature resistant glass. The name **halogen** is used to identify a group of chemically related non-metallic elements, such as iodine, chlorine, and fluorine. Most halogen lamps use iodine vapor. These lamps provide brighter light because the filament is able to burn at higher temperatures, due to the presence of halogen in the bulb. Another positive about a halogen lamp is the filament does not break down, as it does in an incandescent bulb, due to the reaction of the burning tungsten and the halogen. As a result, the metal vapor from burning is redeposited on the filament.

Fluorescent Lamps

Like a neon lamp, a fluorescent lamp is a gas-discharge lamp. The excited gas in the lamp is typically mercury vapor. The enclosure of the lamp is coated with phosphor **(Figure 20–3)**. When current flows through the mercury vapor, the mercury atoms

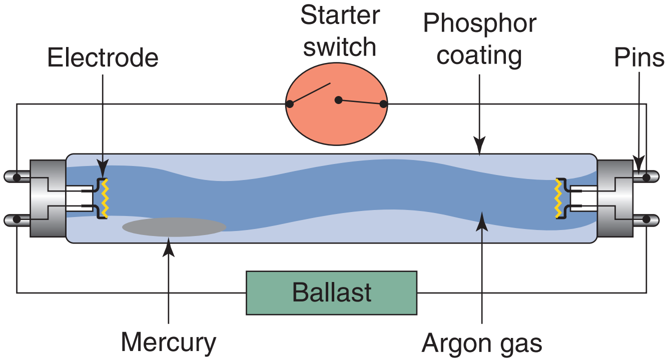


FIGURE 20-3 The construction of a fluorescent bulb.

produce short-wave ultraviolet light causing the phosphor to fluoresce, providing visible light. The advantage of using fluorescent lamps is they use less energy than a conventional incandescent lamp. However, their initial cost is higher because they need an electric ballast assembly to regulate the current through the tube.

High-Intensity Discharge Lamps

High-intensity discharge (HID) lamps provide more visible light, for the amount of consumed electrical power, compared to fluorescent and incandescent lamps. This is because less heat is lost while the lamp is lit. Light is emitted when an electric arc jumps across the tungsten electrodes inside a clear or opaque tube filled with a gas and metal salts. The gas helps the voltage jump the gap between the electrodes. Once the gap is jumped, the heat of the electrical arc reacts with the metal salts and forms a highly ionized gas that provides a great amount of light. The presence of the gas also reduces the amount of energy required to provide the light. A ballast unit is required to start and maintain the arcing in a HID lamp.

There are many types of HID lamps including:

- **Mercury-vapor lamps** are commonly found in large parking lots or assembly halls. Like fluorescent lamps, they require a ballast to start. Older designs produced a bluish-green light, but the light from current versions has little color. Due to inadequate lighting, energy costs, and the noise of the ballast, mercury vapor lamps are being replaced by other designs.
- **Sodium-vapor lamps** have two types: low pressure and high pressure. Both are rather energy efficient and the high-pressure lamps provide a much whiter light.
- **Metal-halide** and ceramic-metal halide lamps can emit white light with lower cost and reduced noise than a mercury-vapor lamp.
- **Xenon lamps** are metal-halide lamps filled with xenon gas. Xenon gas gives off light almost immediately after arcing begins across the electrodes of the lamp. Xenon bulbs provide a bright light that increases in intensity shortly after the arc has been established.

Light-Emitting Diodes (LED)

A **light-emitting diode (LED)** is a semiconductor that emits light when current passes through it **(Figure 20–4)**. LEDs also produce more light than heat and are much smaller than other types of lamps. The brightness of an LED depends on its temperature. More light is produced when the LED is operating with low current and is at a low temperature. Also, in order for an LED to provide a constant light output, it needs to be powered by a constant-current power supply. The power supply helps keep the LED within the desirable temperature range.

FIGURE 20–4 An LED lamp.

Unlike other lamps, the bulb of an LED lamp does not put off much heat. However, a great amount of heat is produced at the mounting base of the lamp assembly. That heat must be controlled to provide constant light and to protect the lamp. The need to keep LED temperatures low requires the use of heat sinks, ventilation systems, or cooling fans, which are normally quite expensive.

LED lamps are normally used in clusters because a single lamp does not provide the brightness of conventional lamps. For late-model vehicles, LEDs are becoming the bulb of choice for interior lights, brake, parking, turn signals, daytime running lamps and headlights.

Organic LED (OLED)

Organic LEDs are made from organic (carbon) compounds plus other ingredients. OLEDs may have applications in the future for automotive lighting or displays as the cost to produce them decrease. OLEDs can refresh nearly 1,000 times faster than LCD displays, making them suitable for instrument panels, display screens, and other automotive applications.

Headlights

Headlights are mounted on the front of a vehicle to light the road ahead during periods of low visibility, such as darkness or precipitation. Headlight designs and construction have been influenced by the changes in technology and safety regulations. In the past, all cars had two or four round or rectangular headlamps. Now headlights are an integral part of a vehicle's overall design **(Figure 20–5)**.

A headlamp system must offer a low and a high beam. The two beams on each side of the vehicle may have two separate lamps or a single lamp that can deliver both beams. Low beams are intended to be used whenever other vehicles are in front of a vehicle or approaching it from the opposite direction. Low beams are designed to provide adequate lighting in front of the vehicle with some light spread to the sides of that forward beam. But they are also set to minimize the amount of light that can shine in the eyes of other drivers, which can temporarily blind them. Low beams are often called "dip" beams because the angle of their light is lower and more to the right than high beams. Low-beam headlights are offset downward and rightward between ½ degree and 3 degrees away from a straight-ahead direction.

FIGURE 20–5 Today's headlights are an integral part of the appearance of vehicles.

High beams should be used when there are no other close vehicles and extra lighting is desired. High beams are designed to place the light beam parallel to the road's surface and illuminate as much of the road as possible. This means the light beams can directly hit the eyes of oncoming drivers, temporarily blinding them.

Sealed-Beam Headlights

Until the late 1980s, all vehicles had sealed-beam headlights. A sealed-beam headlamp is an air-tight assembly with a filament, reflector, and lens. The curved reflector is sprayed with vaporized aluminum and the inside of the lamp is normally filled with argon gas. The reflector intensifies the light produced by the filament, and the lens directs the light to form a broad flat beam **(Figure 20–6)**. To direct the light, the surface of the glass lens has concave prisms.

There are various ways to identify sealed-beam headlights, such as #1, #2, and the "halogen" or "H" marking molded on the front of the headlight lens. A type #1 is high beam only and has two electrical terminals. The type #2 has both low beam and high beam and three terminals. When a type #2 is switched to low beam, only one of its filaments is lit. When the high beam is selected, the second filament lights in addition to the low beam.

Halogen Headlamps

A halogen headlamp **(Figure 20–7)** is a glass lamp filled with halogen that encloses a tungsten filament. The tungsten-halogen combination, also called

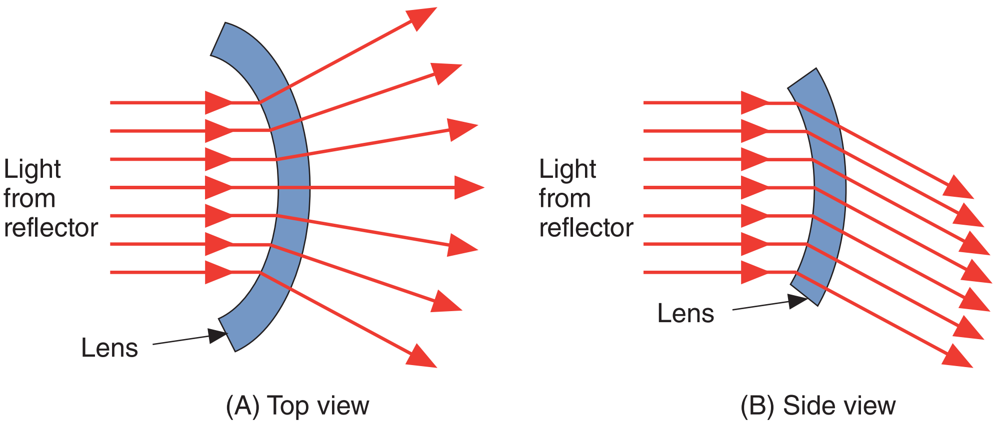


FIGURE 20–6 The reflector intensifies the light produced by the filament, and the lens directs the light to form a broad flat beam.

FIGURE 20-7 A halogen insert headlamp.

quartz-halogen, increases the light emitted by the tungsten filament. In other words, a tungsten-halogen lamp emits more lumens than other lamps when the watts used to produce the light are considered. As you may recall, a lumen is a simple measurement of the total amount of visible light a source emits. A halogen sealed beam provides about 25 percent more lighting than conventional bulbs.

Composite Headlights Many vehicles have halogen headlight systems that use a replaceable bulb **(Figure 20–8)**. Replaceable halogen bulbs were permitted in the United States in 1983 and their popularity grew quickly. Composite headlights allow manufacturers to produce any style of headlight lens they desire. This improves the aerodynamics, fuel economy, and styling of the vehicle.

The bulb is inserted into the composite headlight housing. The filament is capable of withstanding high temperatures because of the presence of the halogen. Therefore, the filament can operate at higher temperatures and can burn brighter.

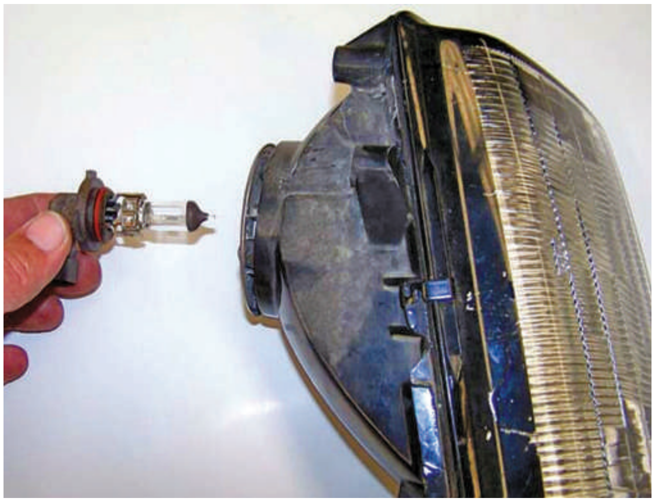


FIGURE 20-8 A composite headlamp with a replaceable halogen bulb.

Warning! Whenever you replace a halogen lamp, be careful not to touch the lamp's envelope with your fingers. Staining the bulb with skin oil can substantially shorten the life of the bulb. Handle the bulb only by its base.

Composite headlight housings are often vented to release some of the heat developed by the bulbs. The vents allow condensation to collect on the inside of the lens assembly. The condensation is not a problem and does not affect headlight operation. When the headlights are turned on, the heat generated by the halogen bulb quickly dissipates the condensation. Ford uses integrated nonvented composite headlights. On these vehicles, condensation is not considered normal. The assembly should be replaced.

High-Intensity Discharge (HID) Headlamps

High-intensity discharge (HID) or **xenon headlamps** create light by creating and maintaining an electrical arc across two electrodes inside a bulb. The arc excites the gas and salts inside the bulb **(Figure 20–9)**. This allows the arcing to continue to emit light. These lights are recognizable by their slightly bluish light beams **(Figure 20–10)**. They emit this colored light because the inside of the bulb is filled with xenon gas mixed with mercury or bismuth. The result is a light that is much closer to natural daylight than that of other bulbs.

The lamps use AC voltage and at least 30,000 volts are needed to jump the gap between the electrodes. Once the voltage bridges the gap, only about 80 volts are needed to keep current flowing across the gap.

SHOP TALK

Because the filament is inside the inner bulb, cracking or breaking of the housing or lens does not prevent the bulb from working. As long as the filament envelope has not been broken, the filament will continue to operate. However, a broken lens will result in poor light quality, so the assembly should be replaced.

FIGURE 20–9 A HID headlight bulb.

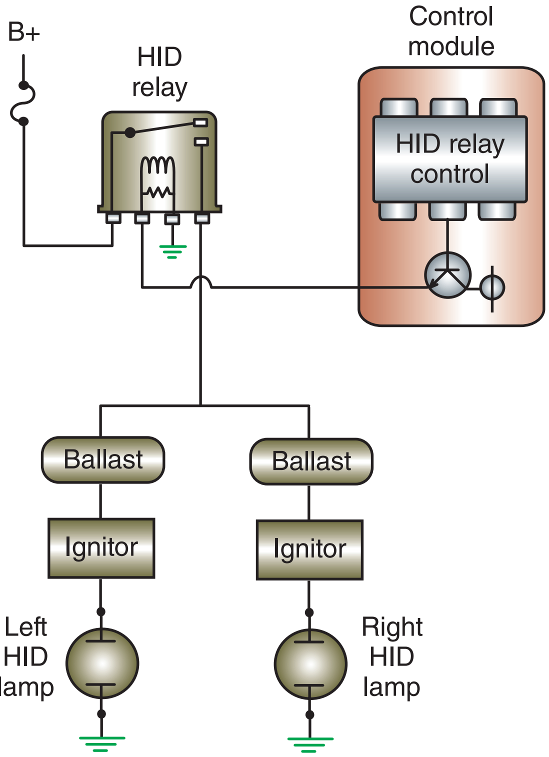


FIGURE 20–11 An HID headlamp schematic showing the lamps, ballasts, and igniters.

FIGURE 20–10 HID (xenon) headlights are readily identifiable by their bluish light.

FIGURE 20–12 The igniter is connected to the ballast by a cable.

Each HID assembly includes a lamp, ballast unit, and starter (igniter) **(Figure 20–11)**. The igniter may be part of the bulb assembly or mounted externally **(Figure 20–12)**. The ballast unit includes a DC to AC converter and an ECU to regulate the voltage, provide for a gradual warm-up of the lamp, and allow for instant restart when it is necessary **(Figure 20–13)**. The control unit also monitors the system. If it senses a faulty lamp, it turns off the lamp's power to eliminate the hazardous situation of stray, high voltage.

When the headlights are switched on, it takes approximately 15 seconds for the lamps to reach maximum intensity. However, during ignition these lamps provide more than adequate light for safe driving.

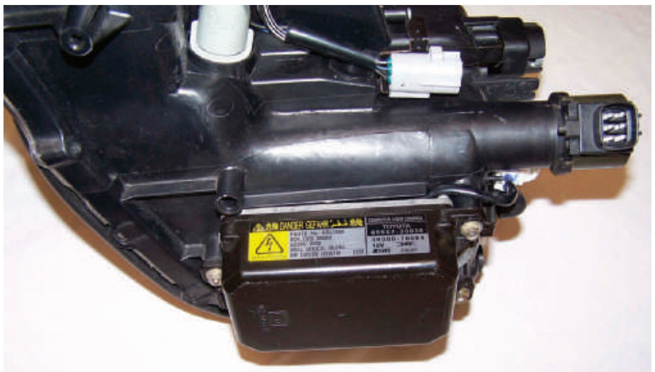


FIGURE 20–13 A HID ballast.

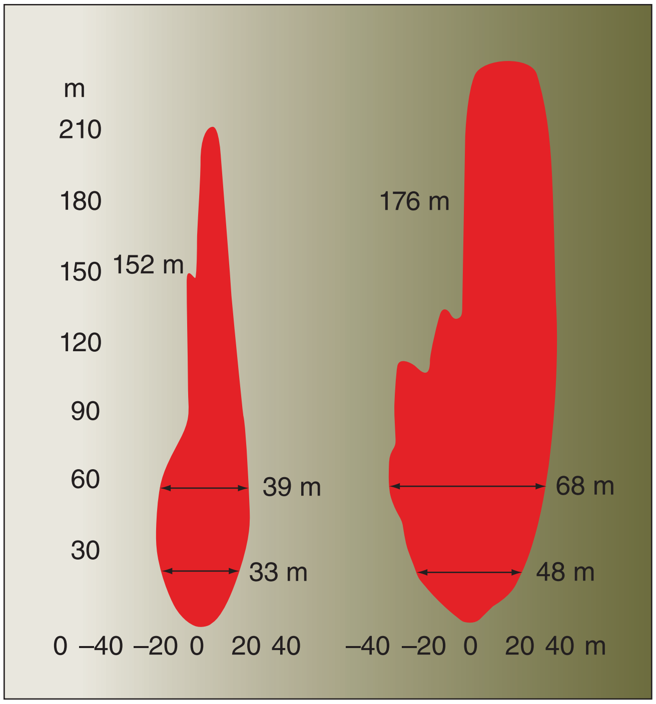


FIGURE 20–14 A comparison of the light pattern and intensity between a halogen (left) and a xenon (right) headlamp.

Xenon headlights illuminate the area to the front and sides of the vehicle with a beam that is both brighter (twice the amount) and much more consistent than the light generated by halogen headlamps **(Figure 20–14)** to make night driving safer. The light output of these lamps allows the headlamp assembly to be smaller and lighter. Xenon lights also produce significantly less heat because they use about two-thirds less power to operate and will last two or three times longer than conventional lamps.

Bi-Xenon Lights Some vehicles have bi-xenon headlamps that provide xenon lights for low and high beams. These may also be fitted with halogen lights that are used for the flash-to-pass feature. Bi-xenon lights rely on a stepper motor or solenoid controlled shield plate, or shutter, that physically obstructs a portion of the overall light beam emitted by the arc. When the driver selects high beams, the shutter reacts and allows the headlights to project the complete, unobstructed light beam.

Cylindrical Housings To provide more precise light beam patterns, many manufacturers are using headlamp assemblies that have cylindrical bulb housings **(Figure 20–15)**. These housings are the main component of projector beam headlights, which are commonly used with HID lamps. Basically the light beam is shot out of the cylinder. The aim of the cylinder projects the beam through a lens and light moves forward without much scattering **(Figure 20–16)**.

SHOP TALK

HID lamps offer great visibility but often drivers approaching a vehicle with HIDs become annoyed by the glare or brightness of the lamps. To eliminate these concerns, HID systems often have self-leveling and washer systems. Both of these are required in Europe and most European vehicles with HIDs sold in the United States have these features.

FIGURE 20–15 A headlamp assembly with cylindrical bulb housings.

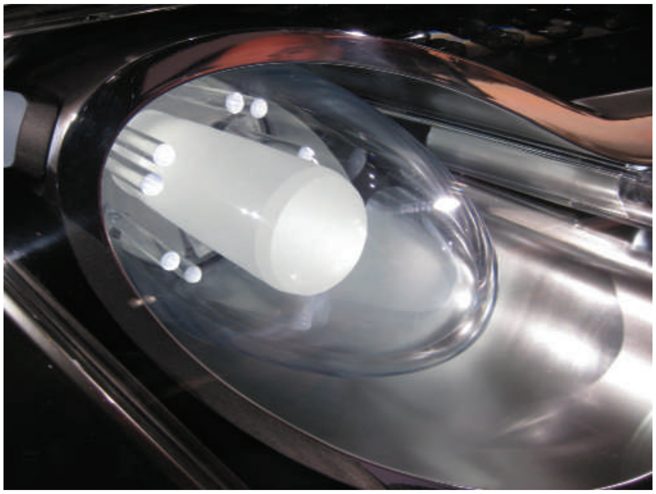


FIGURE 20–16 A cylindrical lamp assembly is used to focus light in a designated location.

LED Headlights

Currently available on some vehicles are LED headlamps. An individual LED does not produce enough light to serve as a headlamp. Ten to twenty LEDs are needed for ample forward lighting **(Figure 20–17)**. There are many reasons for using LEDs in headlights:

- LEDs do not require a vacuum bulb or high voltage to work.
- LED-based lighting sources require up to 40 percent less power than traditional lighting sources. This improves a vehicle's fuel economy.
- LEDs provide a whiter light than xenon.
- LEDs are mercury-free, making them environmentally friendly unlike some HID/xenon systems.
- The average operating life of an LED is twice that of the vehicle itself. This means the headlamp may never need to be replaced.
- LEDs are resistant to shock and vibration.
- LED headlamps reduce oncoming driver perception of glare.
- LED-based headlamps are up to 55 percent thinner than other designs, which give designers more flexibility and freedom.

Incorporating LED technology into headlamps presents a problem common to all semiconductors, that being heat. The heat from the engine compartment and the rear of the lamp can cause failure. Therefore, LEDs need temperature controls and must be mounted to heat-retarding materials. LED bulbs release very little heat; in fact their lenses never get warm enough to melt snow or ice. Therefore, a lens heater fan must be incorporated in the lamp assembly.

FIGURE 20–17 A headlight assembly of HID bulbs and LEDs.

FIGURE 20–18 LED lamps used for low and high beams.

LEDs also require precise current control, which requires complicated electronic circuitry. In spite of these obstacles, LED headlamps can open the door to other headlamp-related safety features. It is possible to have light beams that meet the current conditions automatically. This can be done by varying the number of LEDs powered or by the placement of special lenses in front of a particular group of LEDs.

Current vehicles with LED headlamps rely on several LEDs for the low beam and several more designated for the high beam **(Figure 20–18)**. The placement of the lamps is dictated by the desired light pattern and the design of the light assembly. Many assemblies use projector bulbs or lenses to channel and aim the light beams.

Laser Headlights

BMW has introduced a laser headlight system that does not actually shoot laser light out of the headlights, but it does use lasers to power the lights. A blue laser emits a very powerful beam that is reflected into a lens filled with yellow phosphorus. The excited phosphorus emits very strong white light that is then focused off reflectors and out the headlight housing. BMW claims the laser headlights can boost lighting range to 650 yards (594 meters) ahead of the vehicle, doubling the LED high-beam range.

The system can also work with the vehicle's navigation system to illuminate corners, in advance, as well as alert the driver of animals, people, and other obstacles within a distance of 330 feet (100 meters). Sensors and cameras are used to detect oncoming vehicles and prevent the laser headlight beam from illuminating the approaching traffic.

Daytime Running Lights

A large number of vehicles have **daytime running lights (DRLs)** for added safety. This system typically uses the high-beam light circuit. The control circuit is connected directly to the ignition switch to allow the lights to be turned on whenever the vehicle is running. The circuit has a control module that reduces battery voltage to about 6 volts. This voltage reduction causes the high-beam lamps to burn with less intensity and extends the life of the bulbs. When the headlight switch is moved to the HEADLIGHT position, the DRL circuit is shut down and the headlights work with their normal intensity and brightness. Applying the parking brake also deactivates the DRL system to make sure the lights are not on when the vehicle is parked with the engine running.

LED DRL Systems Many cars and light trucks now use LED daytime running lights **(Figure 20–19)**. The lamps are on a separate circuit that does not rely on resistors to decrease normal headlamp voltage. This means less energy is wasted and therefore the vehicle's fuel consumption is reduced. It is estimated that these lights consume more than 50 percent less power than the typical DRL. In addition, they use less space.

Auxiliary Lights

Auxiliary lights are only a concern to a technician when the owner of the vehicle feels the need to add lighting to what he or she already has. Although headlights provide adequate illumination of the road during normal driving conditions, some want additional lighting for special conditions, such as driving

FIGURE 20–19 LED DRLs.

FIGURE 20–20 Fog lamps.

in heavy fog. Normal light does not penetrate fog well. When an intense beam of light hits some fog, all the driver sees is a glare. To provide some light through the fog, fog lights **(Figure 20–20)** are designed to send a flat, wide beam of light under the blanket of fog. This is why they are mounted low and are aimed low and parallel to the road. Because fog tends to reflect light back at the driver, fog lights are often fitted with yellow or amber lenses to reduce the discomfort caused by the glare. Some vehicles have OEM fog lights that are part of the normal lighting circuit.

Driving lights normally use an H3 or H4 quartz halogen bulb and a high-quality reflector and lens to project an intense, pencil-thin beam of light far down the road. Proper aiming of these lights is extremely important. They are used to supplement the high beams and should be used in conjunction with them. Driving lights should be wired so that they are off when the high beams are off. One way to do this is

SHOP TALK

Auxiliary lights are easy to install when everything is carefully considered. Before beginning, become familiar with the local regulations for auxiliary lights and adhere to them. These regulations can be obtained from your state's department of transportation. Also, always follow all federal, state, and local laws when aiming headlights, fog lights, and driving lights.

SHOP TALK

When adding auxiliary lights, make sure that the generator and wiring are heavy enough to handle the increased wattage requirement. Installing a higher output generator may be recommended, especially if other electrical accessories are also being installed. The choice of wire size should be based on the current of the load. Most light kits include a relay as a safeguard. A relay is used because the required current for these lights, especially halogen ones, can be quite high. It is not unusual that they require as much as 25 amperes.

to supply the controlling switch with current from the high-beam circuit, rather than from a circuit that is live all the time.

Headlight Switches

The headlights are controlled by a power or ground input. Headlight switches are either mounted to the instrument panel **(Figure 20–21)** or are part of the multifunction switch on the steering column. The headlight switch controls most of the exterior lighting for the vehicle. Most switches have three positions: off, park, and headlight. Most vehicles have a warning system that alerts the driver that the park or headlamps are on and that the driver's door is open. Switches may control battery voltage and the bulbs have a fixed ground. However, many systems rely on a ground side switch to control the headlights. In these systems, voltage is always available at the headlights. The headlight switch completes the circuit to ground and the headlights turn on. In these systems, the dimmer switch is also a ground control switch.

FIGURE 20–21 A headlight switch.

When the headlight switch is in the OFF position, the open contacts prevent battery voltage from continuing to the lamps **(Figure 20–22)** or keeps the ground circuit open. When the switch is in the PARK position, the ground circuit is completed or battery voltage is applied to the parking lights, side markers, taillights, license plate lights, and instrument panel lamps. This circuit is usually protected by a separate fuse. When the switch is in the HEADLIGHT position, the ground circuit is completed or battery voltage is applied to the headlights. The lamps lit by the PARK position remain on.

A relay or a self-resetting circuit breaker is sometimes installed between the battery feed and the headlights. If a problem causes the breaker to open, the lights will go off until the breaker resets. Then the lights will come back on. If there is a serious problem in the circuit, the headlights might flash as the breaker cycles. Some vehicles have a separate fuse for the headlight on each side of the vehicle. This allows one headlight to operate if there is a problem in the circuit for one side of the vehicle. The relay uses a low current circuit to turn on the headlamps, if the circuit has excessive current; the relay will cycle the lamps on and off until the problem is corrected.

The headlight switch is often used as an input for the body control module (BCM) or lighting module. When the driver selects Auto or Low beam operation, the switch completes a circuit from the BCM. The BCM then supplies power to the headlights directly or completes the control circuit for the headlight relay.

The instrument panel lights come on whenever the headlight switch is in the PARK or HEADLIGHT position. The brightness of these lamps is adjustable. A rheostat is used to allow the driver to control the brightness of the bulbs. This control may be part of the headlight switch, in which case the driver simply rotates the headlight switch knob to adjust the panel lights. Most vehicles have a separate control for instrument panel brightness **(Figure 20–23)**. Some of these display a brightness scale on the instrument panel **(Figure 20–24)** to show the driver where the lights are adjusted within their possible range.

Dimmer Switches

The dimmer switch provides a way for the driver to switch between high and low beams. A dimmer switch can act as an input request for the lighting

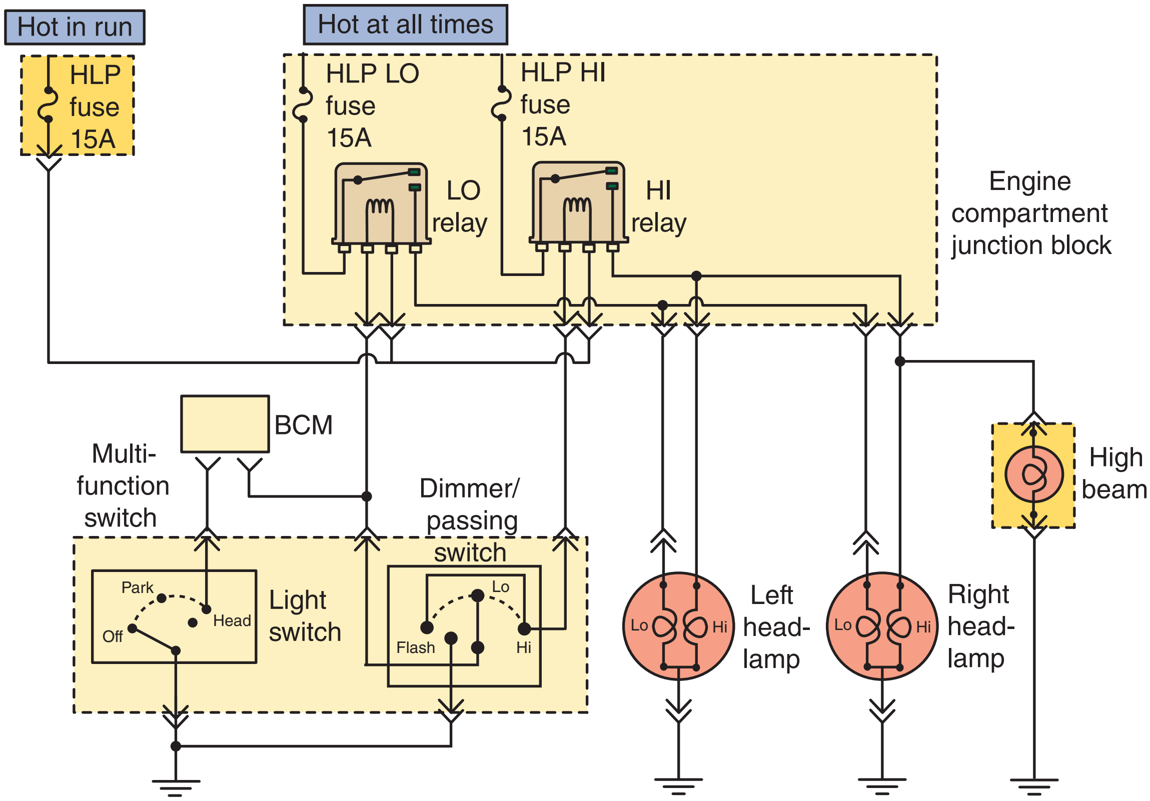


FIGURE 20–22 A schematic of a headlight circuit with switches.

FIGURE 20–23 An instrument panel light control switch. This switch may also reset the trip odometer.

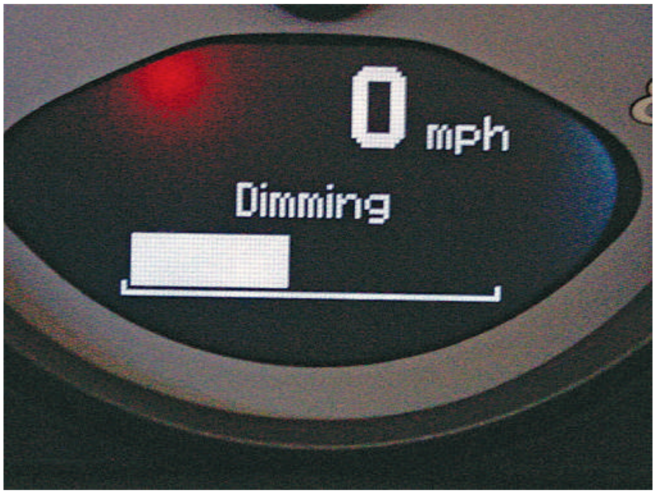


FIGURE 20–24 Some vehicles display a brightness scale on the instrument panel as the brightness control is moved.

module or can be in series with the headlight circuit and controls the path of current to the headlights; many dimmer switches connect the circuit to a good ground. When low beams are selected, current only flows through that circuit, likewise, when high beams are selected, current flows through that part of the circuit. The low-beam headlights are wired separately from the high-beam lamps. Often there is a relay for each set of beams. Newer vehicles have the dimmer switch on the steering column **(Figure 20–25)**.

When the headlight switch is in the HEADLIGHT position, current flows to the dimmer switch. If the

FIGURE 20–25 Most newer vehicles have the dimmer switch mounted on the steering column.

dimmer switch is in the LOW position, current flows through the low-beam circuit. When the dimmer switch is in the HIGH position, current flows to the high-beam circuit (see **Figure 20–22**).

Flash-to-Pass

Most steering column-mounted dimmer switches have a feature called "flash to pass." This circuit turns the high-beam headlights on even when the headlight switch is OFF or in the PARK position when the multifunction switch lever is pulled or pushed. When the driver pushes or pulls the multifunction switch's lever, the contacts of the switch complete the circuit to the high-beam filaments for as long as the driver holds the lever for pass-to-flash.

Automatic Light Systems

As with many other systems, exterior lights are controlled by electronic control modules. This allows for automatic high-beam dimming, automatic on-off, glare-free high beam, headlamp leveling systems, directional headlamps, intelligent light systems, adaptive headlights, dynamic beam control and advanced front-lighting systems. Cameras and a variety of optical sensors have been added to these computer-controlled lighting systems.

The systems are normally controlled by a conventional headlight switch **(Figure 20–26)**. They are typically equipped with a photocell sensor/amplifier and a control relay.

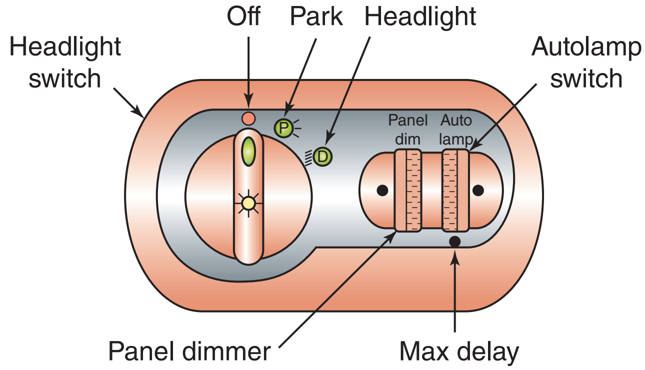


FIGURE 20–26 Headlight switch, instrument panel light control, and the auto lamp control.

Automatic Headlamps

Automatic headlamp systems automatically turn the headlights on when it becomes dark outside and turn them off when the natural light provides decent lighting. An electric photocell **(Figure 20–27)** located on the dashboard detects the current lighting conditions and activates the headlight control relay, which switches the headlamps on and off. As the level of light decreases, the photocell's resistance increases. When resistance reaches a preset amount, the photocell's amplifier sends power to the headlight relay. The lights will remain on until the system is turned off or the light outside gets bright enough.

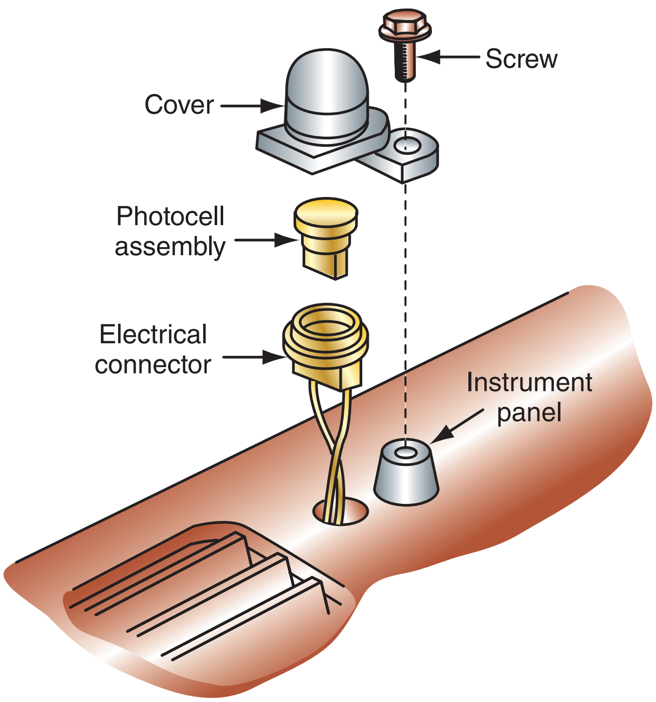


FIGURE 20–27 Most automatic headlight systems have a photocell located in the dash to sense ambient light levels.

FIGURE 20–28 A photocell for an automatic lighting system.

High-Beam Detection This system also automatically turns the high-beam headlights on or off according to conditions. A light sensor (commonly referred to as a camera) on the rearview mirror monitors the light in front of the vehicle **(Figure 20–28)**. When it is dark enough, the system will switch the high beams on. They will stay on until the sensor detects the headlights or taillights of another car. At that time, the high beams are switched off until the lights of the other vehicle are no longer detected. The absence of those lights causes the system to switch back to high beams. The system also fades the change from low to high to prevent abrupt changes to the light on the road ahead.

Delay Systems Some automatic headlamp systems allow the driver to set the length of time the vehicle's exterior lights will stay on after the passengers exit the vehicle. Normally, the variable switch can be adjusted to keep the headlights on for several minutes after the ignition is turned off. Of course, the driver can turn off the delay system and the headlamps will shut off as soon as the ignition is turned off.

Adaptive High-Beam Assist

Adaptive high-beam assist systems continuously adjust the lighting range of the headlamps so the beams only extend to the vehicle ahead. Doing so allows for a maximum range of lighting without causing excessive glare in the eyes of other drivers. These systems are offered by many manufacturers and each call the system by a different name. However, most of these systems do the same basic thing. Some have additional features in addition to the basic package.

These systems provide for a continuously changing range of lighting. There is no distinct transition from low to high beams. The intensity and aim of the lamps gradually changes as conditions change. When there is no traffic close enough for glare, the system provides full high beam. When the system detects an approaching vehicle or a vehicle's taillamps, the high beams will turn off. Most of these systems allow the headlamps to adjust about every 40 milliseconds.

A camera and/or a light sensor are located in a module at the front of the inside rear view mirror **(Figure 20–29)**. The sensor analyzes the color of the light, its intensity and movement to distinguish between vehicle lights and other light sources. The systems are designed to ignore non-vehicular light sources.

FIGURE 20–29 A digital camera module mounted to a rear view mirror.

CUSTOMER CARE

If the customer's car is equipped with an automatic light control system, point out the location of the perforated holes or slots. Warn the customer not to place any items that may block light from the sensor/amplifier assembly. Blockage causes erratic operation of the system. The photocell must always be exposed to an outside light to function properly.

Glare-Free High Beams

A glare-free high-beam system uses a camera-driven lighting control strategy. The system selectively looks at shady spots with the lighted area ahead of the vehicle and slices out segments of light from the high-beam light pattern to protect other drivers from glare. At the same time, the system attempts to provide the driver with maximum seeing range. The dynamic shadowing is achieved by movable shadow masks that are moved into the normal light path of the headlamp. The dynamic beam control automatically adjusts the light beams to the current traffic and ambient lighting conditions.

When the system is activated, the camera in or around the windshield recognizes vehicles through its image processing system. The system then calculates the optimum light distribution and sends the appropriate commands to the headlights.

Adaptive Headlights

Adaptive headlight systems (AHS) aim the headlight beams to follow the direction of the road directly ahead as the vehicle turns **(Figure 20–30)**. These systems are electronically controlled by a module and inputs from the steering system and vehicle speed.

Some vehicles have headlamps that are directly connected to the steering linkage to allow the lamps to follow the movement of the front wheels. As an example, the 1948 Tucker Sedan was equipped with a third headlamp, located in the center of the front of the car, that responded to the movement of the steering system. Today, systems rely on inputs from a variety of sensors and actuators to move the headlamps.

Adaptive headlight systems are available on many vehicles, each with their own way to "bend" the light beams in anticipation of a turn. Regardless of the system's components, the system is controlled by the BCM in response to the vehicle's current steering angle, yaw rate, and road speed.

One design swivels the entire headlamp assembly with electric motors attached at the base of the lamp assembly **(Figure 20–31)**. The motor can move the left headlamp up to 15 degrees to the left and 5 degrees to the right, and the right headlamp up to 5 degrees to the left and 15 degrees to the right. In addition to switching between low and high beams, the system can respond to suspension position sensors and operate the motor to keep the headlight beam level with the road.

Some manufacturers adjust the light beam by rotating the lamp's projector, reflector, or lens. This system uses a motor to rotate a drum inside the light assembly. The drum changes the light pattern to provide the best illumination for the current conditions. With these systems, the aim of the beam can

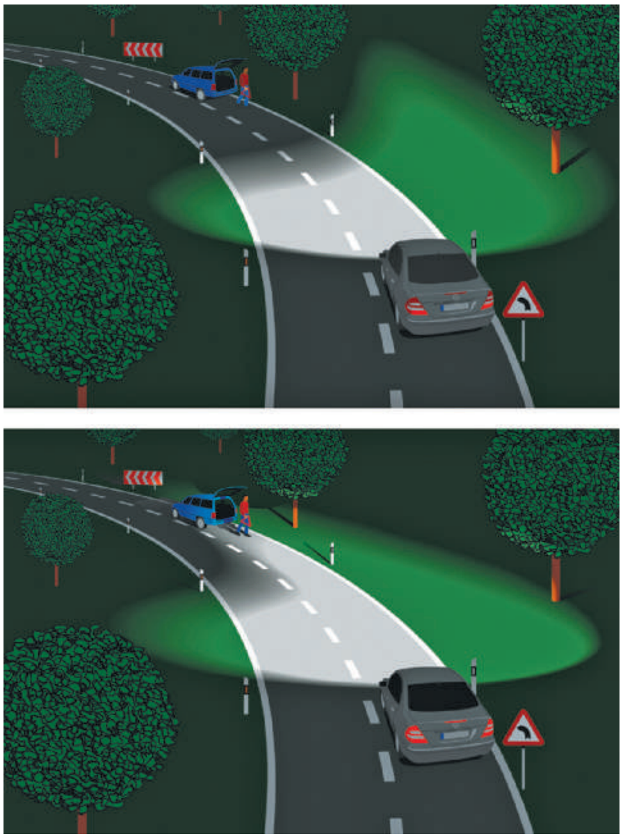


FIGURE 20-30 A comparison of how the road is lit up with a conventional (top) headlamp system and an adaptive (bottom) system.

Courtesy of Chrysler LLC.

FIGURE 20-31 A headlamp assembly for an adaptive headlight system.

be adjusted in response to conditions by moving the lamp assembly or by adjusting the lamp's position within the reflector.

Another design uses extra lamps that turn on according to steering angles. For example, a newer system illuminates individual LED lamps sequentially and with various intensities. These lights may be housed in the headlamp or fog light assembly, or they can be a separate unit. These lamps normally only turn on during low-speed turning.

Adaptive headlights can also be controlled by GPS navigation and digital road maps. Information about the road ahead allows the system to anticipate curves and rotate the headlamps so they can illuminate those curves before the driver starts to turn the steering wheel.

Headlamp Leveling Systems

Due to differences in safety regulations in Europe and North America, headlight leveling systems are much more common on European vehicles. Headlight aiming was such a concern in Europe that the 1948 Citroen 2CV had a headlamp leveling system that was manually controlled by a knob connected to the steering rod linkage. The effect of the light on the oncoming traffic was not considered with this system. However, in 1954, a system was introduced that was responsive to movements of the suspension system and kept the headlamps correctly aimed regardless of the vehicle's load and without adjustments made by the driver.

In the 1970s, other European countries required leveling systems that allowed the driver to lower the lamp's aim by a control lever or knob on the instrument panel. The rear of the vehicle sits lower if the weight of the passengers and load is high. This causes the beam from the lamps to rise and create a glare in the eyes of the drivers in front.

Headlamp leveling systems are not required for vehicles sold in North America. However, recent research strongly recommends the use of automatic levelers on all headlamps. Headlight leveling depends on many sensors and a BCM-controlled motor. In Europe, the headlights' vertical aim must be maintained regardless of vehicle load. If the vehicle is not equipped with an adaptive suspension, a headlight leveling system is needed to keep the headlamps aimed correctly.

Vehicles with xenon lamps and some high-power halogens must be equipped with headlamp self-leveling systems. These systems sense the level of the vehicle caused by load and road inclination, and then adjusts the headlamps' vertical aim to keep it correctly aimed without any involvement by the driver.

Headlight Service

When there is a headlight failure, it is typically caused by a burned-out bulb or lamp, especially if only one lamp fails. However, it is possible the circuit for that one lamp has an open or high resistance. Check for voltage at the bulb before replacing a bulb. If there is no voltage present, the circuit needs work and the original bulb may still be good. If more than one lamp (including the rear lights) is not working, carefully check the circuit. A problem there is much more likely than having a number of burned-out bulbs. Of course, if the charging system is not being regulated properly, the high voltage will cause lamps to burn out prematurely. **Figure 20–32** shows common headlight problems and their probable causes.

Restoring Headlight Lenses

Many lenses are made of plastic (polycarbonate) and are affected by the environment and deteriorate. The result is a cloudy lens that reduces the light of the lamps. The cloudiness is caused by the oxidation of the lens' protective coating installed by the lens' manufacturer. The lenses may also become pitted by road dirt and pebbles and can crack. Cracks can allow water to enter the headlamp assembly and shorten its life.

If the damage to the lens is minor, it may be able to be corrected by using car polish. In more severe conditions, the deterioration is deeper than the

CUSTOMER CARE

Restoring the lens is an easy procedure. There are many available products to restore the lenses. These may be special sanding pads or specially designed chemical compounds. Most damaged headlamp covers will require wet sanding to remove the worst of the damage before a polishing compound is used on the lens. Some restoration kits include a sealer to help prevent the lens from future damage.

PROBLEM AREA	SYMPTOMS	POSSIBLE CAUSES
Headlights	One low-beam headlamp does not work	Bad bulb High resistance in the power or ground circuit
	Both low beams do not work	Open in the power or ground circuit Bad (control) switch Blown fuse Bad bulbs due to overcharging
	One high-beam headlamp does not work	Bad bulb High resistance in the power or ground circuit
	Both high beams do not work	Open in the power or ground circuit Bad (control) switch Blown fuse Bad bulbs due to overcharging
	Dim headlight illumination	Poor ground connection Corroded headlight socket Poor battery cable connections Low generator output Loose or broken generator drive belt
	Lights dimmer than normal	Excessive circuit resistance on the power or ground side of the circuit Low generator output, wrong lamps, or incorrect wiring
	Lights brighter than normal	Higher than specified generator output Improper lamp application Dimmer switch stuck in the high-beam position
	Intermittent headlight operation, headlights flicker	Defective circuit breaker Overload in circuit Improper connection Defective switch Poor ground Excessive resistance
	No or improper headlight	Burned-out headlights Defective headlight switch Open circuit Defective circuit breaker Overload in circuit Improper or poor connection Poor ground Excessive resistance Defective relay Blown fuse Faulty dimmer switch Short in insulated circuit Improper bulb application Improper headlight aiming

FIGURE 20-32 Common headlight problems and their probable causes. (*continued*)

PROBLEM AREA	SYMPTOMS	POSSIBLE CAUSES
Automatic headlight system	Headlights fail to turn on	Faulty headlight switch Power feed to relays Faulty relay(s) Open, short, or high resistance in relay control circuit motor control circuits Headlamp circuit failure Burned out headlamp elements Controller power and ground circuits Faulty controller
	Headlights fail to turn on in automatic mode, headlights work in manual mode	Open input circuit from switch to control module Faulty module Faulty switch
	Headlights turn on in daytime when switch is in AUTO mode	Faulty photocell Open photocell circuit Shorted photocell circuit Faulty control module Bus communications error Immobilizer system inoperative
Automatic high/low beam	Headlights fail to automatically switch to high beam	Obstruction in front of camera Improper headlight aiming System not initialized Camera alignment System voltage to module Module ground circuit Bus network failure Faulty controller
Daytime running lights	DRL fail to turn on	Faulty headlight switch input or circuit Power circuit to DRL relay or relay module Defective relay or relay module Parking brake switch or circuit System voltage to module Module ground circuit Bus network failure Faulty controller
Headlight leveling system	Headlights fail to level properly	Improper headlight aiming Faulty switch input or circuit Faulty headlight level sensor or sensor circuits Disconnected link to headlight level sensor(s) Circuits to motor(s) Defective motor(s) System voltage to module Module ground circuit Bus network failure System not calibrated Faulty controller

FIGURE 20-32 (*continued*)

actual outer plastic material. This damage can only be corrected by replacing the entire headlamp lens.

Sanding or aggressively polishing the lenses can provide a temporary fix. But it may remove the protective coating from the lens, which can cause the lens to deteriorate quicker and more severely.

The reflector, which is a thin layer of vaporized aluminum on a metal, glass or plastic structure, can become dirty, oxidized, or burnt. This happens when water enters the headlamp assembly, bulbs of higher than specified wattage are used, or simply due to age and use. If degraded reflectors cannot be cleaned, they must be replaced.

Lens Cleaners The light beams from headlights can scatter if the lens is dirty. The scattering increases the glare experienced by drivers in front of the vehicle. This is especially true if the vehicle is equipped with HID headlamps. Although lens cleaners are required, in Europe, on all vehicles with HID lamps, the United States has no such law. However some vehicles do have lens cleaners. The two basic types of cleaners found on today's vehicles: a small motor-driven wiper blade or a fixed or pop-up high-pressure nozzle that cleans the lens with a steady spray of windshield washer fluid.

Headlight Replacement

There can be slight variations in procedure from one model to another when replacing headlights. For instance, on some models the turn signal light assembly must be removed before the headlight can be replaced. Overall, however, the procedure does not differ much from the following typical instructions. Make sure the replacement bulb is the same type and part number as the one being replaced.

Sealed-Beam Headlight Replacement

Replacing a sealed-beam headlamp is rather straight forward. The lamp is normally secured with a bezel or ring. This needs to be removed and the lamp pulled partially out of its housing. Then disconnect the electrical connector from the back of the lamp **(Figure 20–33)**. Carefully inspect the connector for signs of damage or corrosion. Some manufacturers recommend coating the prongs and base of a new headlamp with dielectric grease for corrosion protection. Connect the new lamp to the electrical connector. Place the new lamp into the housing. Position the lamp so the embossed number on its lens is at

FIGURE 20–33 After unplugging the old bulb, check and clean the contacts in the connector before installing the new bulb.

the top. Install the headlight bezel. Secure it with the retaining screws. Check the aim of the headlight and adjust it, if necessary.

Composite Headlight Replacement

Replacing a composite headlight bulb is typically very easy—getting to it often is not. Bulbs are secured one of the three ways; with a retaining ring **(Figure 20–34A)**, by twisting and locking into the housing **(Figure 20–34B)**, or by a wire bale **(Figure 20–34C)**. Before attempting to replace the bulb, refer to the service information for instructions. If the bulb can be removed from the engine compartment, place a fender cover on the vehicle and remove any protective cover from the back of the housing and remove the bulb.

To access the bulbs in some vehicles, the bumper cover is removed to access the bolts that hold the headlight assembly. When removing a bumper cover, you will probably have to replace the plastic body clips that are used to hold panels in place. On some vehicles, the inner fender liner is removed to access the bulbs **(Figure 20–35)**. Regardless of how to get to the bulb, avoid touching the glass of the new bulb when installing it into the housing.

SHOP TALK

Because of the extremely high voltages involved, any work on xenon lighting should be done carefully and according to the manufacturer's recommendations.

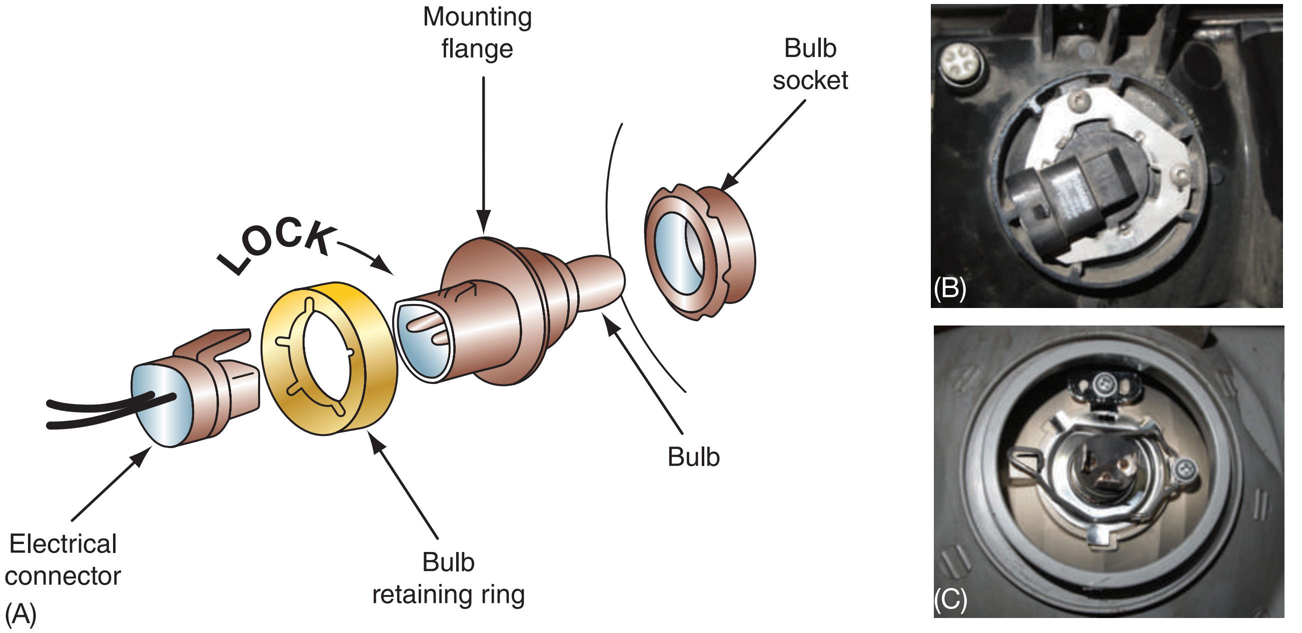


FIGURE 20-34 (A) Twist to unlock the retaining ring to remove the bulb. (B) Turn the bulb counterclockwise to remove the bulb from the housing. (C) Press and slide the wire bale out to remove the bulb.

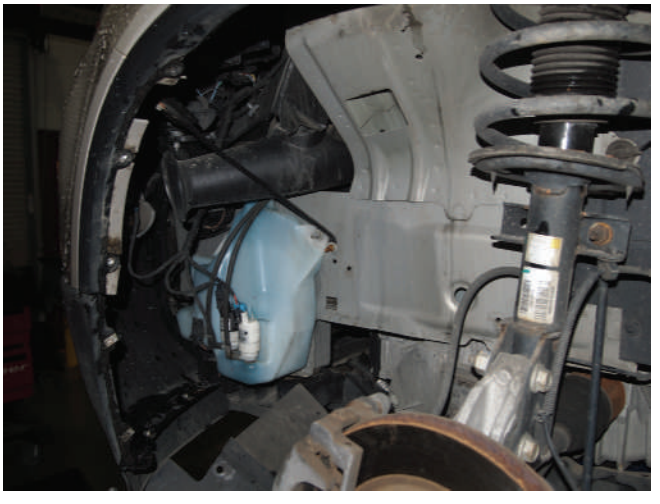


FIGURE 20-35 Accessing the headlights may require removing inner fender liners or bumper covers.

HID Diagnosis and Service

Proper diagnosis of these systems depends on understanding how the circuit works. If only the low beams have an HID system, the headlights contain an arc tube and ballast. The ballast increases the voltage so an arc can be established across the electrodes. When the headlight switch is moved to the HEADLIGHT position, the ground for the low-beam relay is completed by the control computer (BCM). This energizes the relay and battery voltage is applied to the ballast in each headlamp assembly. The ballast increases the voltage and starts the high-voltage arcing to light the bulb. Once the arc is established, much less voltage is necessary to maintain the arc across the electrodes.

In bi-xenon systems, there is no separate high-beam bulb. Rather a solenoid or stepper motor attached to a shutter is used to redirect the light beams from the bulb. When the headlamp dimmer switch is moved to the high-beam position, ground is applied through the dimmer switch to the BCM. In response to this signal, the BCM completes the ground for the high-beam relay, energizing the relay. Battery voltage is then applied to the left and right high-beam solenoids that move the shutter.

When an HID lamp is not working, do not automatically assume there is a faulty lamp. The ballast assembly could be bad or there is a fault in its electrical circuit. To make sure the circuit is operating fine, check for battery voltage at ballast and also check its ground. Do not try to measure voltage supplied to the bulb. The start-up voltage could be 30,000 volts or more. Look at the lamp, a smoky or blackened lamp may indicate the bulb is burned out. If the bulb looks good, but does not illuminate, it is likely that the ballast or igniter is faulty.

Normal Delay Often the wait period for xenon lights to become fully illuminated is considered a problem. This is not a problem; it is normal. The ballast needs to provide high voltage to start and keep the lamps illuminating. This takes a little time; it may take

2 seconds to establish the arc and then another 30 seconds to have full illumination. Obviously, if it takes longer than that, there is a problem.

Bulb Color Another normal concern is the color of the light. HIDs produce a bluish-white light. However, some produce a light beam that appears pure white. This is not a problem, even if one side appears to be a different color than the other side. The color of the light depends on many normal factors. A worn bulb may have a dim pinkish glow. Often replacement bulbs will have a yellowish-white look for the first 5 minutes when turned on. The lamps still provide the same amount of light as the originals and will provide a bluish light after about 100 hours of operation.

Bulb Replacement HID bulbs normally do not suddenly stop working. As the bulb wears, it will shut off and then turn back on. When the bulb is in the early stages of wear, this will happen very infrequently. As time goes on, the bulb will shut down and come on again rather frequently. This problem may progress to flickering until the system totally shuts down. Each manufacturer has a procedure for monitoring and diagnosing the system; always follow those.

Over time the resistance across the bulb's electrodes increases. This makes it harder for the ballast to establish and maintain the arcing. When the arcing is lost, the system will trigger the ballast to establish the arc again. This is what causes the light to flicker. It is best to replace the bulb before the lights constantly go on and off.

Every time the bulb shuts down, the ballast uses high voltage to reestablish the arc. The repetitive high voltage surges across the electrodes damages the ballast. Eventually, the system will stop sending current to the ballast and the bulb will not work. When the lights have been flickering for a while the ballast should be replaced along with a new bulb.

Adaptive High-Beam Assist

Most adaptive high-beam assist systems rely on an LED to inform the driver of any system fault. The green LED is located along the bottom plane of the inside rearview mirror. If the LED is flashing slowly, the system recognizes that its camera needs to be properly aimed. Always follow the manufacturer's procedure for doing this. If the LED is continuously flashing rather quickly, a system fault has been detected and a DTC has been set.

Headlight Adjustments

Headlights must be kept in adjustment to obtain the safest and best light beams on the road ahead. Headlights that are properly adjusted cover the correct range and afford the driver the proper nighttime view. Headlights that are out of adjustment can cause other drivers discomfort and sometimes create hazardous conditions.

Before adjusting or aiming a vehicle's headlights, make the following inspections to ensure that the vehicle is level. Any one of these conditions can result in an incorrect setting.

- If the vehicle is coated with snow, ice, or mud, clean it, especially the underside. The additional weight can alter the riding height.
- Try to make the adjustment with the fuel tank half full; this should be the only load present on the vehicle.
- Worn or broken suspension components affect the setting, so check the springs or shock absorbers.
- Inflate all tires to the recommended air pressure levels.
- Make sure the wheel alignment and rear axle tracking path are correct before adjusting the headlights.
- After placing the vehicle in position for the headlight test, push down on the front fender to settle the suspension.

Headlight assemblies have adjusting screws **(Figure 20–36)** to move the headlight within its assembly to obtain correct headlight aim. Lateral or side-to-side adjustment is made by turning the adjusting screw at the side of the headlight (see Figure 20–23). Vertical or up-and-down adjustment is made by turning the screw at the top of the headlight.

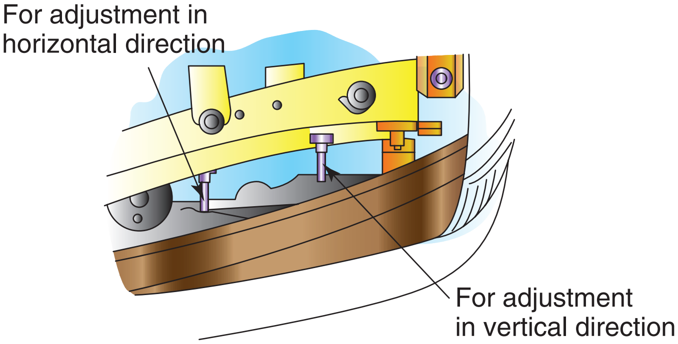


FIGURE 20–36 An example of headlight adjustment screws.

SHOP TALK

While adjusting headlight beams, make sure they meet the standards established by your local community, state, or province.

To properly adjust sealed beam headlights, aiming equipment can be used. These special aimers use mirrors with split images, like split-image finders on some cameras, and spirit levels to make exact adjustments. When using any mechanical aiming tool, follow the manufacturer's instructions.

When headlight-aiming equipment is not available, alignment can be checked and adjusted by projecting the beam of each light on a screen or chart placed about 25 feet in front of the headlight **(Figure 20–37)**. The vehicle must be exactly perpendicular (at a right angle) to the chart.

Measure the distance between the centers of the headlights. Use this measurement and draw two vertical lines on the chart that corresponds with the center of the headlights. Then draw a vertical centerline halfway between the two vertical lines. Measure the distance from the floor to the centers of the headlights. Subtract 2 inches from this height and draw a horizontal line on the screen at this new height.

With the headlights on high beam, the hot spot of each projected beam should be centered at the intersection of the vertical and horizontal lines on the chart. If necessary, adjust the headlights vertically and laterally to obtain proper aim.

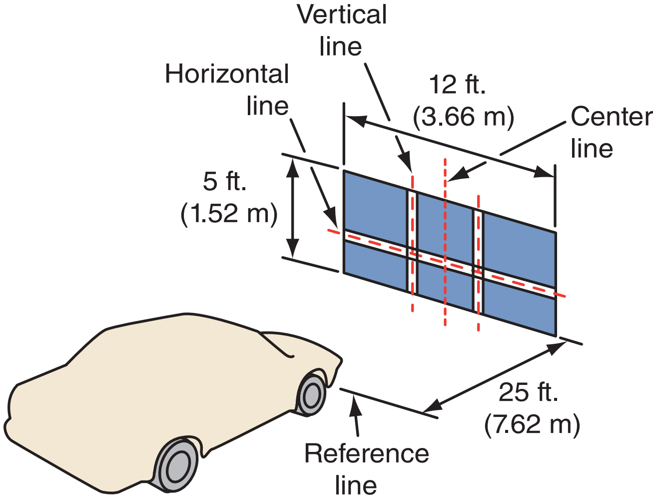


FIGURE 20-37 Acceptable beam patterns on a wall screen.

FIGURE 20-38 Some vehicles have a bubble level at the headlights to aid in alignment.

Some vehicles have a horizontal indicator gear at each headlamp assembly. Prior to making any adjustments, it is recommended that this indicator be at "0." A screwdriver is used to bring the gear back to "0." After this, the headlamps can be adjusted to specifications.

Also, many headlamps have a bubble level to aid alignment. The bubble level **(Figure 20–38)** is calibrated to the earth's surface; therefore, the vehicle must be on level ground when the headlights are aimed. If the headlight beam projection appears high to oncoming traffic, check the alignment on an alignment screen. If the beam pattern is above or to the left of the specified location on the screen, adjust the headlights, and then recalibrate the bubble level and magnifying window. Ideally, if the headlights are aligned, the bubble level and magnifying window will be centered. Never change the calibration of the magnifying window or bubble level if the headlights are out of alignment.

Auto-Leveling Headlamps

Some vehicles, primarily those equipped with xenon headlamps, have an automatic headlight leveling system. With this system there is no need to adjust the headlamps. However, if this system fails, the headlamps will not be properly aligned and the system must be diagnosed. Before diagnostics can take place, an understanding of how the system works is important.

Diagnosis Diagnosis is done with a scan tool. The scan tool can be used to order the motors to move up and down. With the ignition on, do this and observe

the headlamps. If they do not move, test the motors. If the motors move, check the voltage of the front and rear leveling position sensors. Normally the voltage should be between 0.5 and 4.9 volts. If the reading is not within the specified range, check the sensors.

The scan tool may also retrieve fault codes for the system. Possible fault codes can be set for a short to ground, open/high resistance, short to voltage, and abnormal signal performance for the following areas:

- Front and rear headlamp leveling sensor
- Front and rear headlamp leveling sensor 5-volt reference
- The headlamp leveling motor control circuits on both sides

The motor assembly is checked with an ohmmeter. With the ignition off, disconnect the electrical connector at each headlamp leveling motor. Take resistance readings across the various terminals of the connector and compare your reading to the specifications. The leveling sensors are checked with a voltmeter. First the reference voltage is checked at the specified terminals. If the voltage is higher than normal, there is a short to ground, an open, or high resistance in the circuit. If all circuits test normal, the appropriate headlamp leveling sensor may be bad.

Automatic Headlight System Diagnosis

Automatic headlight systems respond to changes in outside light levels. A photocell, normally in the vehicle's dash, sends a signal to the BCM. The BCM energizes the low-beam circuit when it is appropriate. If the headlamps turn on when the headlight switch is placed on the position but not when it is in "auto," the problem is in the auto circuit. Check the area around the photocell for anything that may be blocking light from the sensor. Check all connections in the system. The circuit normally contains a relay and amplifier along with the photocell. Each should be tested according to the procedures given by the manufacturer.

The photocell, or camera, must be properly aligned in order for the system to respond to the lights of oncoming vehicles and not lights coming from the far sides of the road. This typically is a very involved process and the procedures given by the manufacturer must be followed. This involves many measurements and conducting tests with a scan tool **(Figure 20–39)**.

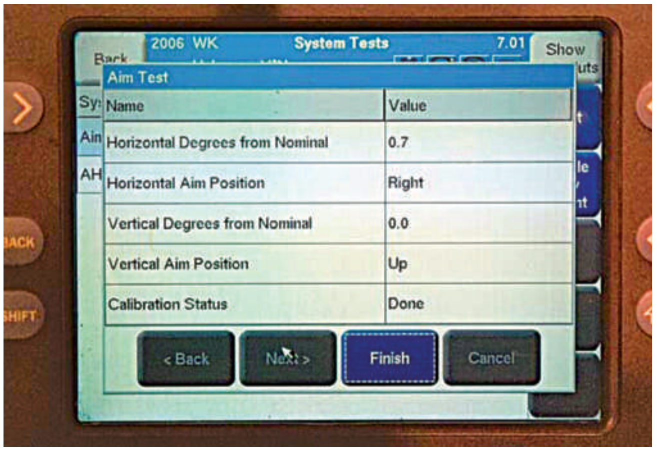


FIGURE 20–39 Calibration of the photocell includes a check with a scan tool.

Most systems also keep the lights on for a short time after the vehicle has been parked. The controlling device for this feature is a potentiometer incorporated into the headlamp switch. When the delay feature is not working properly, begin testing at the timer control.

Adaptive Headlight Diagnosis

The operation of the adaptive headlight system is controlled by the headlamp control module. Therefore, diagnosis begins with a scan tool. Because the system responds to many inputs, each one should be monitored.

The headlamp control module receives serial data from the engine control module, transmission control module, electronic brake control module, and BCM. The control module calculates the desired headlamp angle and orders the actuators or motors, at each headlight to move the headlamps. The control module also monitors the condition of the motor control circuits. If a problem is detected, a DTC will be set and a message displayed in the instrument panel to alert the driver of a problem.

Basic Lighting System Diagnosis

Several types of light bulbs are used in today's vehicles **(Figure 20–40)**. Each has a unique purpose and a unique way that it fits into its socket. Within a particular design, the different bulbs may have their own power rating. When replacing a bulb, make sure it is the exact replacement. Lamp types can be

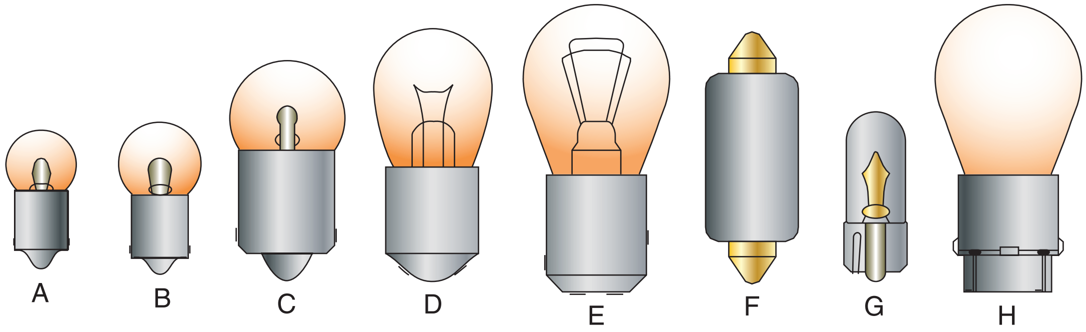


FIGURE 20–40 Common types of automotive bulbs.

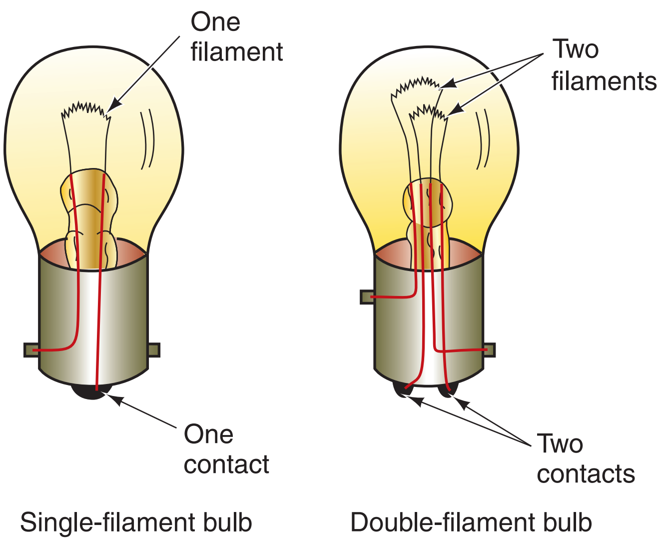


FIGURE 20–41 Single and dual filament light bulbs. Notice the number of contacts and the position of the locating pins on the side of the bulbs' ground, these identify the type of bulb.

identified by the lamp's standard trade number, usually present on the lamp's housing.

Lamps are normally one of two types: they have a single filament or a double filament **(Figure 20–41)**. Double-filament bulbs serve more than one function. They can be used as the lone bulb in the stoplight circuit, taillight circuit, and the turn signal circuit, or combinations of these.

Taillights, turn signals, hazard lights, side lights, parking lights, and fog lamps may use an LED or a cluster of LEDs. When a light is not working, make sure you know if an LED is being used before getting a new bulb or beginning diagnostics.

Light problems can be solved by simply replacing bulbs. A bulb can be quickly checked with a powered testlight or an ohmmeter. Connect the testlight across two of the bulb's terminals. If there is continuity, the bulb is good.

When a burnt-out bulb is not the problem, corroded or loose wiring is the next most common problem. All wiring connections should be clean and tight; light assemblies need to be securely mounted to provide a good ground. **Table 20–1** is a basic troubleshooting guide for lighting problems.

Bulb Replacement

Bulbs are held in their sockets in a number of ways. Some bulbs are simply pushed into and pulled out of their sockets **(Figure 20–42)**, and some are screwed in and out. Some bulbs must be depressed and turned counterclockwise to remove them.

When replacing a bulb, inspect the bulb socket. Often moisture gets into a bulb socket and causes corrosion at the electrical contacts in the socket. At times,

TABLE 20-1 BASIC TROUBLESHOOTING CHART FOR LIGHTING SYSTEMS

Problem Area	Symptoms	Possible Causes
General	One light does not work	Bad bulb Open in that circuit
	One light is dim	High resistance in the power or ground circuit
	All lights in a circuit do not work	Open in the power or ground circuit Blown fuse Bad (control) switch
	All lights in a circuit are dim	High resistance in the power or ground circuit
	Flickering lights	Loose electrical connection A circuit breaker that is kicking out because of a short
	Bright illumination, early bulb failure	Generator output too high Defective dimmer switch

FIGURE 20-42 Many light bulbs are pulled out and pushed into their sockets.

the corrosion can be removed with sandpaper. Other times, the socket or light assembly should be replaced.

Light bulbs may be contained in an assembly and access to the bulb is gained by reaching around the rear of the assembly and removing the socket. Other assemblies require the removal of the light's outside lens. With the lens removed, the bulb is removed from the front. While doing this, inspect the lens and gasket for damage and replace any damaged parts. If the lens is not sealed, dirt and moisture can enter the assembly and cause problems in the future.

On some light fixtures, the light assembly must be removed and the bulb and socket are removed from the rear of the assembly. Do not remove the lens from the assembly. It is a sealed unit and dust and other contaminants can cause serious damage to the reflector. Also, never attempt to clean the reflector. Wiping its surface can seriously reduce the light's brightness.

Light Circuits

Older light systems may only use one wire to the light, making use of the car body or frame to provide the ground. Because many of the manufacturers are now using plastic sockets and mounting plates (as well as plastic body parts) to reduce weight, most lights must now use two wires, the second one for the ground. Many bulbs have a single filament.

Double-filament bulbs are actually two separate bulbs in one casing; therefore, they have two hot wires. Most are grounded through their case and require a third wire for ground. Many light circuits are switched or controlled on the power side of their circuit; however, there are ground-controlled circuits. Because many newer vehicles use either the BCM or a lighting control module to monitor and control light operation, knowing how the light is controlled is important for diagnostics.

Rear Exterior Lights

The rear of a vehicle has many different lights. These include the taillights, turn signal and hazard lamps, brake lights, a center high-mounted stoplight, side marker lamps, reverse or back-up lights, and license plate lamps. Many of them are incorporated in the taillight assembly. Rear lighting is definitely part of the overall style of the vehicle and most make a styling statement **(Figure 20–43)**.

Taillight Diagnostic Tips

If all lamps don't operate, check the condition of the fuse. If the fuse is good, check the operation of the

FIGURE 20–43 A stylish taillight assembly using LED technology.

taillight relay. You can use a testlight or voltmeter to check for the presence of voltage and ground at various parts of the circuit at the relay. If the system uses a BCM or lighting module, check for light switch input with a scan tool. If no voltage is measured at one of the circuits, there is probably an open in that circuit. If no voltage is reaching the taillights but the headlamps are working fine, replace the switch. **Table 20–2** is a typical diagnostic chart for rear lighting circuits.

Turn, Stop, and Hazard Warning Light Systems

For older, non-computer controlled systems, power for the turn (directional signal), stop, and hazard warning light systems is provided by the fuse panel

TABLE 20–2 REAR LIGHTING DIAGNOSTIC CHART

Problem Area	Symptoms	Possible Causes
Park/Taillights	No or improper Park/Taillights operation	Defective headlight switch Open circuit Defective circuit breaker Overload in circuit Improper or poor connection Poor ground Excessive resistance Defective relay Blown fuse Short in insulated circuit Improper bulb application
Turn Signals	Slow turn signal operation	Bad flasher unit High resistance in the power or ground circuit Incorrect bulb
	Turn signal on one side does not work	Bad bulb High resistance in the power or ground circuit
	Turn signals do not operate in either direction	Blown fuse Defective or worn flasher unit Defective or faulty turn signal switch Open circuit
	Turn signal lamp does not illuminate	Improper bulb Burned out bulb Open circuit Failed flasher unit
	Turn signal indicator illuminates but does not flash	Improper bulb Burned out bulb Open circuit Failed flasher unit

TABLE 20-2 *(continued)*

Problem Area	Symptoms	Possible Causes
Brake Lights	Intermittent brake lamp operation	Misadjusted brake light switch Poor ground connection Excessive resistance Faulty sockets Poor connections Faulty turn signal switch contacts Defective brake light switch
	Dimmer-than-normal stop lights	Excessive circuit resistance Poor ground connection Improper bulb application Improper connections Faulty turn signal switch contacts Improper bulb application
	No stoplamps illuminate. Stoplights fail to illuminate when the brakes are applied.	Faulty brake light switch Open in the circuit Improper bulb application Faulty turn signal switch Improper common ground connection Burned out light bulbs
Hazard light operation	Hazard lights fail to operate when activated.	Blown fuse Defective or worn flasher unit Defective or faulty hazard light switch Open circuit Defective turn signal switch
Back-up light	Back-up lights fail to operate some of the time.	Misadjusted back-up light switch Poor ground connection Excessive resistance Faulty sockets Poor connections
	Dimmer-than-normal back-up lights	Excessive circuit resistance Poor ground connection Improper bulb application Improper connections Faulty back-up switch contacts
	Back-up lights fail to illuminate when the transmission is in reverse.	Faulty back-up light switch Misadjusted back-up light switch Blown fuse Open in the circuit Improper bulb application Improper common ground connection Burned out light bulbs
	One back-up light fails to illuminate when the transmission is in reverse.	Burned out lamp Loose connection Open circuit to lamp

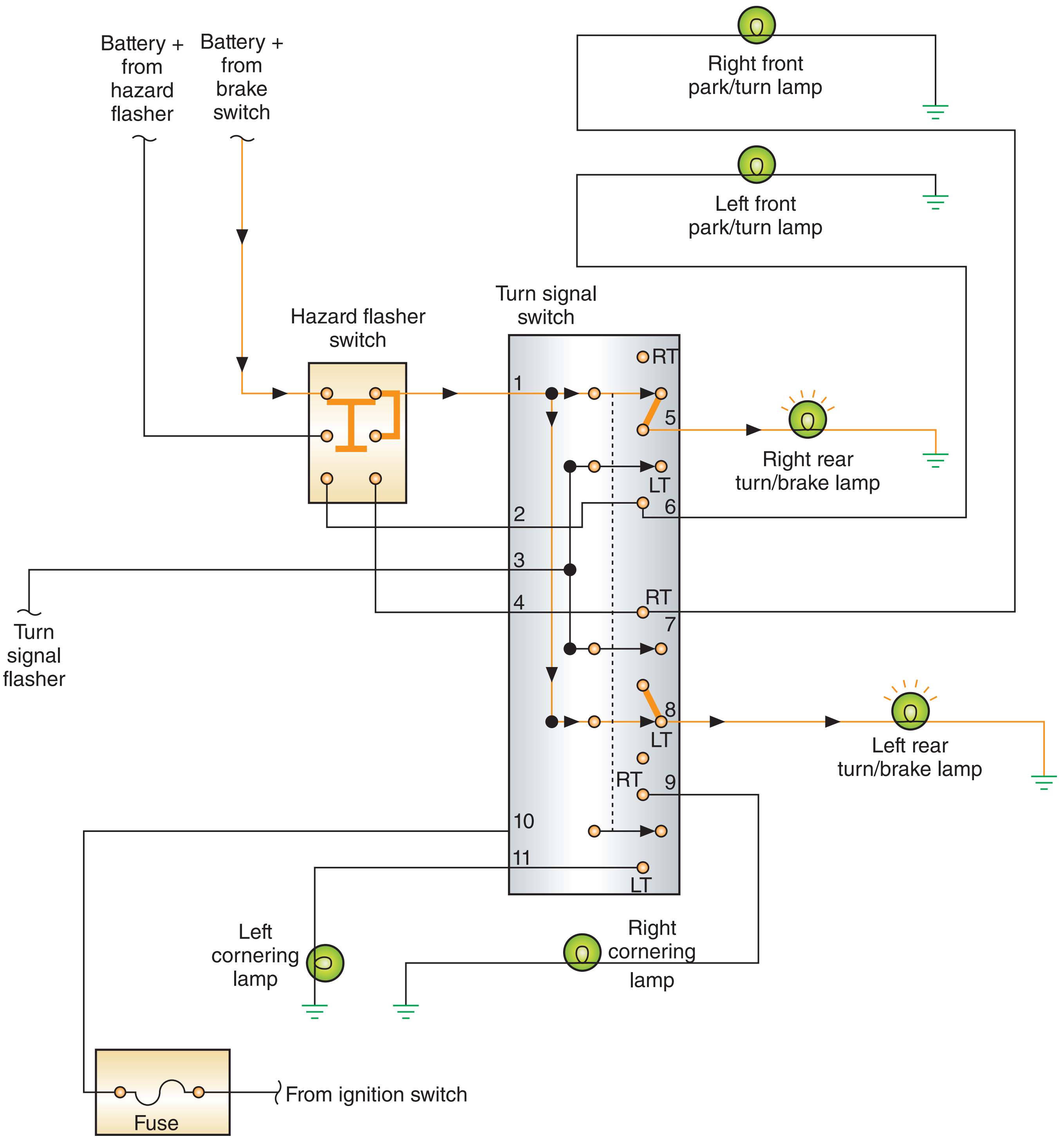


FIGURE 20–44 A turn signal circuit for a two-bulb system.

when the ignition switch is on **(Figure 20–44)**. Each system has a switch that must close to turn on the lights in the circuit. The hazard lights are also powered through the fuse panel; however, they have power at all times regardless of ignition switch position. Hazard lights are commonly referred to as 4-way flashers because the lights at all four corners of the vehicle will flash when the circuit is turned on.

Side markers are connected in parallel with the feed circuit (from the headlight switch) for the filaments of the front parking lights and rear taillights.

The turn signal and hazard light switches on many current vehicles are part of a multifunction switch. When the turn or directional signal switch is activated, only one set of the switch contacts is closed—left or right. However, when the hazard switch is activated,

all contacts are closed and all turn signal lights and indicators flash together and at the same time.

What a multifunction switch controls depends on the make, model, and year of the vehicle. Some control the directional signals and serve as the dimmer switch. Others control the turn and hazard signals and serve as the headlight, dimmer, windshield wiper, and windshield washer switch.

This switch is not repairable and must be replaced if defective. Photo Sequence 18 outlines the typical procedure for removing a multifunction switch. Some of the steps shown in this procedure may not apply to all types of vehicles; always refer to the service information before removing this switch. Also study the procedures and identify any special warnings that should be adhered to, especially those concerning the air bag.

Flashers Flashers are components of both turn and hazard systems. Older systems use a temperature-sensitive bimetallic strip and a heating element. The bimetallic strip is connected to one side of a set of contacts. Voltage from the fuse panel is connected to the other side. When the left turn signal switch is activated, current flows through the flasher unit to the turn signal bulbs. This current causes the heating element to emit heat, which in turn causes the bimetallic strip to bend and open the circuit. The absence of current flow allows the strip to cool and again close the circuit. This intermittent on/off interruption of current flow makes all left turn signal lights flash. Operation of the right turn is the same as the operation of the left turn signals.

Modern vehicles use either an electronic flasher unit or a module to control exterior light operation. Electronic flasher units control both the turn signals and the hazard lights and use transistors to control light operation. If the BCM or lighting module is used, the turn signals, stop, and hazard light switches are inputs to the module **(Figure 20–45)**. When the driver moves the turn signal stalk, the input signal is grounded through the multifunction switch. This causes the module to switch power to the requested

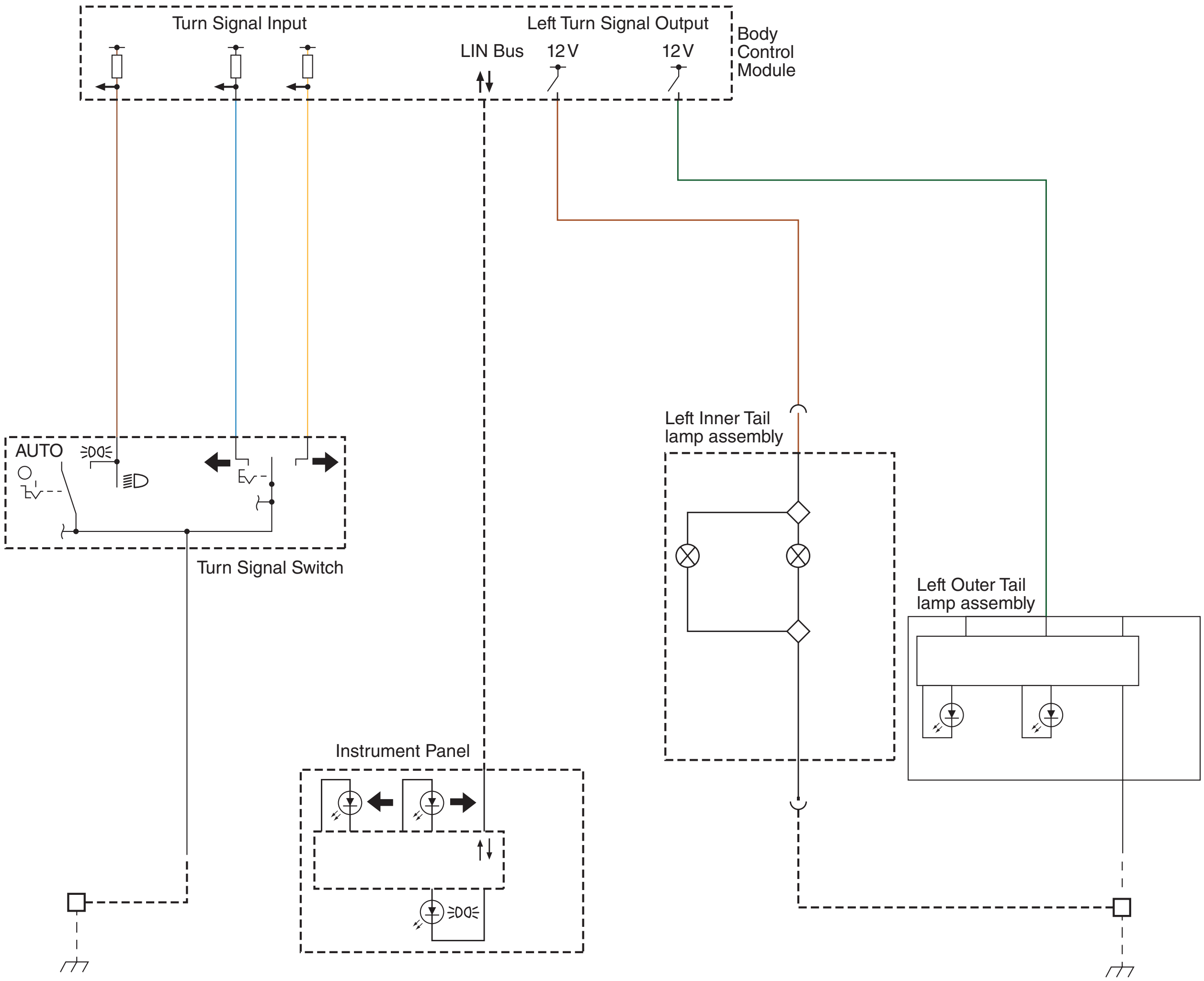
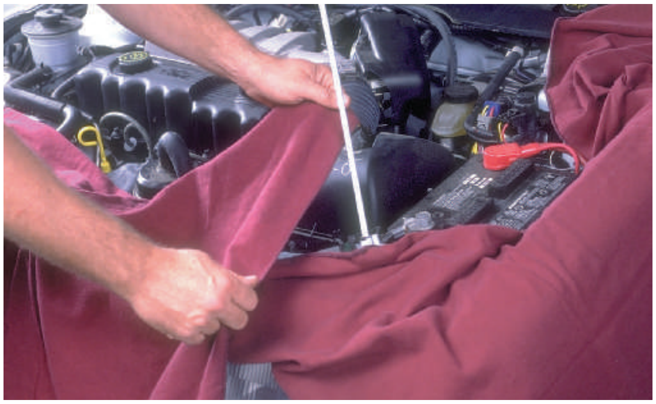


FIGURE 20–45 An example of a BCM lighting circuit.

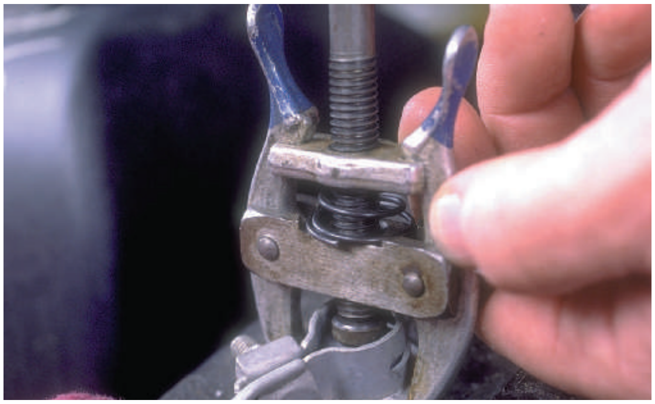
PHOTO SEQUENCE 18

Removing a Multifunction Switch

P18-1 The tools required to test and remove a multifunction switch are fender covers, battery terminal pliers and pullers, assorted wrenches, Torx driver set, and an ohmmeter.



P18-2 Place the fender covers over the fenders of the vehicle.



P18-3 Loosen the negative battery clamp bolt and remove the battery clamp. Place the cable where it cannot contact the battery.

P18-4 Remove the shroud retaining screws and remove the lower shroud from the steering column.

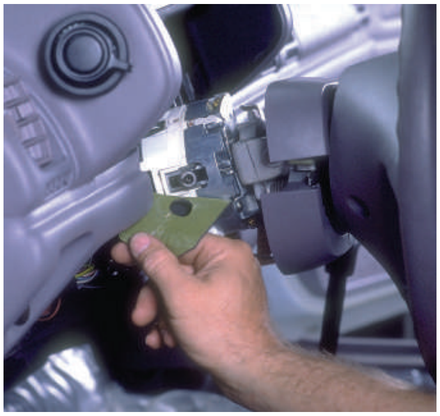
P18-5 Loosen the steering column attaching nuts. Do not remove the nuts.

P18-6 Lower the steering column just enough to remove the upper shroud.

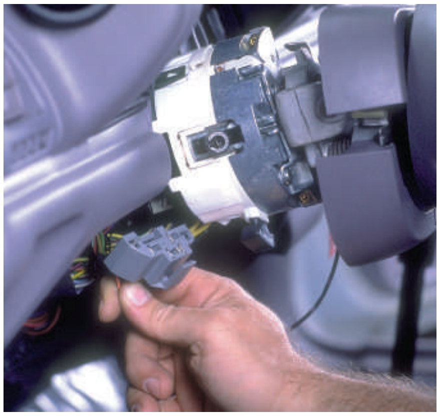
P18-7 Remove the turn signal lever by simply rotating the outer end of the lever. Then pull it straight out.

PHOTO SEQUENCE 18

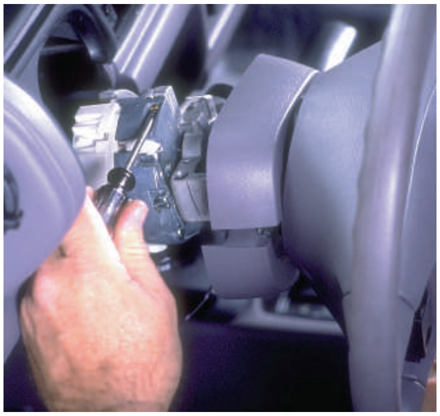
Removing a Multifunction Switch *(continued)*



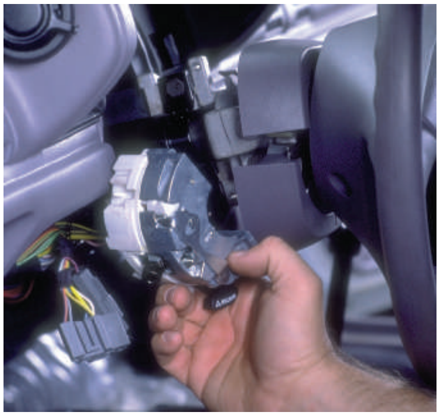
P18-8 Peel back the foam shield from the turn signal switch.



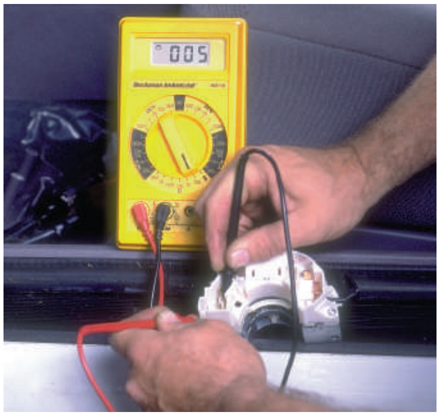
P18-9 Disconnect the turn signal switch electrical connectors.



P18-10 Remove the screws that attach the switch to the lock cylinder assembly.

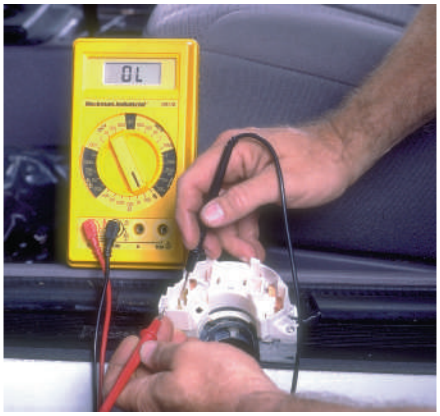


P18-11 Disengage the switch from the lock assembly.



P18-12 Use an ohmmeter to test the switch. Check for continuity when the dimmer switch is in the low-beam position.

P18-13 When the switch is in the low-beam position, the circuit should be open between the high-beam terminals.



P18-14 Also check the other terminals and circuits that should be open when the dimmer switch is in the low-beam position.

P18-15 With the switch in the high-beam position, there should be continuity across the high-beam circuit. Also check for continuity across the other circuits that should be open when the switch is in the high-beam position.

P18-16 When the dimmer switch is in place in the flash-to-pass position, there should be continuity across those designated terminals and an open across the others.

turn signal bulbs. The turn signal sound is supplied by the audio system and door speaker.

Flasher Diagnostic Tips

Occasionally, the flasher does not flash as fast as it once did, or it flashes faster. This is also cause for replacement. If it flashes too slowly or not at all, check for a burned-out bulb first. However, keep in mind the flasher rate is affected by the type of flasher.

Flashers are designed to operate a specific number of bulbs to give a specific candlepower (brightness). If the candlepower on the turn signal bulbs is changed, or if additional bulbs are used (if a vehicle is hooked up to a trailer, for instance), a heavy-duty flasher must be used. This usually fits the socket without modifications. Although heavy-duty flashers will operate additional bulbs, they have one big disadvantage and should not be used unless it is necessary. These flashers will not cause the turn signals to flash slower if a bulb burns out. When a turn signal bulb fails, the driver has no idea that it did.

Warning! The flasher unit for turn signals should not be switched with a flasher unit for the hazard lights.

Newer vehicles may have a combination flasher unit that controls the flash rate of both the turn signals and the hazard lights. These combination flashers are electronic units. The actual turning off and on of the lights is caused by the cycling of a transistor. This type of flasher also senses when a bulb is burned out and causes the remaining bulbs on that side to flash faster. Because this flasher is an electronic device, it cannot be tested with normal test equipment. The only test of the flasher is to substitute it with a known good one. If the lights flash normally, the original flasher unit was bad and needs to be replaced. Electronic flashers will flash faster when a bulb is burned out. Also, the flasher rate will change if the wrong types of bulbs are used.

On computer controlled systems, the module will increase the blink rate if a burned-out bulb is detected. If a turn signal does not operate or if replacing the bulb does not correct the concern, connect a scan tool and monitor switch input and the commanded state of the circuit **(Figure 20–46)**.

Brake Lights

The brake (stop) lights are usually controlled by a stoplight switch or brake pedal position sensor (BPP) that is normally mounted on the brake pedal arm

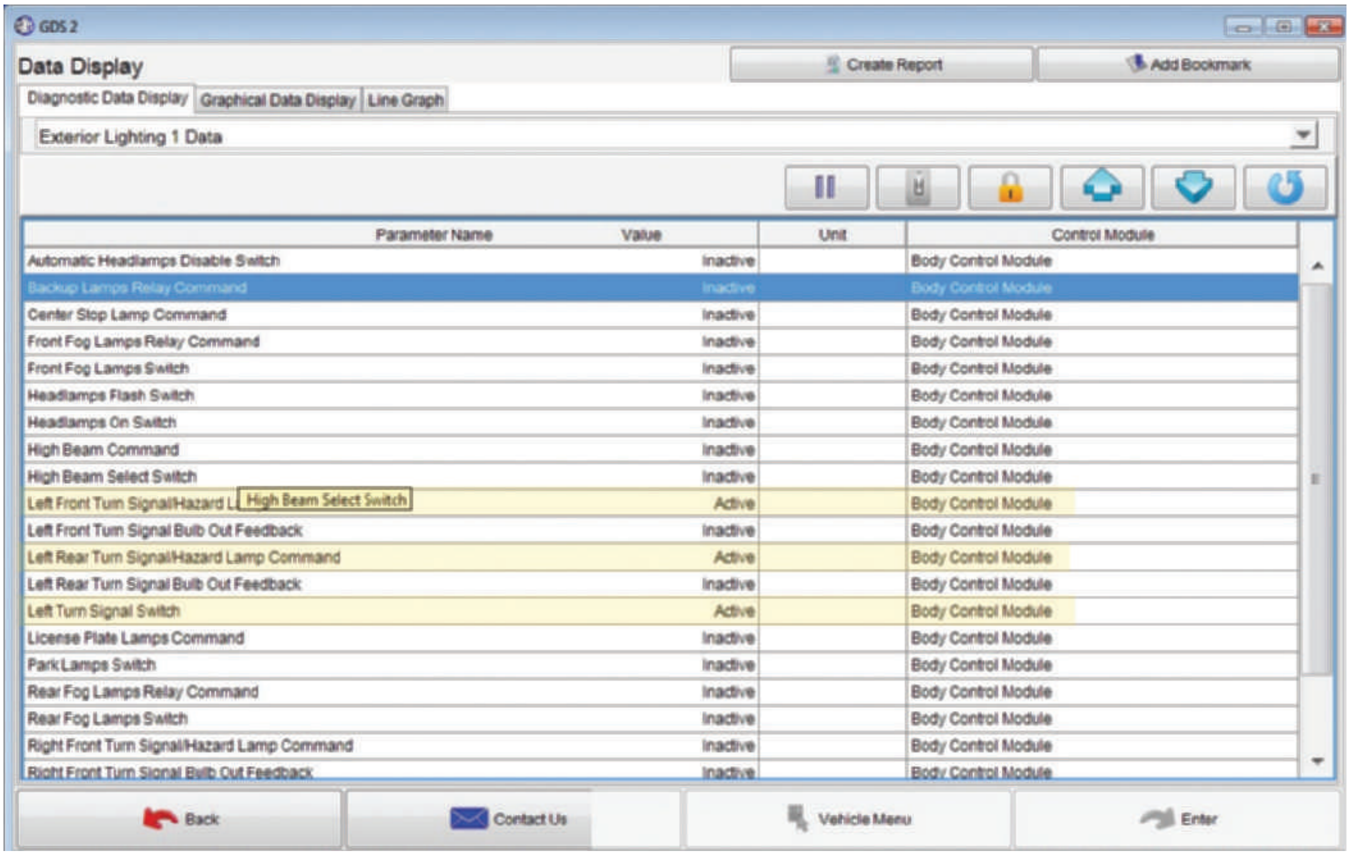


FIGURE 20–46 A scan tool used to check turn signal operation.

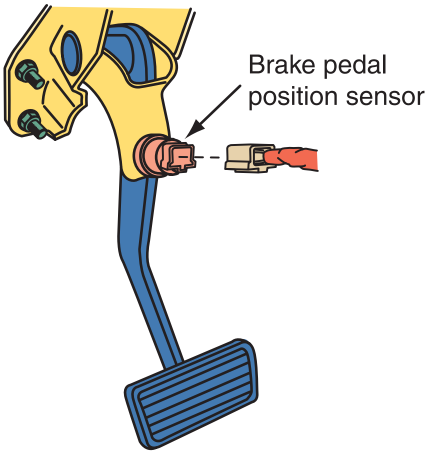


FIGURE 20–47 A brake pedal position sensor located at the brake pedal assembly.

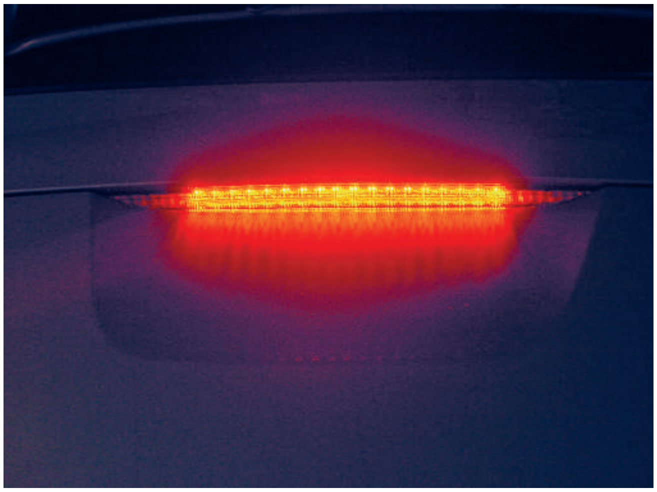


FIGURE 20–48 A CHMSL with LEDs.

(Figure 20–47). Some cars are equipped with a brake or stoplight switch mounted on the master cylinder, which closes when hydraulic pressure increases as the brake pedal is depressed. In either case, voltage is present at the stoplight switch at all times. Depressing the brake pedal causes the stoplight switch contacts to close. Current can then flow to the stoplight filament of the rear light assembly. These stay illuminated until the brake pedal is released.

In addition to the stoplights at the rear of the vehicle, all late-model vehicles have a center high-mounted stoplight (CHMSL) that provides an additional clear warning signal that the vehicle is braking **(Figure 20–48)**. Federal studies have shown the additional stoplights to be effective in reducing the number and severity of rear collisions. The high-mounted stoplight is activated when current is applied to it from the stoplight switch. It stays illuminated until the brake pedal is released. When its contacts are closed, the stoplight switch can also provide current to the cruise control, antilock brake control module, and the electric brake controller connector.

Brake Light Circuit In a three-bulb taillight assembly **(Figure 20–49)**, the brake lights are controlled by a brake light switch. The right and left brake lights are wired in parallel to each other. The taillights are also wired in parallel and are controlled by the headlight switch. The turn signal lamps are wired independent of each other and are individually controlled by the turn signal switch.

A quick study of the circuit shows how simple it can be to diagnose a brake light problem. The circuit shows a typical taillight circuit, with three separate filaments for each side of the rear of the vehicle. A constant source of fused B+ is made available to the brake switch. The brake switch is usually located on the brake pedal and is closed by pushing down on the brake pedal. B+ is now available to the bulbs. Releasing the brake pedal allows the spring-loaded normally open (NO) switch to open and turn the

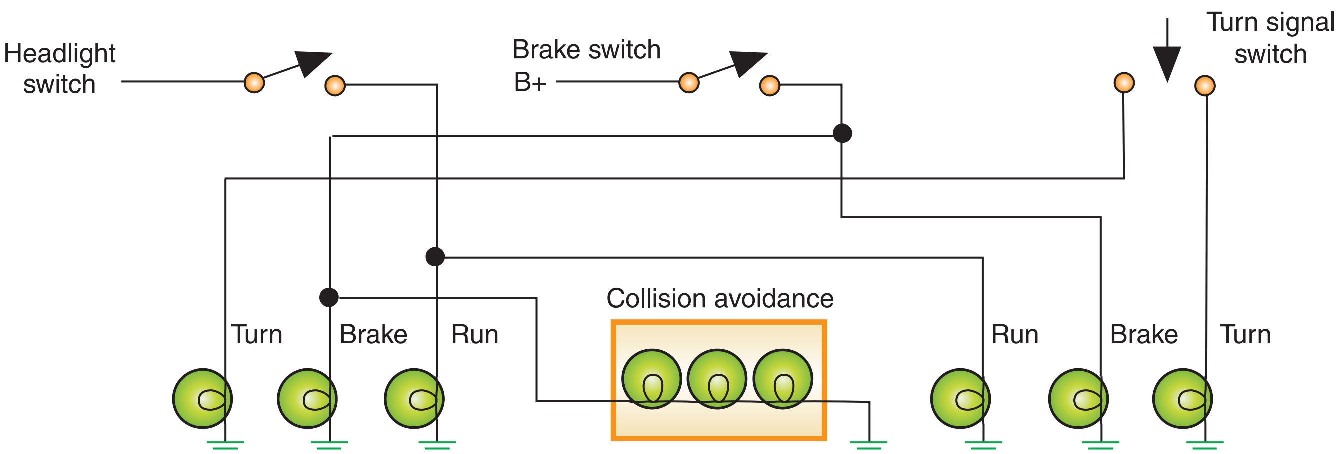


FIGURE 20–49 The circuit for a CHMSL in a three-bulb circuit.

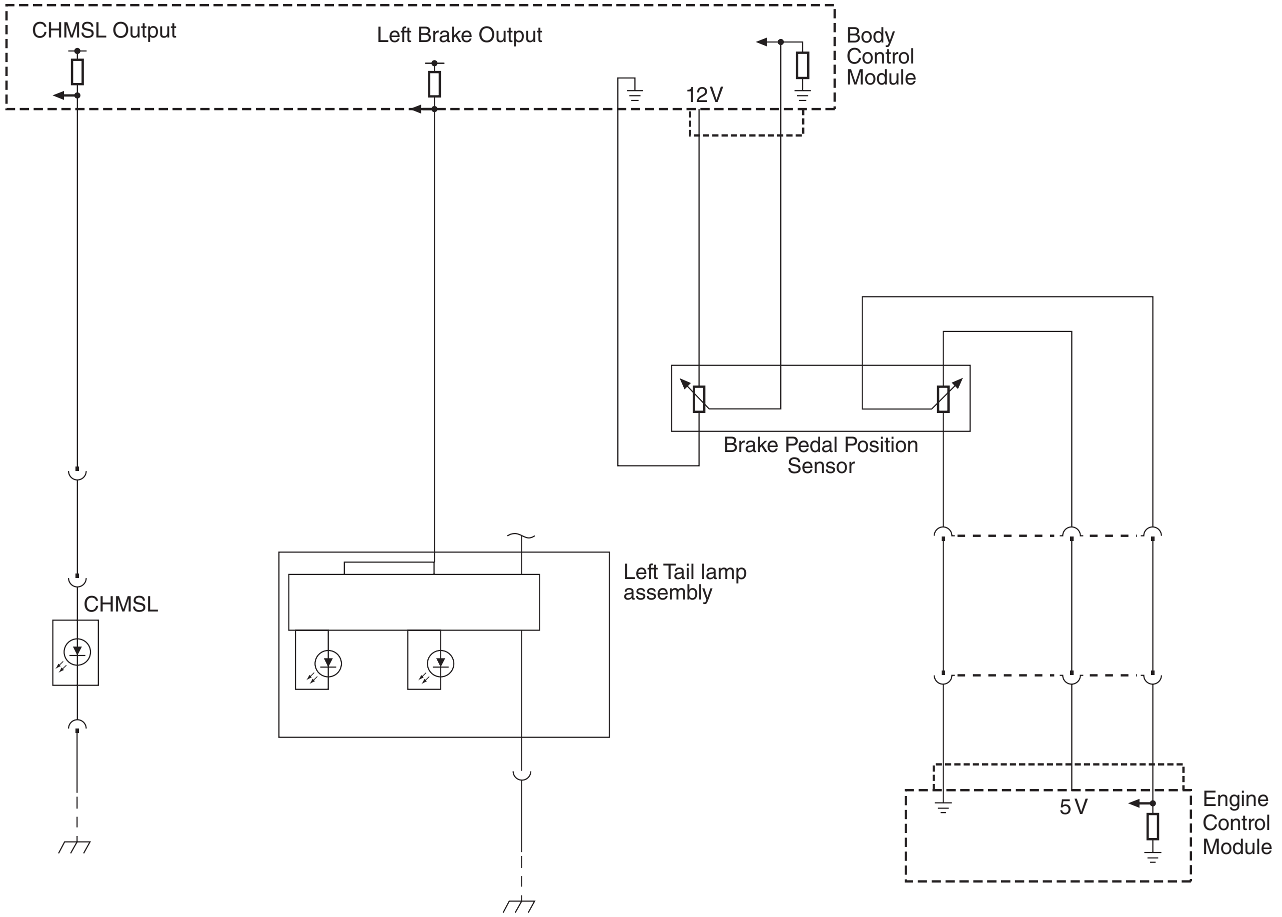


FIGURE 20-50 A BCM controlled brake light circuit.

brake lights off. This is a simple circuit that requires only a 12-volt testlight or a voltmeter for diagnosis. The most common cause of failure is bulbs that burn out. Testing for B+ and ground at the bulb socket should verify the circuit. If B+ is not available at the socket, test for power at each connector, moving back toward the switch until it is found. Repair the open.

Modern BPPs are used as inputs to the ECM and other modules **(Figure 20–50)**. Brake input is used for the stop lights, cruise control, ABS, transmission operation, and numerous safety systems. If the cruise control and/or stop lights do not work, check for DTCs and switch operation with a scan tool. When replacing a BPP sensor, a sensor calibration or relearn may be required. Connect a scan tool, clear any BPP sensor DTCs and then navigate to the sensor calibration function. Once recalibrated, verify correct stop light operation.

LED Lights

Some vehicles use neon lamps and/or LEDs for tail, brake, and turn signal lights. Neon lights are more energy efficient and turn on more quickly than regular lights. Because neon bulbs have no filament, the neon bulb will last longer than a conventional light bulb.

Whereas conventional bulbs take around 200 milliseconds to reach their full brightness, neon bulbs turn on within 3 milliseconds. The importance of this time difference is that it gives the driver behind the vehicle an earlier warning to stop. This early warning can give the approaching driver 19 more feet for stopping when driving at 60 miles per hour.

LEDs offer the same advantages as neon bulbs and turn on even quicker because they do not need to heat up to illuminate. LEDs achieve their full output in less than 1 millisecond. Several LEDs are placed behind the lens and are activated at the same time to give a bright illumination of the light assembly. LEDs also require a much smaller space so they are much less intrusive in the trunk. LEDs have a long operating life and provide a more precise contrast and signal pattern, thus attracting attention much more effectively.

Using the same basic technology as LEDs, laser-lit taillights consume seven times less power than

incandescent sources. These savings are extremely important for electric vehicles. The light waves of a laser light beam move in the same direction and the light is all the same color. When used with rear exterior lights, fiber optics carry red light from a diode laser to a series of mirrors, which send the beam across a thin sheet of acrylic material.

Adaptive Brake Lights This system can select one of two available brake light areas for illumination: Moderate braking activates the standard brake lights incorporated within the taillight assemblies as well as the center high-mount brake light. Under intense braking and during all braking maneuvers with active ABS intervention, additional lamps are lit thereby changing the size of the brake lights and their intensity **(Figure 20–51)**. By increasing the brake lights' illuminated surface area, the system alerts drivers of following vehicles that the vehicle in front has started braking and decelerating at a rapid rate. This warning allows the driver of the following vehicle to react more quickly and reduces the danger of a rear impact.

An electronic control unit processes signals supplied by the speed sensor and the antilock brake system. It then uses these data to calculate the intensity of the braking as reflected by the vehicle's rate of deceleration.

Back-Up Lights When the transmission is placed in reverse gear, back-up lights are turned on to illuminate the area behind the vehicle and to let other drivers know that the vehicle is in reverse. The major components in the system are the back-up light switch and the lights.

Power for the back-up light system is provided by the fuse panel. When the transmission is shifted to reverse, the back-up light switch closes and power flows to the back-up lights. That is, any time the transmission is in reverse, current flows from the fuse panel through the back-up light switch to the back-up lights. On many vehicles, the fuse that protects the back-up light system also protects the turn signal system.

FIGURE 20–51 Adaptive brake lights: the left photo is the result of normal braking and the right one is the result of hard braking.

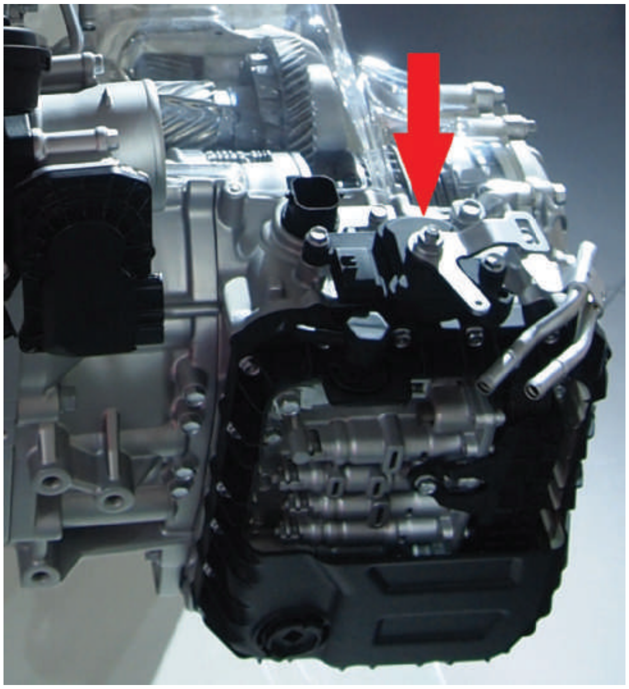


FIGURE 20–52 A combination backup and neutral safety switch installed on an automatic transmission.

In general, vehicles with a manual transmission have a separate switch. Those with an automatic transmission use a combination neutral start/back-up light switch **(Figure 20–52)**. The combination neutral start/back-up light switch used with automatic transmissions is actually two switches combined in one housing. In park or neutral, current from the ignition switch is applied through the neutral start switch to the starting system. In reverse, current from the fuse panel is applied through the back-up light switch to the back-up lights.

Newer vehicles often have transmission range switches, which do not directly close the back-up light circuit. Switch position is monitored by the transmission control module (TCM), ECM, and BCM. When placed in reverse, the TCM sends the data to the other modules on the network and the BCM activates the lights.

The back-up light system is relatively easy to troubleshoot. On vehicles that use one fuse to protect both the turn signals and the back-up lights, the fuse can be checked. If the back-up lights are not working, check turn signal operation. If they work, the fuse is good. Check for power at the back-up light switch input and outlet with the transmission in reverse. (Make sure the parking brake is set.)

If the switch is okay, or there is no power to the switch, check the wiring—especially the connectors. If the back-up lights stay on when the transmission is not in reverse, suspect a short in the back-up light switch.

Interior Light Assemblies

Table 20–3 is a diagnostic chart for most of the common interior light circuits. The types and numbers of interior light assemblies used vary significantly from one vehicle to another **(Figure 20–53)**. Following are the more common ones.

Engine Compartment Light Operating the hood causes the engine compartment light mercury switch to close and light the underhood area. Some pickup trucks and SUVs are equipped with an underhood retractable magnetic base lamp mounted on a reel. The lamp can be used anywhere around the vehicle.

Courtesy of Chrysler LLC.

FIGURE 20–53 Full interior illumination is available with this light setup.

Glove Box Light Opening the glove box door closes the glove box light switch contacts and the light comes on.

TABLE 20–3 BASIC TROUBLESHOOTING CHART FOR INTERIOR LIGHTS

Problem Area	Symptoms	Possible Causes
Instrument cluster lighting	Intermittent brightness control of instrument cluster light circuits Dash lights flicker	Improper connection Defective headlight switch rheostat Poor ground Excessive resistance Faulty printed circuit
	Low-level light intensity from panel illumination lights	Burned-out bulbs Defective headlight switch rheostat Improper bulb application Improper connection Poor ground Excessive resistance Defective or faulty printed circuit
	No bulb illumination	Blown circuit protection device Burned-out bulbs Defective headlight switch rheostat Open circuit Improper connection Poor ground Excessive resistance Improper bulb application Defective printed circuit

TABLE 20-3 *(continued)*

Problem Area	Symptoms	Possible Causes
	No dash light brightness control	Defective headlight switch rheostat
Courtesy lights	Intermittent courtesy light operation	Improper connection Defective headlight switch Defective door jam switch Defective or sticking door switch Poor ground Excessive resistance
	Dimmer-than-normal courtesy lights Battery condition good	Improper bulb application Improper connection Poor ground Excessive resistance
	No courtesy light illumination	Blown circuit protection device Burned-out bulbs Defective headlight switch Defective door switches Open circuit Improper connection Poor ground Excessive resistance Improper bulb application
	Courtesy lights stay on all of the time	Defective door jam switch Defective headlight switch Shorted circuit
Entry System	Courtesy light fail to turn on	Faulty headlight switch input or circuit Faulty door ajar switches or circuits Dead battery in remote FOB Defective FOB Open, short, or high resistance in the lamp driver circuit Power circuit to the module Defective relay or relay module Module ground circuit Bus network failure Burned out lamp elements Faulty controller
	Courtesy light fail to turn off	Faulty headlight switch input or circuit Faulty doer switches or circuits Short to ground in the lamp driver circuit Power circuit to the module Defective relay or relay module Module ground circuit Bus network failure Faulty controller

Luggage Compartment Light The light is mounted in the underside of the trunk deck lid in the luggage compartment.

Trunk Lid Light Lifting the trunk lid causes the light mercury switch to close and the light to come on.

Vanity Light Pivoting the sun visor downward and opening the vanity mirror cover causes the vanity light switch contacts to close and the light to come on.

Courtesy Lights Vehicles may have courtesy lights in the door trim panels, under each side of the instrument panel, above the foot wells, or in the center of the headlining. Their sole purpose is to allow light inside the vehicle. They are illuminated when one of the doors is opened, by rotating the headlight switch to the full counterclockwise position, or by depressing the designated switch. **Figure 20–54** is a wiring diagram of a typical courtesy light circuit. The courtesy lights are also turned on by the illuminated entry or keyless entry systems, if the vehicle is equipped with one or both of these. LEDs are often used for interior lighting and custom colors can be often selected by the driver **(Figure 20–55)**.

Typically, power is supplied from the fuse block to the courtesy lights. The ground is controlled by the position of the door switch. The door switches are held in an open position and do not provide for a ground circuit. When the door is opened, a spring pushes the switch closed to ground the circuit, and

FIGURE 20–55 Interior LED lights.

the courtesy lights come on. Interior and courtesy lights rarely give any trouble. However, if they do not operate, check the fuse, bulb, switch, and wiring.

Illuminated entry systems make entry into the vehicle safer by illuminating the door lock cylinder when it is dark so the lock can be easily located. At the same time, the vehicle's courtesy lights are illuminated. Some vehicles are using puddle lights, mounted in the outside mirror housing, to illuminate the ground next to the door. These lights come on when entering and exiting the car so you can see where to walk and stand to keep your feet dry.

Most of these systems have an electronic module, an illuminated lock cylinder, a latch switch, and

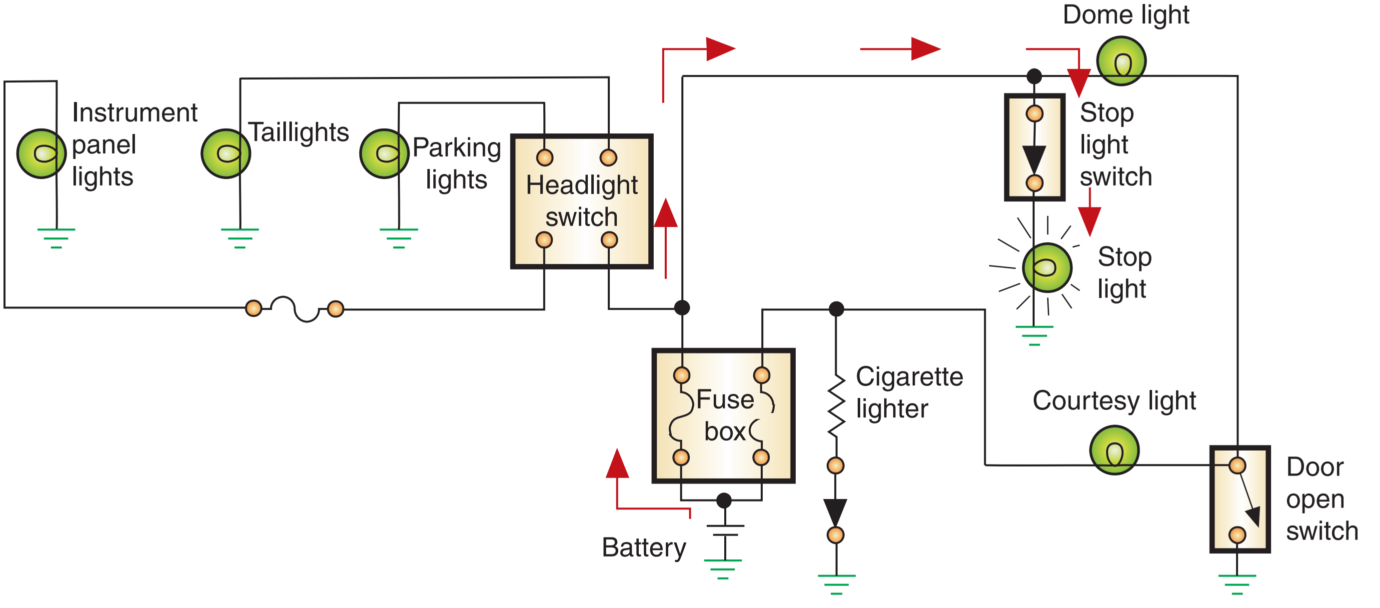


FIGURE 20–54 A typical courtesy light circuit with grounding door switches.

wiring harness in each door. The system is activated by raising the door handle, depressing a button on the key fob, or entering a code on the keyless entry system. These momentarily close a switch at the door latch mechanism, which completes the ground circuit of the actuator module and turns the system on. The vehicle's interior lights turn on, and both front door lock cylinders are illuminated by a ring of light around the area where the key enters. These remain on for approximately 25 seconds and then turn off. During the 25-second period, the system can be manually turned off by turning the ignition switch on.

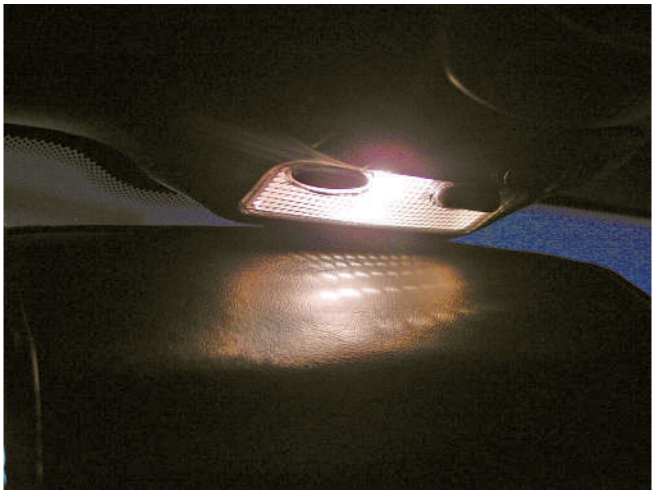


FIGURE 20–56 A dome light.

Dome/Map Light

Map lights are typically located on each side of the dome/map light housing. They are operated independently of the dome light by switches located at each map light. The dome light **(Figure 20–56)** is activated by a switch or along with the courtesy lights when the door is opened.

Distributed Lighting System

Distributed lighting refers to light present at one source and transmitted through fiber optic "tubes" to one or more other locations **(Figure 20–57)**. This technology has been around for quite some time and used to illuminate all instrument panel gauges with a single lamp. On today's vehicles, the light source is now most likely to be a single LED. Distributed lighting is typically used to add lighting at places where it might not be practical to have a bulb.

This technology is also favored because fiber-optic connections won't corrode. More significantly, distributed lighting reduces noise interference on the data communications bus. As the electronic content of vehicles increases, distributed lighting will be used for more interior and exterior lighting.

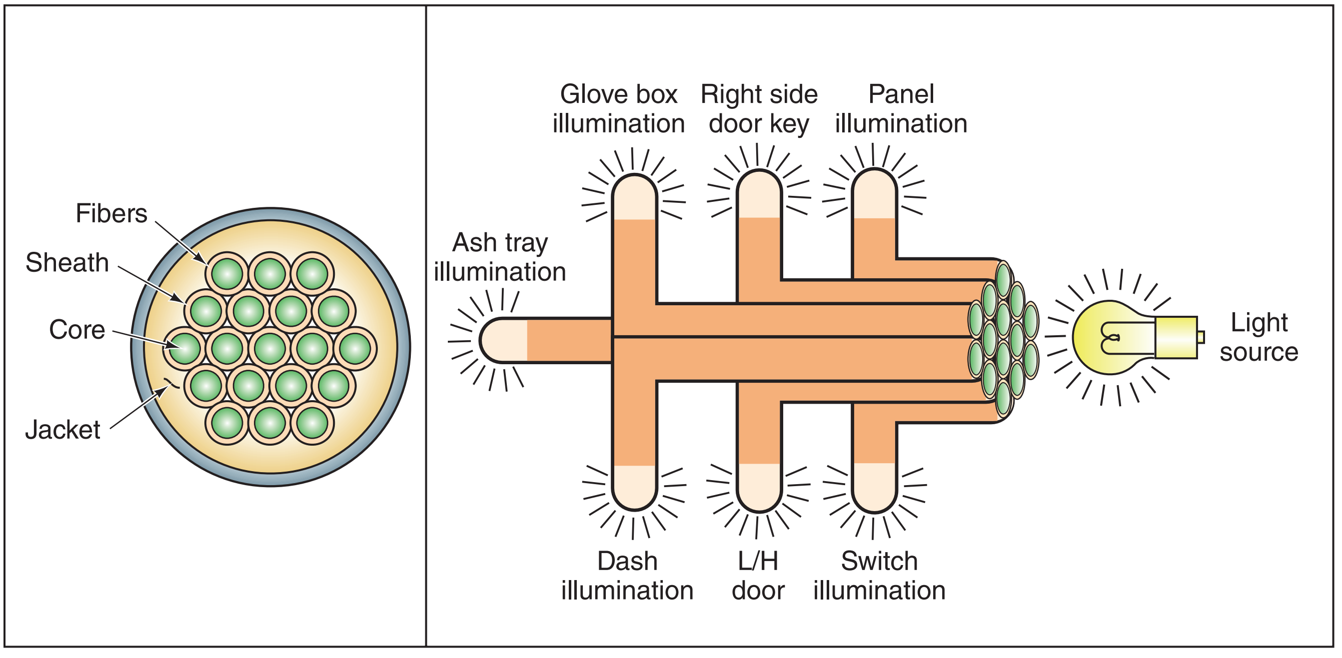


FIGURE 20–57 One light source can illuminate several locations by using fiber optics.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2005	**Make:** Ford	**Model:** F-150	**Mileage:** 115,209	**RO:** 17947
Concern:	Turn signals are not working correctly. Customer installed new bulbs, lights blink very quickly.			
The technician verifies the concern and checks the new bulbs to determine if they are correct for the truck.				
Cause:	Found all bulbs replaced with LED replacements. LED bulbs do not have the wattage as the correct bulbs, causing the fast blink rate.			
Correction:	Removed LED bulbs and installed correct bulbs. Turn signals working normally.			

KEY TERMS

Daytime running lights (DRLs)
Halogen
High-intensity discharge (HID) lamp or xenon headlamps
Light-emitting diode (LED)

SUMMARY

- Headlight systems consist of two or four sealed-beam, halogen, xenon bulbs, or multiple LEDs on each side.
- The headlight switch controls the headlights and all other exterior lights, with the exception of the turn signals, hazard warning, and stoplights.
- Dimmer switches allow the driver to select high or low headlight beams.
- Many vehicles have daytime running lights, which are typically normal headlamps powered by low voltage.
- Automatic headlight systems switch the headlights from high beam to low beam in response to current lighting conditions.
- Headlights must be kept in adjustment to obtain maximum illumination for safe driving.
- The rear light assembly includes the taillights, turn signal/stop/hazard lights, high-mounted stoplight, rear side marker lights, back-up lights, and license plate lights.
- Flashers are used in turn signal, hazard warning, and side marker light circuits.
- The back-up light system illuminates the area behind the vehicle when it is put in reverse gear.
- There are a number of interior lights found on today's vehicles. These vary with the make or model of the vehicle.
- Replacement light bulbs should be an exact match of the originals.

REVIEW QUESTIONS

Short Answer

1. What lighting systems are controlled by the headlight switch?
2. What is a CHMSL?
3. How many wires are normally connected to a double-filament light bulb?
4. What are the most probable causes for one low-beam headlamp not working?
5. Why do some manufacturers protect the headlamp circuit with a circuit breaker instead of a fuse?
6. What types of headlights do not have a filament?
7. What is the primary tool used to diagnose an auto-leveling headlamp system?

True or False

1. *True or False?* HID lamps produce more heat and white light than a halogen bulb.
2. *True or False?* The headlights on many adaptive headlight systems can swivel up to 5 degrees in the direction the vehicle is turning.
3. *True or False?* All turn signal flasher units contain a temperature-sensitive bimetallic strip and a heating element.

Multiple Choice

1. Which of the following may cause the turn signal blink rate to be incorrect?
   a. Burned out bulb
   b. Open in turn signal circuit
   c. Incorrect flasher unit installed
   d. All of the above
2. Circuits that can energize the high beams even if the headlight switch is off are known as ___ circuits.
   a. flash-to-pass
   b. mercury
   c. dimmer
   d. retractable
3. Which of the following would probably *not* cause the headlights on both sides of the vehicle not to work?
   a. An open in the power or ground circuit
   b. A bad headlight switch
   c. A blown fuse
   d. Low generator output
4. The stoplight switch is normally mounted on the ___.
   a. instrument panel
   b. transmission
   c. brake pedal arm
   d. none of the above
5. Which of the following is *not* a true statement about LED-based lights?
   a. LEDs achieve their full output in about 200 milliseconds.
   b. LEDs require a much smaller space so they are much less intrusive in the trunk.
   c. LEDs have a long operating life.
   d. LEDs provide a more precise contrast and signal pattern, thus attracting attention much more effectively.

ASE-STYLE REVIEW QUESTIONS

1. While troubleshooting a headlight problem: Technician A says that when one headlamp does not work, the problem may be a burned-out bulb or lamp. Technician B says that you should check for voltage at the bulb before replacing a bulb. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. Technician A says that the condition of the vehicle's springs and shocks should be checked before aligning a headlight. Technician B says that the vehicle should have a full tank of fuel when its headlights are being adjusted. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. Composite headlights are being discussed: Technician A says that they have replaceable bulbs. Technician B says that condensation on the lens will prevent the operation of a composite headlamp. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. While troubleshooting a brake light problem: Technician A says that when the pedal is depressed the brake lights should come on. Technician B says that on some systems only part of the brake light should illuminate when there is slight pressure on the brake pedal. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Technician A says that a composite headlight housing that is cloudy should be replaced. Technician B says that clouding or oxidizing of the composite housing or lens may be removed. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

6. While diagnosing an HID lamp that does not turn on: Technician A says a smoky or blackened lamp may indicate the bulb is burned out. Technician B says before replacing a suspected bad ballast, check to make sure it is getting power and ground. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. Technician A says that flickering vehicle lights can be caused by a circuit breaker that is kicking in and out due to a short. Technician B says that flickering vehicle lights can be caused by a loose electrical connection. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. The turn signals operate in the left direction only: Technician A says that the flasher unit is bad. Technician B says that the fuse is probably blown. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. The right back-up lamp is dim: Technician A says that the back-up lamp switch may have high resistance. Technician B says that the back-up lamp fuse may have corroded terminals. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. When the headlights are switched from low beam to high beam, all headlights go out: Technician A says that the problem may be a bad dimmer switch. Technician B says that the ignition switch may be bad. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

INSTRUMENTATION AND INFORMATION DISPLAYS

CHAPTER 21

OBJECTIVES

- Know the purpose of the various gauges used in today's vehicles and how they function.
- Describe the operation of the common types of gauges found in an instrument cluster.
- List and explain the function of the various indicators found on today's vehicles.
- List and explain the function of the various warning devices found on today's vehicles.
- Explain the basics for diagnosing a gauge or warning circuit.

Every vehicle has a number of electrical instruments. The number and type, and their related parts, vary from model to model and year to year. The appearance of the instrument panel also varies from the quite simple **(Figure 21–1)** to the elaborate **(Figure 21–2)**. No matter what they look like, the instrumentation must be easy to read and give accurate

FIGURE 21–1 A simple but functional approach to the layout of the essential gauges in an instrument panel.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2007	**Make:** Toyota	**Model:** FJ Cruiser	**Mileage:** 133,502	**RO:** 17899
Concern:	Customer states fuel gauge always reads below empty.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

Courtesy of Toyota Motor Sales, U.S.A., Inc.

FIGURE 21–2 An elaborate arrangement of the essential gauges in an instrument panel.

> **SHOP TALK**
>
> Most warning displays and gauges use International Standards Organization (ISO) symbols, which were developed by this organization to provide symbols easily recognizable throughout the world.

information. Instrument gauges, warning lights, and indicators provide valuable information to the driver concerning the vehicle's various systems.

Instrument Panels

An instrument panel is a design element for the interior of a vehicle. It is an assembly that expands across the interior width of the vehicle and contains a glove compartment, air ducts and registers, air bags, various driver information displays, and entertainment systems. The shape, texture, and appearance of the panel are carefully considered by the manufacturer. It also contains an array of gauges, indicators, and controls connected to hidden mazes of wiring, printed circuitry, and vacuum hoses.

Displays

The displays on an instrument panel have many purposes, the most important of which are showing the status of current engine and vehicle information; these will be the primary topic of most of this chapter.

> **GO TO** Chapter 23 for more information on driver information displays.

The two basic types of information displays are analog and digital. In an analog display **(Figure 21–3)**, an indicator moves in front of a fixed scale to indicate a condition. The indicator is often a needle but it can also be a liquid crystal or graphic display. A digital display uses numbers rather than a needle or graphic symbol. Analog displays show relative change better than digital displays **(Figure 21–4)**. They are useful when the driver must see something quickly and the exact reading is not important. For example, an analog tachometer shows the rise and fall of the engine speed better than a digital display. The driver does not need to know the exact engine speed. The most important thing is how fast the engine is reaching the red line on the

FIGURE 21–3 An analog instrument panel.

FIGURE 21–4 A digital instrument panel.

gauge. A digital display is better for showing exact, real-time data, but is difficult to quickly observe because it is constantly changing. Many speedometer-odometer combinations are examples of both analog (speed) and digital (distance).

Heads-Up Display

A **heads-up display (HUD)** projects vehicle information onto the windshield using a vacuum fluorescent light source via a dash mounted prismatic mirror to project the images and to complement in-dash instrumentation **(Figure 21–5)**. Because these images are projected in the driver's field of vision, the driver does not need to move his or her eyes from the road to see certain pertinent information.

HUD systems may have a central control that turns the display on and off, plus a brightness control. The brightness control is important to the comfort and sight of the driver. If the display is too bright, the road ahead can be distorted. If the image is too dim, the driver may focus too much on the windshield.

Among the images HUD may display are vehicle speed, turn-signal indicators, low fuel warning, and a high-beam indicator. HUD systems work best with a clean windshield and dim ambient lighting.

Three types of digital electronic displays are used today.

Vacuum Fluorescent

These displays use glass tubes filled with argon or neon gas. The segments of the display are little fluorescent lights. When current is passed through the tubes, they glow very brightly. These displays are both durable and bright.

Light-Emitting Diode (LED)

These displays are either used as single indicator lights or they can be grouped to show a set of letters or numbers. LED displays are commonly red, yellow, or green and can be hard to see in bright light.

Liquid Crystal Diode (LCD)

These displays are made of sandwiches of special glass and liquid. A separate light source is required to make the display work. When there is no voltage, light cannot pass through the fluid. When voltage is applied, the light passes that point of the display. The action of LCDs slows down in cold weather. These displays are also very delicate and must be handled with care. Any rough handling of the display can damage it.

An LCD display is used to show the information provided by the vehicle's systems **(Figure 21–6)**. The LCD may be part of the instrument panel or in a separate unit, called the central stack that extends from the instrument panel into the seating area. Today, the center stack is mostly used to display the entertainment and climate controls. The multi-information display (MID) has been available for quite some time. A few vehicles are using two or more LCDs in the center stack and instrument panel. An LCD screen can also allow the driver to see navigation instructions, information about the music currently being played, high-voltage battery status, and the transactions of a cell phone.

The LCD screen may also display the view from the rearview and other cameras and may become more common as vehicles are equipped with rearview cameras and displays on the instrument panel or center stack. However, the display of the cameras

FIGURE 21–5 The HUD system projects information on the inside of the windshield.

FIGURE 21–6 An LCD display.

FIGURE 21–7 The backup camera's LCD display may be shown on the inside rearview mirror.

FIGURE 21–9 An LCD display with an analog speedometer.

may also be embedded in the inside rearview mirror **(Figure 21–7)**.

A full digital LCD instrument panel can allow the driver to switch between a digital and analog speedometer, or display both at the same time. It can even allow the driver to increase the font size on the screen.

Thin-Film-Transistor (TFT) LCD

TFT displays improve the image quality over that of an LCD by actively controlling each pixel with a transistor. TFT displays offer greater display options and contrast and are used extensively as dash and infotainment displays.

Cadillac CUE Cadillac's User Experience (CUE) infotainment package has an 8-inch LCD touch screen **(Figure 21–8)**, integrated into the top of the instrument panel or center console. The screen displays CUE's home page, which resembles a smartphone screen by using large, easy-to-target icons to execute commands. The touch screen is much like an iPad or tablet and has icons that are used to execute commands. Interactive motions, such as: tap, flick, swipe, and spread, are functional on the screen. CUE can be combined with a 12.3-inch digital instrument cluster. The cluster has several preset gauge configurations that can display phone, navigation, entertainment, and vehicle information.

FIGURE 21–8 A large LCD touch screen display in the center console of this Cadillac.

Ford's SmartGauge This LCD system is primarily found in Ford's hybrids **(Figure 21–9)**. It shows the driver how economically he or she is driving. The system has a pair of 4.5-inch LCDs on each side of the speedometer. If the driver is conserving a great amount of fuel, a collection of green leaves appears on the screen. The driver can also customize what the gauges show, including a navigation screen, phone information, infotainment information, or efficiency.

Mechanical Gauges

Gauges provide the driver with a scaled indication of the condition of a system. All gauges require an input from either a sending unit, sensor, switch, or module. With sending or sensor units, a change or movement made by an external component causes a change in electrical resistance. Movement may be caused by pressure against a diaphragm, by heat, or by the motion of a float. Some engines use a switch as an input for a gauge. An example is an oil pressure switch. With the engine off or operating with low oil pressure, the switch is open and the gauge reads low. Once oil pressure reaches a certain pressure, the switch closes and the gauge needle reads normal. In today's vehicles, control computers and the gauges need the

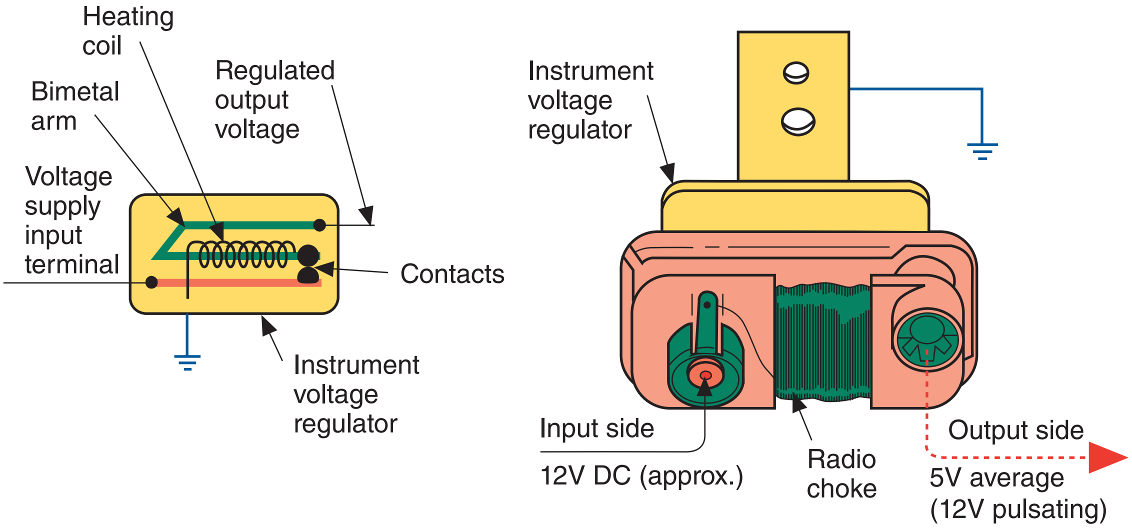


FIGURE 21–10 An IVR.

same information. The information passes through the computer and then to the gauge.

Some earlier model vehicles have an **instrument voltage regulator (IVR)** to stabilize and limit voltage to the gauges. The use of an IVR provides more accurate gauge readings. When a vehicle has an IVR, it also has a radio **(Figure 21–10)** choke. A radio choke is a small coil of wire installed in the battery lead to the IVR. The choke prevents radio interference caused by the pulsations of the IVR.

Air-Core Gauge

Today, the most commonly used gauge is the air-core gauge. This design relies on the interaction of two electromagnets and the effect of the strength of those fields on a permanent magnet **(Figure 21–11)**. The needle of the gauge is attached to the permanent magnet. The electromagnetic windings do not have a metal core; rather the permanent magnet is placed inside the windings. One of these windings is a reference winding and receives battery voltage at all times. The other winding, called the field winding, is placed at an angle to the reference winding. When current flows through the coils, their magnetic fields superimpose and the magnet is free to align with the combined fields. The amount of movement is controlled by the resistance of the sending unit.

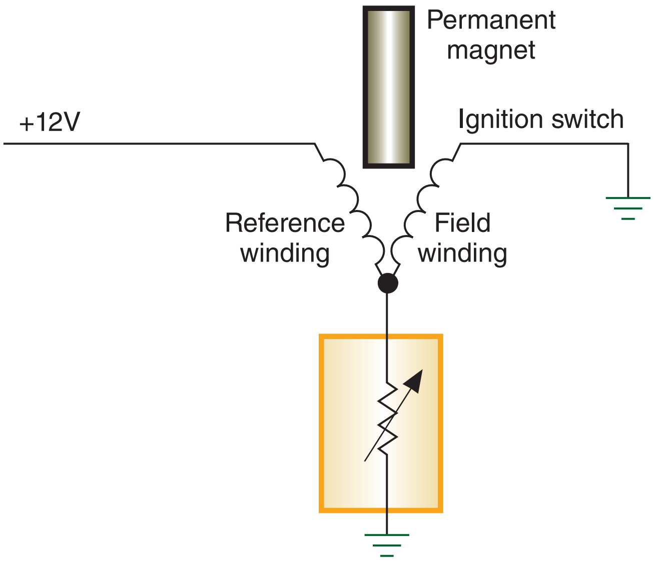


FIGURE 21–11 An air-core gauge circuit.

Quartz Analog Gauge

Computer-controlled quartz analog gauges **(Figure 21–12)** are becoming increasingly common.

FIGURE 21–12 Quartz analog instrumentation.

They operate in much the same way as an air-core gauge, but are not controlled in the same way. These gauge circuits rely on a permanent magnet generator sensor installed in the part or system that will be monitored. As the sensor rotates, a small AC signal is produced. This signal is then sent to a buffer circuit where it is changed to a digitalized signal. That signal is then sent to a quartz clock circuit and a driver circuit. The driver circuit sends voltage pulses to the windings in the gauge. The permanent magnet and the windings cause the needle to move. These gauges display very accurate readings.

The needle may be moved by a stepper motor **(Figure 21–13)**. A stepper motor is simply a motor that can rotate in small steps in response to digital signals from a computer. A stepper motor uses a permanent magnet and two electromagnets. The electromagnets are controlled by the computer, which pulses the windings and changes the polarity of the windings to cause the motor's armature to rotate 90 degrees at a time. Each signal pulse is recognized by the computer as a count or step. The computer can, therefore, know the position of the motor's armature by counting the number of steps that have been sent to the motor. These motors are widely used in GM gauges.

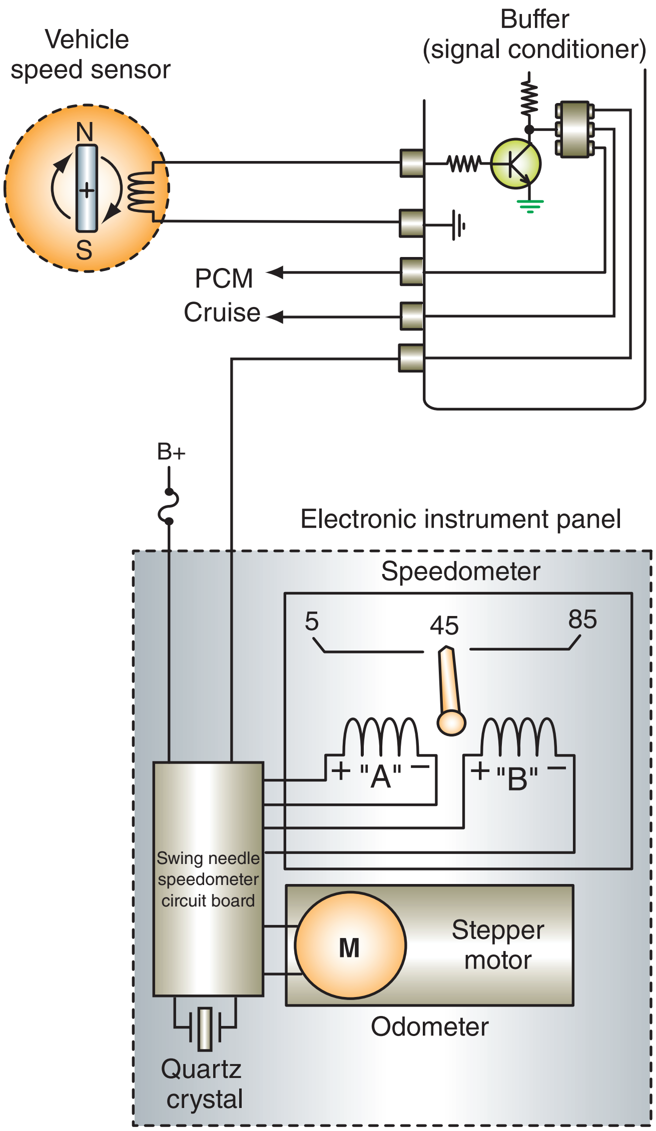


FIGURE 21–13 A schematic of a quartz analog gauge with a stepper motor controlling the position of the needle.

Magnetic Gauges

There are several types of magnetic gauges. The simplest form is the ammeter type **(Figure 21–14)**, in which a permanent magnet attracts a ferrous indicator needle connected to a pivot point and holds it centered on the gauge. An armature, or coil of wire, is wrapped around the base of the needle near the pivot point. When current flows through the armature, a magnetic field is formed. This magnetic field opposes that of the permanent magnet. Attractive or repulsive magnetic forces cause the needle to swing left or right. The direction the needle swings depends on the direction of current flow in the armature. The needle of the gauge pivots on the armature, often called a bobbin. This type of gauge is often referred to as a D' Arsonval gauge.

When sending unit resistance changes, current flow through the bobbin changes, causing the strength of the magnetic field created around the bobbin to change. As the resistance in the sending unit increases, the circuit's current decreases and a lower indicator position is shown on the gauge.

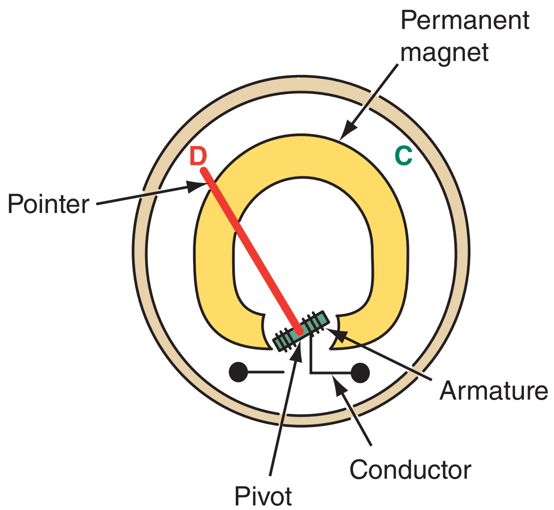


FIGURE 21–14 A simple ammeter that relies on magnetic principles.

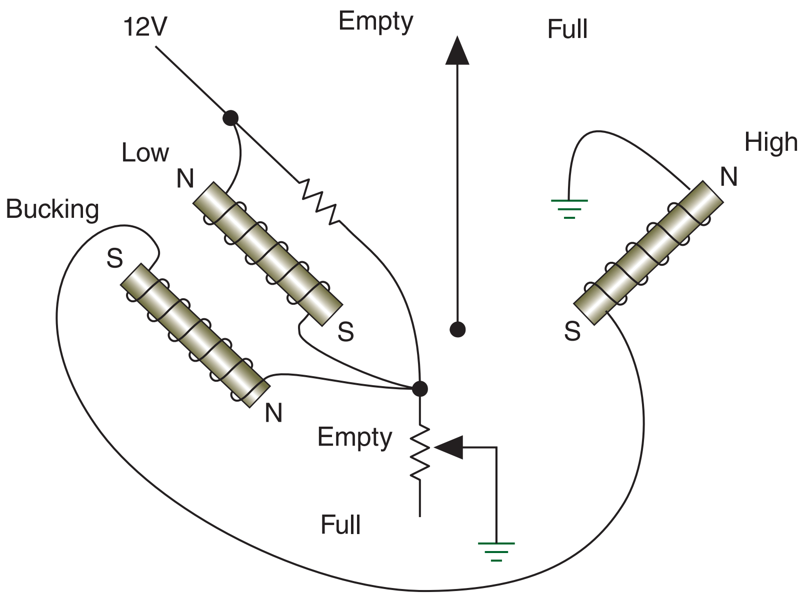


FIGURE 21–15 A three coil gauge circuit. A two-coil gauge is similar.

A **balancing coil gauge** also operates on principles of magnetism. However, a permanent magnet is not used. The base of the indicating arm is pivoted on an armature. Two or three (two plus one) coils are set on either side of the armature **(Figure 21–15)**.

When the same amount of current flows through both coils, the needle settles between the two. When the resistance of the sending unit is low, the right-hand coil receives more current than the left-hand coil, and the needle moves to the right. When the resistance of the sending unit is high, the left-hand coil receives more current. More magnetic force is created in the left-hand coil and the needle swings to the left.

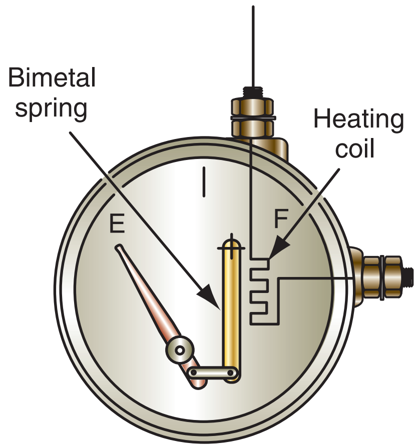


FIGURE 21–16 A bimetallic (thermal) gauge.

Thermal or Bimetallic Gauge

A bimetallic or thermal gauge operates through heat created by current flow **(Figure 21–16)**. A variable-resistance sending unit causes different amounts of current to flow through a heating coil within a gauge. The heat acts on a bimetallic spring attached to a gauge needle. When more heat is created, the needle swings farther up the scale. When less heat is created, the needle moves down the scale.

Diagnosis

If all gauges fail to operate properly, begin by checking the circuit's fuse. Next, test for voltage at the last point common to all the malfunctioning gauges. If voltage is not present, work toward the battery to find the fault. If only one gauge is not working, carefully check its circuit. **Table 21–1** lists basic gauge problems along with their possible causes.

Warning! Many instruments and warning devices are linked to the body control module and multiplexing network. Before troubleshooting a gauge or warning system, check the service information to identify any special procedures or precautions.

TABLE 21–1 BASIC GAUGE PROBLEMS AND THEIR POSSIBLE CAUSES

Symptoms	Possible Causes
One or all gauges fluctuate from low or high to normal readings.	Poor ground connection Excessive resistance Poor connections Faulty stepper motor Faulty sending unit Defective printed circuit
One or all gauges read high.	Faulty instrument voltage regulator Shorted printed circuit Faulty sending unit Short to ground in sending unit circuit Faulty gauge Poor sending unit ground connection
One or all gauges read low.	Faulty instrument voltage regulator Poor sending unit ground connection Improper bulb application Improper connections Faulty back-up switch contacts
One or all gauges fail to read.	Blown fuse Open in the printed circuit Faulty gauge Faulty stepper motor Poor common ground connection Open in the sending unit circuit Faulty sending unit Faulty instrument voltage regulator Poor electrical connection to cluster Shorted sending unit circuit

TABLE 21–2 COMMON INSTRUMENT PANEL PROBLEMS AND THEIR POSSIBLE CAUSES

Symptoms	Possible Causes
Digital display does not light.	Blown fuse Inoperative power and ground circuit Faulty instrument panel
Speedometer reads wrong speed.	Faulty speedometer Wrong gear on vehicle speed sensor (VSS) Wrong tire size
Speedometer always reads zero.	Faulty wiring Inoperative instrument panel
Odometer displays error.	Inoperative odometer memory module in instrument panel
Fuel gauge display is erratic.	Sticky or inoperative fuel gauge sender Fault in circuit Inoperative fuel gauge
Fuel gauge will not display FULL or EMPTY.	Sticky or inoperative fuel gauge sender
Fuel gauge displays top and bottom two bars.	Open or short in circuit
Fuel computer displays CS or CO.	Open or short in fuel gauge sender Inoperative instrument panel
Fuel economy function of message center is erratic or inoperative.	Inoperative fuel flow signal Faulty wiring Inoperative instrument panel
Extra or missing display segments.	Inoperative instrument panel
Temperature gauge displays top and bottom two bars.	Short in circuit Inoperative coolant temperature sender Inoperative instrument panel

Electronic Instrument Clusters

Many of the displays on an instrument panel are controlled by the same sensors used to control the vehicle's powertrain and other systems. The signals from the sensors are part the multiplex system, in which the inputs are used by many systems. The routing of the input signals is handled by the body control module (BCM).

The BCM may also be capable of running diagnostic checks on the instrument panel. If any of the input or output signals are out of the normal range, the BCM will set a DTC. The code is typically retrieved with a scan tool.

Most instrument panel display modules have a self-diagnostic mode. This mode allows the module to isolate faults in the cluster. When this test is initiated, all components and circuits are checked **(Figure 21–17)**. Normally if the self-diagnostic test

Oil gauge	H Norm L — Oil pressure sensor input short circuited light top 2 bars and bottom 2 bars and extinguishes oil can ISO symbol.	H Norm L — Low oil pressure warning or oil pressure sensor input open circuited lights bottom bar and flashes ISO symbol.
Temp gauge	H Norm C — Engine temperature sensor input short circuited lights top 2 bars and bottom 2 bars and extinguishes ISO symbol.	H Norm C — Cold engine temperature indication or engine temperature sensor input open circuited lights bottom bar and ISO symbol.
Fuel gauge	H Norm L — Fuel level sender input short circuited or open lights top 2 and bottom 2 bars and extinguishes ISO symbol.	CO CS — Fuel level sender input short or open circuited displays "CS" (short) or "CO" (open) in driver information center.
Odometer	55 ERROR	Odometer malfunction displays ERROR in odometer display.
Fuel computer	FFS	Fuel flow signal short or open circuited displays FFS in driver information center.

FIGURE 21–17 When the system is in its diagnostic mode, a gauge readout is displayed to show the condition of the gauges.

does not run a complete check, the display module probably needs to be replaced.

Prove-Out Display

Nearly all electronic instrument panels have a prove-out display. This display occurs each time the ignition switch is turned on. During this mode, all segments of the instrument display are illuminated and then momentarily turned off **(Figure 21–18)**. Then the display should return to normal. If the instrument panel did not illuminate, check for power to the panel and the panel's ground. If both of these are good, replace the cluster. If some of the segments or parts of the display do not illuminate, replace the cluster.

Most clusters are a module within a network. As with any module, these may require software updates or flashing to correct some issues. Before replacing a cluster, check the service information and software releases for updated software. If a cluster is replaced, it will need to be programed. In most cases, the vehicle's VIN is written into the new cluster. This locks the cluster and will not allow it to be removed and programed with a new VIN.

FIGURE 21–18 All segments of the electronic instrument cluster should illuminate during the prove-out display.

Basic Information Gauges

The following gauges are found on nearly all instrument panels. **Table 21–2** lists some of the common instrument panel problems and their possible causes.

General Diagnosis and Testing

Diagnosis should begin with a good visual inspection of the circuit. Check all sensors and actuators for physical damage. Check all connections to sensors, actuators, control modules, and ground points. Check the wiring for signs of burned or chafed spots, pinched wires, or contact with sharp edges or hot exhaust parts. After completing the visual checks, use a scan tool to retrieve any DTCs **(Figure 21–19)** and monitor the data stream as necessary. Many systems provide testing the operation of instrument panel gauges and warning lights with a scan tool. Always refer to the manufacturer's recommended procedure before beginning to diagnose a circuit.

DTC	DESCRIPTION
B1500	Open detected in the fuel level sender circuit
U0100	Lost communication with ECM/PCM
U0142	Lost communication with main BCM

FIGURE 21–19 Examples of instrument panel DTCs.

Speedometer

In the past, the speedometer was a nonelectrical or mechanical gauge. It had a drive cable attached to a gear in the transmission that turned a magnet inside a cup-shaped metal piece at the gauge. The cup was attached to a needle, which was held at zero by a hairspring (a fine wire spring). As the cable rotated faster with an increase in speed, magnetic forces acted on the cup and forced it to move. As a result, the needle moved up and down the speed scale.

Electric speedometers are used in all late-model vehicles. While there are several systems in use, one of the most common types receives its speed information from ABS system or from the transmission-mounted (VSS) vehicle speed sensor **(Figure 21–20)**. The speed sensor can be a permanent

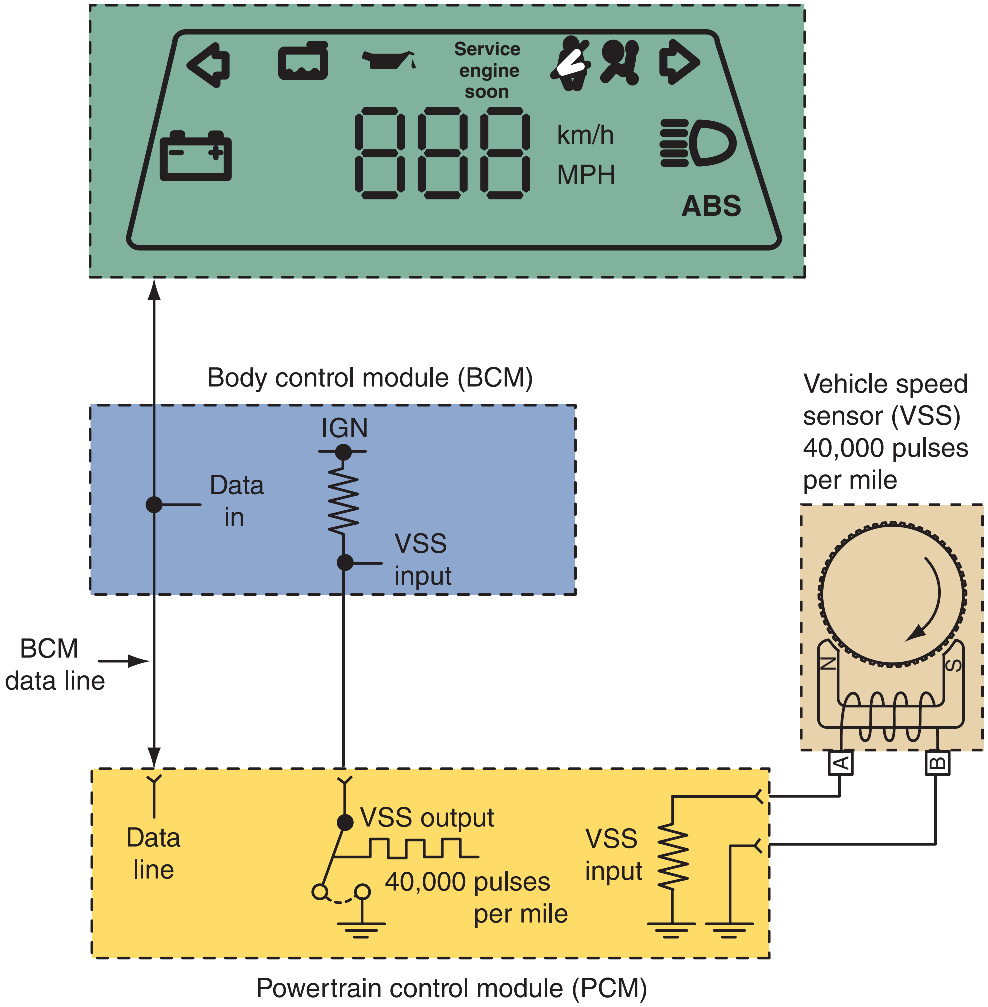


FIGURE 21–20 The speedometer in the instrument cluster receives instructions from the BCM, which shares the signals from the VSS with the ECM.

magnet (PM) generator, Hall-effect switch, or an optical sensor. The VSS monitors the speed of the transmission's output shaft. The output signal from the sensor varies in AC frequency and amplitude, according to speed. The signal is sent to the computer-control system where it is interpreted and used to control the reading on the speedometer. The speed signal is also used by other modules in the vehicle, including the speed control module, ride control module, the engine control module, and others.

Vehicle speed is determined by dividing the input pulse frequency (in hertz) by 2.2 Hz/mph. The circuit is calibrated to move the pointer to a location in proportion to the speed input frequency. Vehicle speed is displayed whether the vehicle is moving forward or backward. Many late-model vehicles do not use a separate vehicle speed sensor, instead, vehicle speed is determined by the output of the wheel speed sensors used by the ABS.

Most digital speedometers have a speed limit. If vehicle speed exceeds that value, the speedometer will display the top of its range.

Odometer A mechanical odometer is driven by the same mechanism as a mechanical speedometer. The odometer's numbered drums are geared so that when any one drum finishes a complete revolution, the drum to its left is turned one-tenth of a revolution.

An electronic odometer receives its information from the VSS. For each 40,000 pulses from the vehicle speed sensor (VSS), the trip and total odometers will increase by 1 mile. On some systems, a stepper motor is used to drive the odometer **(Figure 21–21)**. The motor receives signals from the PCM and causes the odometer to move in steps.

Odometers display seven digits, with the last digit in tenths of a unit. The accumulated mileage value of the digital display odometer is stored in a nonvolatile electronically erasable programmable read-only memory (EEPROM) that retains the mileage even if the battery is disconnected.

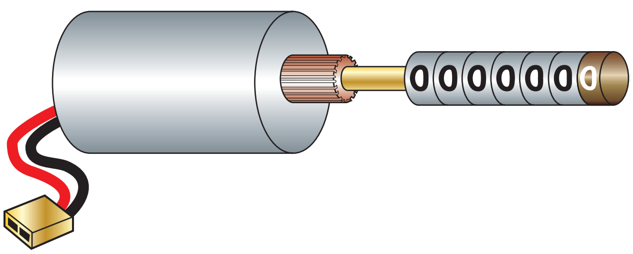


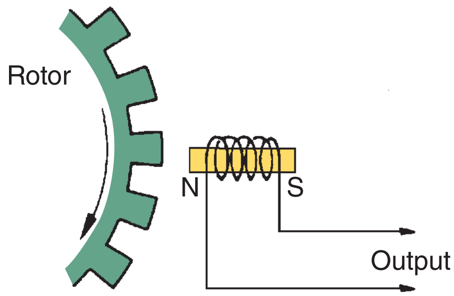
FIGURE 21–21 A stepper motor controls the movement of the odometer drum.

Because the odometer records the number of miles or kilometers a vehicle has traveled, federal laws require that if a speedometer is replaced, the new odometer must be set to the same distance as was registered on the old one. With the use of electronic odometer displays, the odometer reading is often stored in more than one module. This allows for the correct mileage to be displayed in the event the PCM or instrument cluster is replaced.

Trip Odometer This is part of the normal odometer. It records the distance traveled in intervals. The driver activates this gauge and it can be reset to zero whenever the driver desires.

Diagnosis If the speedometer or odometer is not working, the operation of the VSS **(Figure 21–22)** should be checked before anything else. The VSS can be checked with a scan tool, lab scope, and DMM. A bad VSS may also cause erratic speedometer readings.

Connect a scan tool and locate the vehicle speed (VSS) data. Spin the tires or drive the vehicle to check sensor output. If the VSS signal is correct but the speedometer does not show a reading,



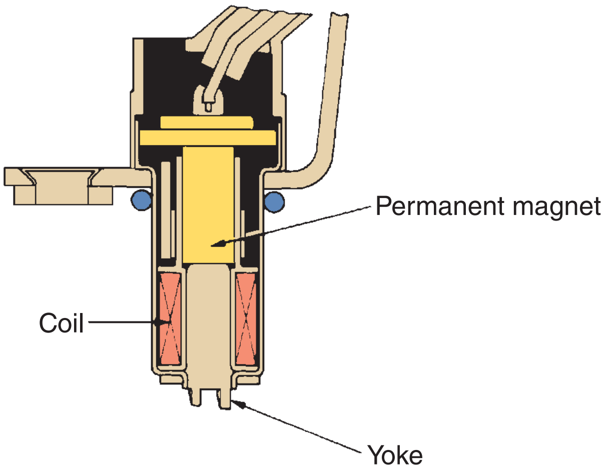


FIGURE 21–22 A vehicle speed sensor (VSS).

command the speedometer self-test using the scan tool. If the speedometer does not respond, the cluster will likely need to be replaced. You can also connect a scope or voltmeter to the circuit and rotate the VSS with a small screwdriver. If the voltmeter reading changes, there may be a problem in the wiring of the circuit. If the voltmeter reading does not change, the VSS or associated wiring is bad.

If the sensor is working fine, check the wiring from the sensor to the gauge. If all checks out, replace the speedometer/odometer assembly.

GO TO Chapter 25 for more information on checking a VSS.

Oil Pressure Gauge

The oil pressure gauge displays engine oil pressure. Normally an engine's oil pressure should be between 45 and 70 psi while the engine is running at the specified speed and operating temperature.

With low oil pressure (or with the engine shut off), the oil pressure switch is open and no current flows through the gauge winding. The needle points to low (L). With oil pressure above a specific limit, the switch closes and current flows through the gauge winding to ground. A resistor limits current flow through the winding and ensures that the needle points to about mid-scale with normal oil pressure.

A piezoresistive sensor **(Figure 21–23)** is threaded into an oil delivery passage in the engine. The pressure of the oil causes a flexible diaphragm to move. This movement is transferred to a contact arm that slides down the resistor. The position of the arm determines the amount of current flow through the gauge.

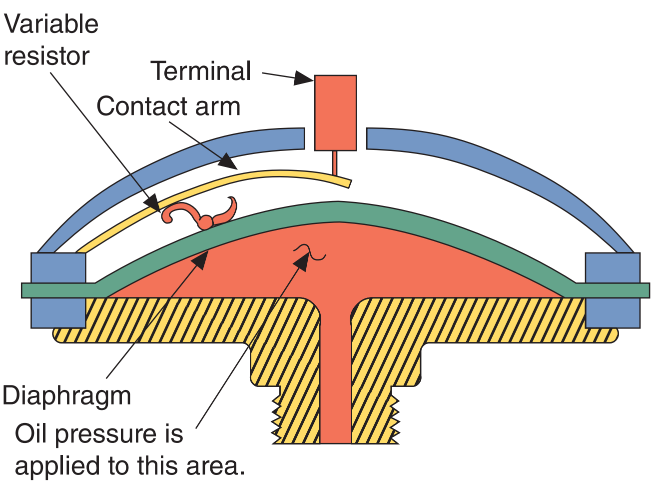


FIGURE 21–23 A piezoresistive sensor used for measuring engine oil pressure.

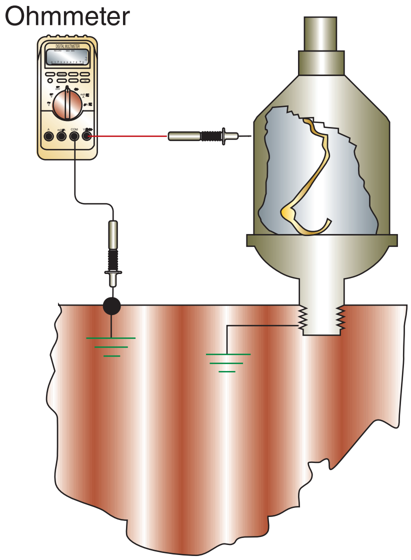


FIGURE 21–24 Using an ohmmeter to test a piezoresistive sensor.

Diagnosis To test a piezoresistive-type sending unit, connect an ohmmeter to the sending unit's terminal and to ground **(Figure 21–24)**. Check the resistance with the engine off and compare it to specifications. Start the engine and allow it to idle. Check the resistance value and compare it to specifications. Before replacing the sending unit, connect a shop oil pressure gauge to confirm that the engine is producing adequate oil pressure.

Coolant Temperature Gauge

This gauge displays the engine's coolant temperature (ECT). It shows a reading between C (cold) and H (hot). The sending unit is typically a negative temperature coefficient (NTC) thermistor. With low coolant temperature, sender resistance is high and the current flow to the temperature gauge winding is low **(Figure 21–25)**. The needle points to C. As coolant temperature increases, sender resistance decreases and current flow increases. The needle moves toward H.

On a digital panel, the temperature gauge is normally a bar type with a set number of segments. With low coolant temperature, few segments are lit. As coolant temperature increases, the number of illuminated segments increases.

Depending on the vehicle, there may be more than one coolant temperature sensor. One sensor

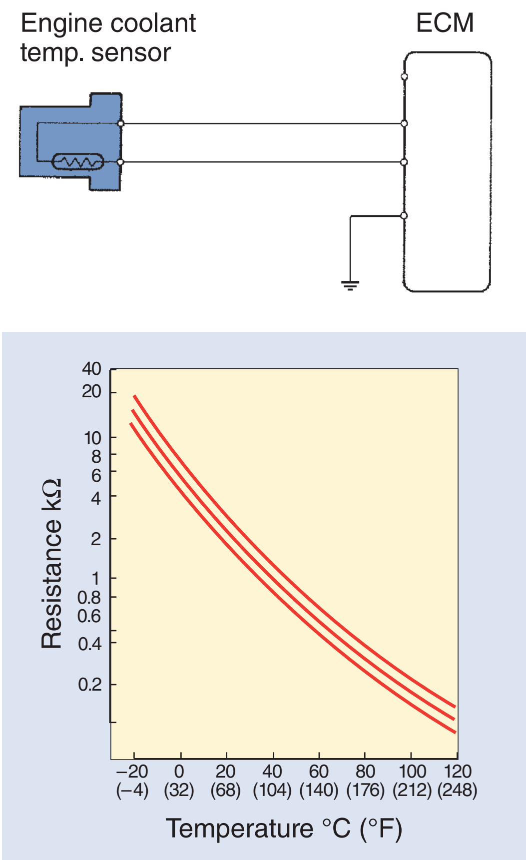


FIGURE 21–25 Most engine coolant temperature sensors use an NTC thermistor. The resistance of an NTC decreases with an increase in temperature.

may be dedicated to the coolant temperature gauge while a second sensor is used by the PCM to monitor coolant temperature and for cooling fan operation. Before attempting to diagnose a temperature gauge concern, make sure you identify the correct sensor used by the gauge.

Diagnosis To test a coolant temperature sending unit, use an ohmmeter to measure resistance across the terminals **(Figure 21–26)**. The resistance value of the NTC thermistor decreases with an increase in temperature. Compare your measurements with the manufacturer's specifications. On most new vehicles, the action of an ECT can be monitored on a scan tool.

Fuel Level Gauge

The fuel level gauge shows the level or amount of fuel in the tank. The display can be found as an analog (meter) or digital (bars) display. Nearly all fuel level gauge circuits use the same type of fuel tank sending unit.

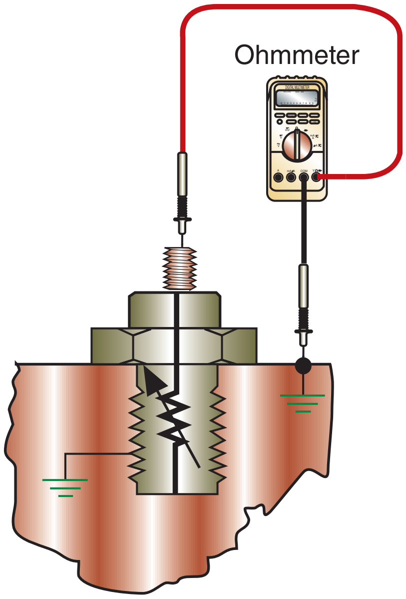


FIGURE 21–26 Testing a temperature sensor with an ohmmeter.

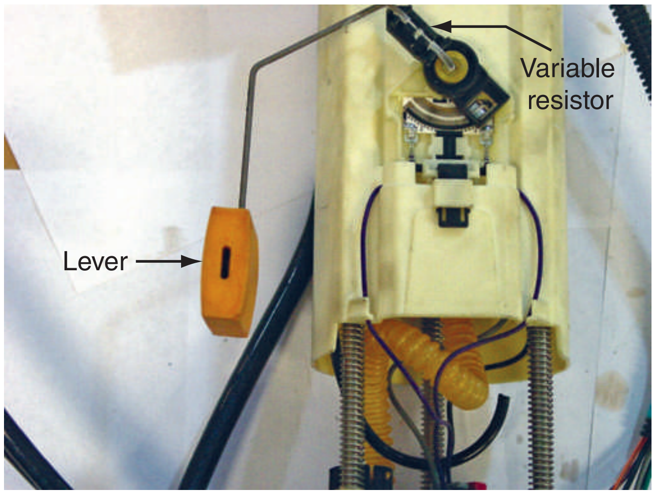


FIGURE 21–27 A fuel gauge sending unit.

The fuel level sending unit is combined with the fuel pump and consists of a variable resistor controlled by a float that positions itself according to level of fuel in the tank **(Figure 21–27)**. When the fuel level is low, resistance of the sender is high and the movement of the gauge needle or number of lit bars is minimal (from empty position). When the fuel level is high, the resistance in the sender is low and movement of the gauge indicator (from the empty position) or number of lit bars on a digital display is greater.

In some fuel gauge systems, an antislosh/low fuel warning (LFW) module is used to reduce fuel gauge needle fluctuation caused by fuel motion in

the tank and provide a low fuel warning when the fuel tank reaches $\frac{1}{8}$ th to $\frac{1}{16}$ th full.

Tachometer

The tachometer displays engine rpm (engine speed). The electrical pulses to the tachometer typically come from the ignition module or PCM. The tachometer, using a balanced coil gauge, converts these impulses to rpm that can be read. The faster the engine rotates, the greater the number of impulses from the coil. Consequently, higher engine speeds are indicated. In vehicles with digital instrumentation, the bar system is used with numbered segments. The numbers represent the engine's rpm times 1,000.

If the tachometer receives a signal from the data bus, use a scan tool to see if the signal is being sent correctly. If the signal is being sent correctly, the problem is either the gauge or the instrument cluster.

Charging Gauges

These allow the driver to monitor the charging system. Whereas a few older cars use an ammeter, most charging systems use a voltmeter or an indicator light. The indicator lamp will light when the voltage from the charging system is less than the voltage at the battery. The ECM may command a charging system warning light or message to display if there is a fault in the charging system. Connect a scan tool to check for DTCs when diagnosing a charging system problem or the warning light is on.

GO TO Chapter 19 for more information on charging indicators.

Indicator and Warning Devices

Vehicles are equipped with several warning devices to alert the driver to problems. Most of these are safety or emissions related. These are controlled by sending units that act as simple on/off switches. The sending units can be normally open or normally closed switches. Warning lights notify the driver that something in the system is not functioning properly or that a situation exists that must be corrected. Some system problem may cause the system to emit an audible sound in addition to illuminating the lamp. Gauges and warning lights often work together to alert the driver to a problem.

FIGURE 21–28 Most warning lights and indicators go through a bulb check when the ignition is first switched to the *on* position.

Indicator lamps inform the driver that something that is normally off is now on, or vice versa. Consider the rear window defogger. When it is turned on, the indicator is lit. Another example is traction control. This system is normally on and when it is switched off, its indicator is lit.

Diagnosis

Warning lights will come on briefly when the engine is first started; this is a bulb check **(Figure 21–28)**. It is unlikely that all of the lamps will be bad so if the lamps do not light during the bulb check, check the circuit's fuse. If the fuse is okay, check for voltage at the last common connection. If there is no voltage there, follow the circuit back to the battery and check for voltage at all available points. If there was voltage at the common connection, test each circuit branch.

Unplugging the electrical connection to the sending unit should cause the warning lamp to either light or go out, depending on whether the sending unit is normally closed or open. The same is true if the disconnected wire is momentarily touched to a ground. If the lamp does not respond as it should, carefully check the circuit. If the lamp did respond normally, the sending unit should be replaced.

Computer-controlled warning lamps are diagnosed with a scan tool. The scan tool can be used to force a lamp to illuminate. If a lamp does not turn on when it is ordered to, the bulb, circuit board, or instrument panel module is bad. If the lamp does turn on, the signal to the instrument cluster should be checked. Common warning lamp problems and their probable causes are shown in **Table 21–3**.

Warning! Be aware that many of the warning and indicator lamps found on today's vehicles are triggered by a PCM or BCM. Often they are part of the multiplexed system. With this in mind, always refer to the testing methods recommended by the manufacturer before testing these systems. Using conventional testing methods on a computerized system may destroy part or all of the system.

FIGURE 21–29 A typical "service engine soon" warning display.

Engine-Related Warning and Indicator Lights

Check Engine Light This may be also labeled as "Service Engine Soon" **(Figure 21–29)**. This warning is primarily an emissions-related light. If something happens that will cause the vehicle to have higher emissions, the PCM will display this warning. This warning may also be triggered by oil pressure or coolant temperature. This warning may illuminate when the computer has stored a fault or diagnostic code in its memory.

Oil Pressure Light This lamp is operated by an oil pressure switch located in the engine's lubricating system. Some vehicles will illuminate this lamp in yellow or red to indicate the action the driver should take, red meaning the engine has an oil pressure problem and the engine should be shut down and yellow indicating the oil level is low and should be topped off as soon as possible.

Charge Indicator Light If there is something wrong with the charging system, this light comes on while the engine is running. In some cases, this light may remain on after the engine is shut off. This also indicates a fault in the charging system.

Check Filler Cap This lamp will be illuminated when the gas filler cap is not tight or off and when the engine control system senses a problem with the fuel system.

Add Coolant Lamp The purpose of this lamp is to inform the driver of low coolant levels in the cooling system.

Electronic Throttle Control Light

Engines equipped with electronic throttle control have a warning light that will turn on if a fault is detected in the system. If this occurs, engine and

TABLE 21–3 COMMON WARNING LAMP PROBLEMS AND THEIR PROBABLE CAUSES

Symptoms	Possible Causes
Warning light remains on all of the time.	Sending unit circuit grounded Faulty sending unit switch
Warning light fails to operate on an intermittent basis.	Loose sending unit circuit connections Faulty sending unit
One or all warning lights fail to operate.	Blown fuse Burned-out bulb Open in the circuit Defective sending unit switches

vehicle speed is typically limited as a safety precaution. This limited operation provides "limp-in" operation so the vehicle can be driven to a repair facility.

Safety-Related Warning and Indicator Lights

Electric Power-Steering Fault Light This light turns on if a fault is present in the electric power-steering assist system. Because the steering is still mechanically linked to the steering gearbox, steering control is maintained, however, power-steering assist will be reduced or absent.

SRS (Air Bag) Readiness Light The air bag readiness light lets the driver know the air bag system is working and ready to do its job. It lights briefly when the ignition is turned on. A malfunction in the air bag system will cause the light to stay on continuously or to flash.

Passenger or Side Air Bag Off Light Some vehicles have an indicator light that alerts the driver when the passenger side air bag or side impact air bags are disabled. This typically occurs when an object of insufficient weight is placed in the passenger seat. The occupant detection system in the seat recognizes that the weight is not enough to be a full-sized person and turns the air bag off.

Fasten Belts Indicator This lamp, typically accompanied by a chime, will illuminate when the driver and/or passenger has not fastened the seat belt **(Figure 21–30)**. The chime and lamp will stay on until the belt is buckled. When the ignition switch is in the ON position, the system is activated for about 5 seconds, whether or not the driver's belt is buckled.

FIGURE 21-30 A typical "fasten your seat belt" warning.

Brake Warning Light When this light is lit, it is an indication that the parking brake is engaged or there is a problem with the brake system. Vehicles built for Canada may have a separate warning lamp that indicates when the parking brake is applied.

Brake Fluid Level Warning Light The lamp is connected to a brake fluid level sensor in the brake fluid reservoir. If the brake fluid drops below a specified level, the sensor is activated and the light turns on while the engine is running.

Antilock Light If an antilock brake system fault is present, the antilock brake module grounds the indicator circuit, and the antilock light goes on **(Figure 21–31)**. Vehicles built for Canada may have a different symbol on their warning lamp.

FIGURE 21-31 Typical "Brake and ABS" warnings.

Traction/Stability Control Light This light often is used with the ABS warning light to indicate a fault in the traction or stability control system. A failure of the ABS, such as from a faulty wheel speed sensor, will turn on both the ABS and traction or stability control lights. The red lamps will also be lit when the system is turned off. Yellow lamps are lit when the system is actively regulating drive torque and braking force.

Brake Pad Indicator This lamp illuminates when the sensors at the wheel brake units sense thin brake pads. The sensors are typically embedded in

the pads and when they contact the metal rotor, the warning light circuit is complete and the lamp is lit.

Lamp-Out Warning The lamp-out warning module is an electronic unit that is designed to measure small changes in voltage levels. An electronic switch in the module closes to complete a ground path for the indicator lights in the event of a bulb going out. The key to this system being able to detect one bulb out on a multibulb system is the use of the special resistance wires. With bulbs operating, the resistance wires provide 0.5 volt input to the light-out warning module. If one bulb in a particular system goes out, the input off the resistance wire drops to approximately 0.25 volt. The light-out warning module detects this difference and completes a ground path to the indicator light for the affected circuit.

Stoplight Warning Light The light is controlled by a stoplight (brake light) checker. The checker has a reed switch and magnetic coils. Magnetic fields form around the coils by the current flowing through each light when the stoplight switch is on. The magnetic fields cancel each other because the coils are wound in opposite directions. As a result, the reed switch and the warning light are off. If a stoplight fails, current only flows through one coil, and the resultant magnetic field causes the reed switch to close and the warning light to illuminate when the brake pedal is depressed.

Driver Information Warning and Indicator Lights

Blind Spot Detection, Back Up, and Lane Departure Warnings Both blind spot detection and lane departure warning systems are becoming common on modern cars and trucks. These systems may use a combination of visual alerts, such as blinking lights in the mirrors, video from cameras displayed on the dash or DIC, audible alerts, or vibrating seats. These alerts are used to inform the driver that an object is detected within the range of view of the various sensors.

Low Fuel Warning This lamp will illuminate when the fuel level is below a quarter full. An electronic switch closes and power is applied to illuminate the lamp.

Maintenance Reminder This lamp turns on to alert the driver that maintenance needs to be performed on the vehicle **(Figure 21–32)**. The light is controlled based on calculations that take into

FIGURE 21–32 The wrench on the gauge indicates that maintenance is due.

account mileage and the driving and operating conditions since the last service. On some older systems, only mileage is used to determine the next service. This is not a warning; it is a reminder. Often the lamp will light for 2 seconds when the car is started, if the vehicle has been serviced within a specified interval. Normally, the required maintenance is an engine oil change. The name of this indicator includes “oil” on many vehicles. When the lamp is not reset during the specified distance, it will flash after the engine has started. If there was no service for about twice the recommended distance, the lamp will stay on continuously until it is reset. The procedure for resetting this reminder varies with the manufacturer.

Transmission Indicator This is part of an automatic transmission’s control system. If the system detects a fault, it may operate the transmission in the fail-safe mode and will illuminate the warning light to inform the driver of the problem and to alert him or her that the transmission may not be working normally.

Drive Indicator Some four-wheel-drive vehicles have a lamp which, when lit, indicates that the vehicle is in four-wheel-drive mode of operation.

O/D Off Indicator This lamp is illuminated when the overdrive function of an automatic transmission has been switched off by the driver.

Eco Drive Indicator

To help drivers save fuel, some vehicles have an Eco light or display. Depending on the car, the light may come on when driving in a manner that saves fuel compared to other driving styles. Other vehicles may

show leaves or similar items that grow as driving efficiency increases.

Rear Defrost Indicator When this light is lit, the defroster or de-icer is operating.

High-Beam Indicator With the headlights turned on and the main light switch dimmer in the high-beam position, the indicator illuminates.

Left and Right Turn Indicators With the multi-function switch in the left or right turn position, voltage is applied to the circuit to illuminate the left or right turn indicator. The turn indicator flashes in unison with the exterior turn signal bulbs.

Fog Light Indicator This lamp is illuminated when the fog lights are turned on.

Tire Pressure Monitor (TPM) When a low-inflated or flat tire is found, this warning light turns on. Some systems will illuminate this lamp in red or yellow. Red means there is an excessively low or flat tire and yellow means a tire has low pressure **(Figure 21–33)**. Some systems also emit a sound to alert the driver. To turn off the TPM lamp, always follow the manufacturer's procedure.

GO TO Chapter 45 for more information on TPMS.

Cruise Control Light This lamp is lit whenever the cruise control is turned on.

FIGURE 21-33 The TPM display with an outline of the vehicle showing there are tire pressure issues on the right side.

Air Suspension Light Voltage is present at the air suspension indicator at all times. If an air suspension fault exists, the ground of the light circuit is closed and the indicator illuminates.

Door Ajar Warning When the ignition is turned on and if the doors are left open or are ajar, this light comes on.

Add Washer Fluid Obviously, the purpose of this lamp is to inform the driver of a low level in the windshield washer fluid reservoir.

Sound Warning Devices

Various types of tone generators, including buzzers, chimes, and voice synthesizers, are used to make drivers aware of current operating conditions. These warnings can include fasten seat belts, air bag operational, key left in ignition, door ajar, and light left on.

Park Distance Control (PDC) This feature uses sensors to measure the distance the front and/or rear of the vehicle is from an object **(Figure 21–34)**. An audible signal changes in frequency as the vehicle gets closer to an object. As the distance between the vehicle and object decreases, the intervals between the tones become shorter. When the object is very close, the tone is emitted continuously. The system uses four ultrasonic sensors at the rear and the front of the vehicle. Some systems include a visual indication of the distances to the obstacles, in addition to the audible warning.

Some systems allow the front sensors to be manually turned off in special situations such as stop-and-go traffic. The rear sensors automatically turn on when the transmission is placed into reverse.

FIGURE 21-34 The sensors measure the distance from the rear of the car to obstacles and triggers the warning system inside the vehicle.

Driver Information Centers

The various gauges, warning devices, and comfort controls may be grouped together into a driver information center or instrument cluster. This may be a simple or an all-encompassing cluster of information. The message center keeps the driver alert of the information available. The types and extent of this information varies from one system to another.

In addition to the standard warning signals, the information center may provide other vital data as fuel range, average or instantaneous fuel economy, fuel used since reset, time, date, estimated time of arrival (ETA), distance to destination, elapsed time since rest, average car speed, percent of oil life remaining, and various engine-operating parameters.

Graphic Displays

Graphic displays are translucent drawings of the vehicle. They use small lamps located at various spots in the graphic. When a lamp is lit, the area indicated by the lamp has a problem. These indicators can note such things as an open trunk or a light bulb not working.

Hybrid Vehicles

Hybrid vehicles have some unique and interesting warnings, indicators, and displays. They all also have normal displays for the engine and other systems. The following is a brief look at the unique stuff they have.

GO TO Chapter 35 for more information on hybrid vehicles.

Honda The instrument panel on most Honda hybrids displays the typical conditions for a gasoline engine, plus they display the operation of the hybrid (IMA) system and the car's fuel efficiency. Also, on cars with a manual transmission, the panel has upshift and downshift lights that are triggered by the PCM to inform the driver when it is most economical to shift gears.

The instrument panel has a meter that displays the status of the battery and IMA system **(Figure 21–35)**. A charge/assist indicator shows when the system's electric motor is assisting the engine. The amount of assist is indicated by bars.

FIGURE 21–35 The instrument cluster in Honda hybrid vehicles has a meter that displays the status of the battery and IMA system.

The number of bars illuminated indicates how much assist is being provided. This same display shows the amount of charge going to the batteries. When more bars are illuminated, the batteries are being recharged at a higher rate. Also on this side of the cluster is a state-of-charge indicator for the battery module. The entire cluster is designed to help the driver achieve maximum fuel economy.

Toyota Most Toyota hybrids have a multi-information display in the center cluster panel. The display, a 7-inch LCD with a pressure sensitive touch panel, serves many functions. Many of these are typical, but some are unique to hybrid technologies. One is the fuel consumption screen. This display shows average fuel consumption, current fuel consumption, and the current amount of recovered energy.

Another unique display is the energy monitor screen **(Figure 21–36)**. This shows the direction and

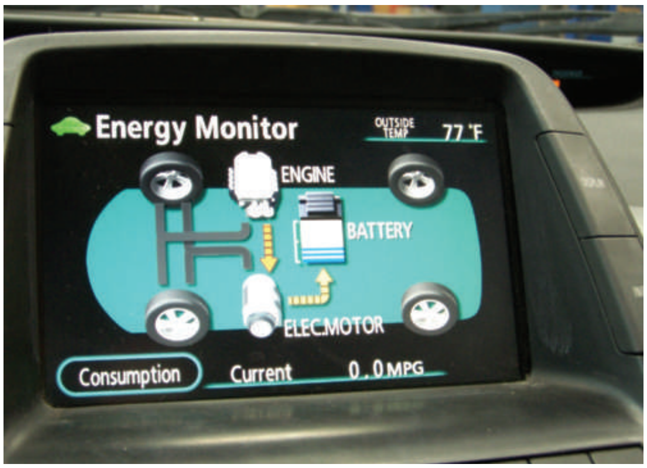


FIGURE 21–36 The energy monitor for a Toyota Prius.

path of energy flow through the system in real time. By observing this display, drivers can alter their driving to achieve the most efficient operation for the current conditions.

Like other vehicles, these vehicles are equipped with a variety of warning lamps and indicators. Here are some of the indicators that are unique:

- *"Ready" light*—This lamp turns on when the ignition switch is turned to START to indicate that the car is ready to drive. The engine may or may not be running at this time, but is ready to start as needed.
- *Output control warning light*—This lamp turns on when the temperature of the HV battery is too high or low. When this lamp is lit, the system's power output is limited.
- *HV battery warning light*—This lamp lights when the charge of the HV battery is too low.
- *Hybrid system warning light*—When the HV control unit detects a problem with the motor/generators, the inverter assembly, the battery pack, or the ECU itself, this lamp will be lit.
- *Malfunction indicator light*—This lamp is tied into the engine control system and will be lit when the PCM detects a fault within that control system.
- *Discharge warning light*—This lamp is tied to the 12-volt system and DC-DC converter. It will illuminate when there is a problem in that circuit.

Hybrid four-wheel-drive SUVs show more information and include lamps for the four-wheel-drive option. The latter is monitored by a four-wheel-drive warning lamp that notifies the driver of any detected fault within the MGR (Motor/Generator—Rear) and rear transaxle. When this lamp is lit, a warning buzzer is also activated.

SHOP TALK

Starting or driving a hybrid is different. When the car is ready to be driven, the engine may not be running, but the "ready" lamp will be lit, which means the motor is ready to move the vehicle. If the "ready" lamp does not come on, the vehicle cannot be driven.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2007	**Make:** Toyota	**Model:** FJ Cruiser	**Mileage:** 133,502	**RO:** 17899
Concern:	Customer states fuel gauge always reads below empty.			
The technician verifies the concern and then checks the service information for how the circuit operates. High resistance from the fuel sending unit means a low fuel level and low resistance means a high fuel level. Since the gauge is reading empty, she suspects a resistance problem at the fuel tank or sending unit.				
Cause:	Found fuel gauge stays below empty. Inspected fuel sending unit connection and measured sending unit resistance. Sending unit measured open.			
Correction:	Replaced fuel sending unit. Fuel gauge now reads correct fuel level.			

KEY TERMS

Balancing coil gauge
Heads-up display (HUD)
Instrument voltage regulator (IVR)

SUMMARY

- The two basic types of instrument panel displays are analog and digital. In an analog display, an indicator moves in front of a fixed scale to indicate a condition. A digital display uses numbers instead of a needle or graphic symbol.
- Three types of digital electronic displays are used today: light-emitting diode, liquid crystal diode, and vacuum fluorescent.
- A heads-up display projects visual images on the windshield by a vacuum fluorescent light source to complement existing traditional in-dash instrumentation.
- A gauge circuit is often comprised of the gauge, a sending unit, and an instrument voltage regulator (IVR).
- Two types of electrical analog gauges—magnetic and thermal—are commonly used with sensors or sending units.

- Indicator lights and warning devices are generally activated by the closing of a switch.
- Various types of tone generators, including buzzers, chimes, and voice synthesizers, are used to inform drivers of vehicle conditions.
- Park distance control uses sensors to measure the distance the front and/or rear of the vehicle is from an object and emits an audible warning as the vehicle gets closer to an object.
- The various gauges, warning devices, and comfort controls may be grouped together into a driver information center or instrument cluster.
- Diagnosis of gauges, indicators, and warning lights should begin with a good visual inspection of the circuit. Check all sensors and actuators; connections and wires to sensors, actuators, control modules, and ground points; and all vacuum hoses.

REVIEW QUESTIONS

Short Answer

1. What is the purpose of an IVR?
2. Explain how an air-core gauge works.
3. What are two ways to provide input for the speedometer?
4. Describe the two types of instrument panel displays.
5. What is the device found in some fuel tanks to prevent fuel gauge fluctuations due to rough road surfaces?
6. What is the correct way to check a coolant temperature sensor?
7. What type of sending unit is typically used to monitor oil pressure?
8. What is the major difference between an indicator lamp and a warning light?

True or False

1. *True or False?* A driver information center projects indicator and warning lights on the windshield rather than illuminating them in the instrument panel.
2. *True or False?* The ABS lamp turns on whenever the system is actively regulating drive torque and braking force.

Multiple Choice

1. The indicator needle on a speedometer is held to the zero position by ___.
   a. magnetic force
   b. the weight of the needle
   c. the speedometer cable
   d. a hairspring
2. Which of the following uses a permanent magnet and two electromagnets?
   a. Air-core gauge
   b. Balancing coil gauge
   c. Quartz analog gauge
   d. D' Arsonval gauge
3. What type of memory is used to store the accumulated mileage in an electronic odometer?
   a. RAM
   b. ROM
   c. PROM
   d. None of the above
4. Which of the following is *not* a true statement about lamp-out warning lights?
   a. The lamp-out warning module measures small changes in voltage levels.
   b. An electronic switch in the module completes a ground path for the indicator lights in the event of a bulb going out.
   c. A special resistance wire is used in multibulb systems.
   d. When a bulb burns out, the module senses the increased voltage drop and turns on the indicator lamp.
5. Which of the following statements about oil gauge circuits is *not* true?
   a. A switch can be used.
   b. A thermistor can be used.
   c. A piezoresistive sensor can be used.
   d. An oil pressure gauge may not show actual oil pressure.

ASE-STYLE REVIEW QUESTIONS

1. While discussing what the maintenance reminders base the time for the next service on: Technician A says that future service is based on the

type of driving the vehicle has seen since the last service. Technician B says that the next interval may be based only on the number of miles or kilometers since the last service. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

2. None of the engine's gauges works: Technician A tests gauge operation using a scan tool. Technician B begins by checking the fuse and then checks for voltage at the last point common to all the malfunctioning gauges. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. The oil pressure light stays on whenever the engine is running, and the oil pressure has been checked and it meets specifications: Technician A says that a ground in the circuit between the indicator light and the pressure switch could be the cause. Technician B says that an open in the pressure switch could be the cause. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. A digital speedometer constantly reads 0 mph: Technician A says that the problem may be the vehicle speed sensor. Technician B says that the problem may be the throttle position sensor. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. All gauges operate but read lower than normal: Technician A says that the connection to the instrument cluster may be corroded. Technician B says that the cluster's IVR may be open. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. When testing an engine temperature sensor: Technician A uses an ohmmeter to test the thermistor. Technician B says that the thermistor reacts to pressure and applies air pressure to the backside of the sensor. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. The coolant temperature gauge stays low (cold) after the engine has been started and ran until the engine is hot: Technician A says that the wires to the sending unit may be shorted together. Technician B says that the sending unit may be electrically open. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. While discussing the instrumentation on a Toyota hybrid: Technician A says that the "ready" light must be on before the vehicle is able to move. Technician B says that the engine must be running before the "ready" light is turned on. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. The TPM warning lamp is lit: Technician A says that the cause could be low inflation. Technician B says that the customer may have used a tire sealant to seal a puncture. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. The yellow electronic throttle control warning lamp comes on occasionally while the vehicle is driven: Technician A says that this means there is a problem with the system. Technician B says that the system is actively regulating drive torque and engine power when the lamp is lit. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER 22

BASICS OF ELECTRONICS AND COMPUTER SYSTEMS

OBJECTIVES

- Explain the advantages of using electronic control systems.
- List and describe the functions of the various sensors used by computers.
- Explain the principle of computer communications.
- List and describe the operation of output actuators.
- Explain the principle of multiplexing.
- Describe the precautions that must be taken when diagnosing electronic systems.
- Perform a communications check on a multiplexed system.
- Reprogram a control module in a vehicle.

Computerized engine controls and other features of today's vehicles would not be possible if it were not for electronics. Capacitors, transistors, diodes, semiconductors, integrated circuits, and solid-state devices are all considered to be part of electronics rather than just electrical devices. But keep in mind that all the basic laws of electricity apply to electronic controls.

Capacitors

A **capacitor** is used to store and release electrical energy. Capacitors can be used to smooth out current fluctuations, store and release a high voltage, or block DC voltage. Capacitors are sometimes called condensers. Although a battery and a capacitor store electrical energy, the battery stores the energy chemically. A capacitor stores energy in an electrostatic field created between a pair of electrodes.

A capacitor can release all of its charged energy in an instant, whereas a battery slowly releases its charge. A capacitor is quick to discharge and quick to charge. A battery needs some time to discharge

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2005	**Make:** VW	**Model:** Beetle	**Mileage:** 113,902	**RO:** 18047
Concern:	Customer states the check engine light stays on. Stopped at auto parts store to have light checked, parts store could not read codes.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

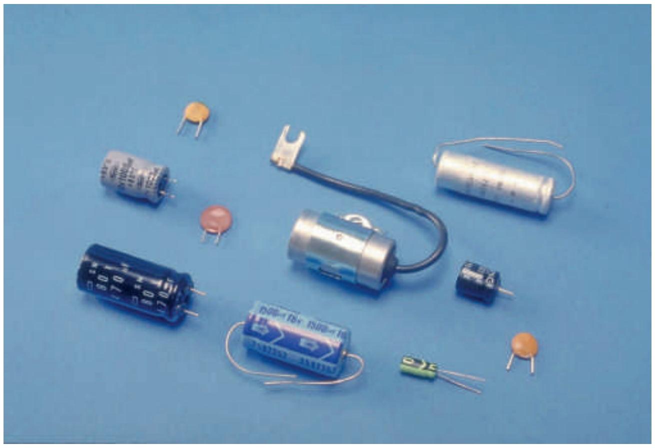


FIGURE 22–1 Examples of the capacitors that may be found in automotive circuits.

and charge but can provide continuous power. A capacitor only provides power in bursts.

Operation

A capacitor has a positive and a negative terminal **(Figure 22–1)**. Each terminal is connected to a thin electrode or plate (usually made of metal). The plates are parallel to each other and are separated by an insulating material called a dielectric. The dielectric can be paper, plastic, glass, or anything that does not conduct electricity. Placing a dielectric between the plates allows the plates to be placed close to each other without allowing them to touch.

When voltage is applied to a capacitor, the two electrodes receive equal but opposite charges **(Figure 22–2)**. The negative plate accepts electrons and stores them on its surface. The other plate loses electrons to the power source. This action charges the capacitor. Once the capacitor is charged, it has the same voltage as the power source. This energy is stored statically until the two terminals are connected together.

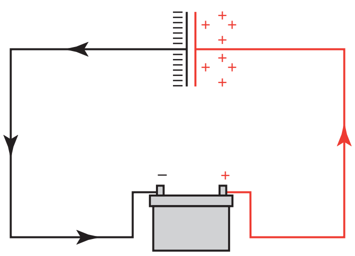


FIGURE 22–2 When voltage is applied to a capacitor, the two electrodes receive equal but opposite charges.

The ability of a capacitor to store an electric charge is called **capacitance**. The standard measure of capacitance is the **farad (F)**. A 1-farad capacitor can store 1 coulomb of charge at 1 volt. A coulomb is 6.25 *billion billion* electrons. One ampere equals the flow of 1 coulomb of electrons per second, so a 1-farad capacitor can hold 1 ampere-second of electrons at 1 volt. A capacitor's capacitance is directly proportional to the surface areas of the plates and the nonconductiveness of the dielectric and is inversely proportional to the distance between the plates. Most capacitors have a capacitance rating of much less than a farad and their values are expressed in one of these terms:

- Microfarads: μF ($1\ \mu F = 10^{-6}$ F)
- Nanofarads: nF (1 nF = 10^{-9} F)
- Picofarads: pF (1 pF = 10^{-12} F)

Capacitors oppose a change of voltage. If a battery is connected to a capacitor as shown in Figure 22–2, the capacitor will be charged when current flows from the battery to the plates. This current flow will continue until the plates have the same voltage as the battery. At this time, the current flow stops and the capacitor is charged.

The capacitor remains charged until a circuit is completed between the plates. If the charge is routed through a voltmeter, the capacitor will discharge with the same voltage as the battery that charged it. This statement explains why capacitors are commonly used to filter or clean up voltage signals, such as sound from a stereo. Current can only flow during the period that a capacitor is either charging or discharging.

Automotive capacitors are normally encased in metal. The grounded case provides a connection to one set of conductor plates and an insulated lead connects to the other set.

Variable capacitors are called **trimmers** or tuners and are rated very low in capacity because of the reduced size of their conducting plates. For this reason, they are only used in very sensitive circuits such as radios and other electronic applications.

Ultracapacitors

Ultra- or supercapacitors **(Figure 22–3)** are used in hybrid vehicles and in some experimental fuel cell electric vehicles **(Figure 22–4)**. Ultracapacitors are capacitors with a large electrode surface area and a very small distance between the electrodes. These features give them very high capacitance; some are rated at 5,000 farads. Ultracapacitors are discussed in more detail in Chapter 35.

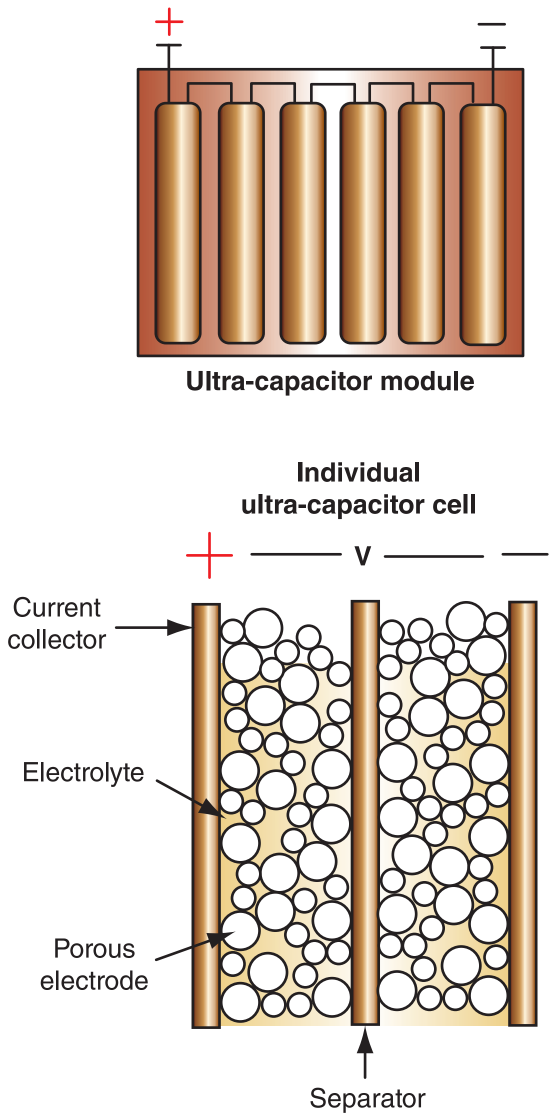


FIGURE 22–3 Ultracapacitor cell construction.

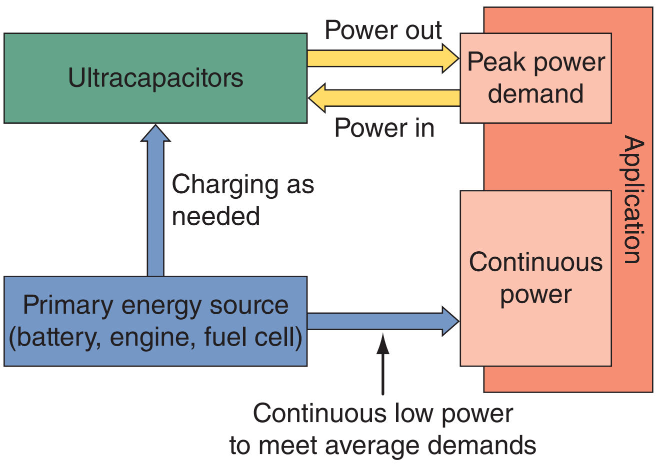


FIGURE 22–4 A look at the power flow for an ultracapacitor in a hybrid or fuel cell vehicle.

Semiconductors

A semiconductor is a material or device that can serve as a conductor or an insulator. Semiconductors have no moving parts; therefore, they seldom wear out or need adjustment. Semiconductors, or solid-state devices, are also small, require little power to operate, are reliable, and generate very little heat. For all these reasons, semiconductors are being used in many applications. However, current to them must be limited, as should heat.

Because a semiconductor can function as both a conductor and an insulator, it is often used as a switching device. How it behaves depends on what it is made of and which way current flows (or tries to flow) through it. Two common semiconductor devices are diodes and transistors. Diodes are used for isolation of components or circuits, clamping, or rectification of AC to DC. Transistors are used for amplification or switching.

Semiconductor materials have less resistance than an insulator but more resistance than a conductor. They also have a crystal structure. This means their atoms do not lose and gain electrons as conductors do. Instead, the atoms in semiconductors share outer electrons with each other. In this type of atomic structure, the electrons are tightly held and the element is stable. Common semiconductor materials are silicon (Si) and germanium (Ge).

Because the electrons are not free, the crystals cannot conduct current and are called **electrically inert materials**. In order to function as semiconductors, a small amount of trace element, called **impurities**, must be added. The type of impurity determines the type of semiconductor.

N-type semiconductors have loose, or excess, electrons. They have a negative charge and can carry current. N-type semiconductors have an impurity with five electrons in the outer ring (called pentavalent atoms). Four of these electrons fit into the crystal structure, but the fifth is free. This excess of electrons produces the negative charge. **Figure 22–5** shows an example.

P-type semiconductors are positively charged materials. They are made by adding an impurity with three electrons in the outer ring (trivalent atoms). When this element is added to silicon or germanium, the three outer electrons fit into the pattern of the crystal, leaving a hole where a fourth electron would fit. This hole is actually a positively charged empty space. This hole carries the current in the P-type semiconductor. **Figure 22–6** shows an example of a P-type semiconductor.

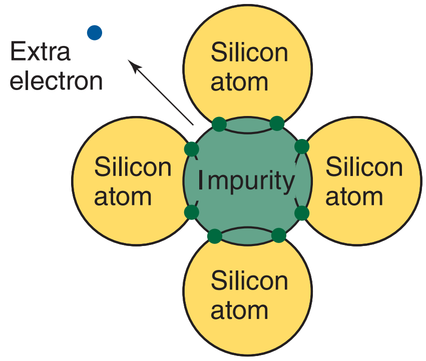


FIGURE 22–5 Atomic structure of an N-type silicon semiconductor.

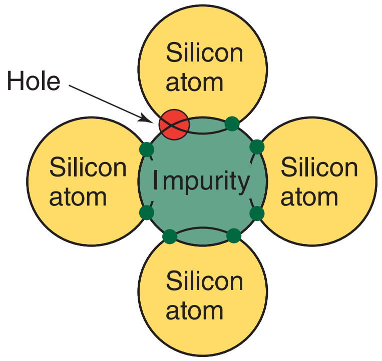


FIGURE 22–6 Atomic structure of a P-type silicon semiconductor.

Hole Flow

Understanding how semiconductors carry current without losing electrons requires an understanding of the concept of hole flow. The holes in a P-type semiconductor, being positively charged, attract electrons. Although the electrons cannot be freed from their atom, they can rearrange and fill a hole in a nearby atom. Whenever this happens, the place where the electron was is now a hole. This hole is then filled by another electron, and the process continues. The electrons move to the positive side of the structure, and the holes move to the negative side.

Diodes

Diodes are simple semiconductors. The most commonly used are regular diodes, LEDs, zener diodes, clamping diodes, and photo diodes. A diode allows current to flow in one direction; therefore, it can serve as a conductor or insulator, depending on the direction of current flow **(Figure 22–7)**. In a generator, voltage is rectified by diodes. Diodes are arranged so that current can leave the AC generator in one direction only (as direct current).

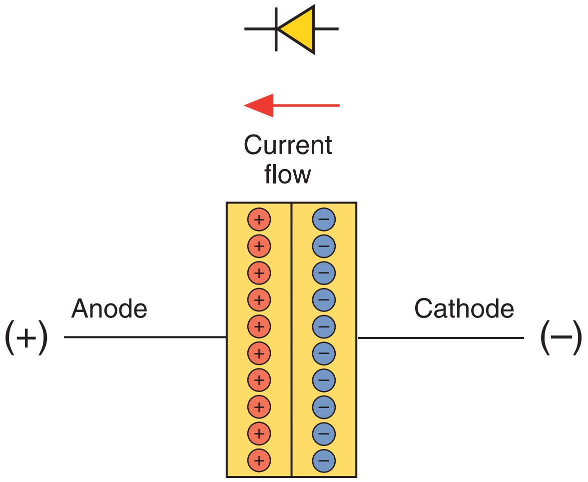


FIGURE 22–7 A diode and its schematical symbol.

Inside a diode are positive and negative areas that are separated by a boundary area. The boundary area is called the PN junction. When the positive side of a diode is connected to the positive side of the circuit, it is said to have **forward bias (Figure 22–8)**.

Unlike electrical charges are attracted to each other and like charges repel each other. Therefore, the positive charge from the circuit is attracted to the negative side. The circuit's voltage is much stronger than the charges inside the diode, which causes the diode's charges to move. The diode's P material is repelled by the positive charge of the circuit and is pushed toward the N material and the N material toward the P. This causes the PN junction to become a conductor, allowing current to flow.

When **reverse bias** is applied to the diode, the P and N areas are connected to opposite charges. Because opposites attract, the P material moves toward the negative part of the circuit and the N material moves toward the positive part of the circuit. This empties the PN junction and current flow stops.

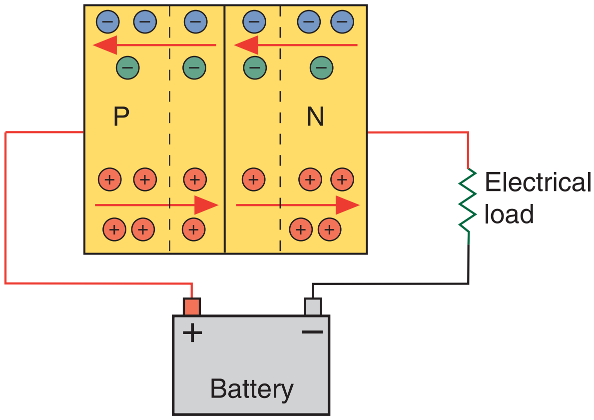


FIGURE 22–8 Forward biased voltage allows current flow through the diode.

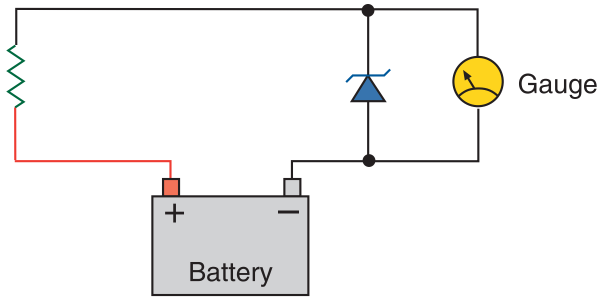


FIGURE 22-9 A simplified gauge circuit with a zener diode used to maintain a constant supply voltage to the gauge.

A **zener diode** works like a standard diode until a certain voltage is reached. When the voltage reaches this point, the diode allows current to flow in the reverse direction. Zener diodes are often used in electronic voltage regulators **(Figure 22–9)**.

LEDs emit light as current passes through them **(Figure 22–10)**. The color of the emitted light depends on the material used to make the LED. Typically LEDs are made of a variety of inorganic semiconductor materials that produce different colors.

Whenever the current flows through a coil of wire, such as used in a solenoid or relay stops, a voltage surge or spike is produced. This surge results from the collapsing of the magnetic field around the coil. The movement of the field across the winding induces a very high-voltage spike, which can damage electronic components. In the past, a capacitor was used as a "shock absorber" to prevent component damage from this surge. On today's vehicles, a **clamping diode** is commonly used to prevent this voltage spike. By installing a clamping diode in parallel to the coil, a bypass is provided for the electrons during the time the circuit is opened **(Figure 22–11)**.

An example of the use of clamping diodes is on some air-conditioning compressor clutches. Because the clutch operates by electromagnetism, opening the clutch coil circuit produces a voltage spike. If the spike is left unchecked, it could damage the clutch coil relay contacts or the vehicle's computer. The clamping diode is connected to the circuit in reverse bias.

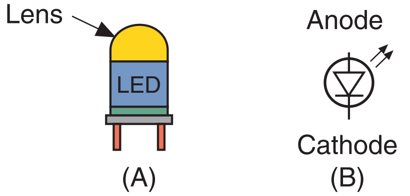


FIGURE 22-10 (A) An LED uses a lens to emit the light generated by current flow. (B) The schematical symbol for an LED.

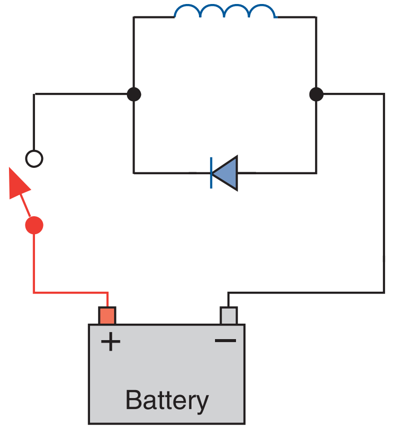


FIGURE 22-11 A clamping diode in parallel to a coil prevents voltage spikes when the switch is opened.

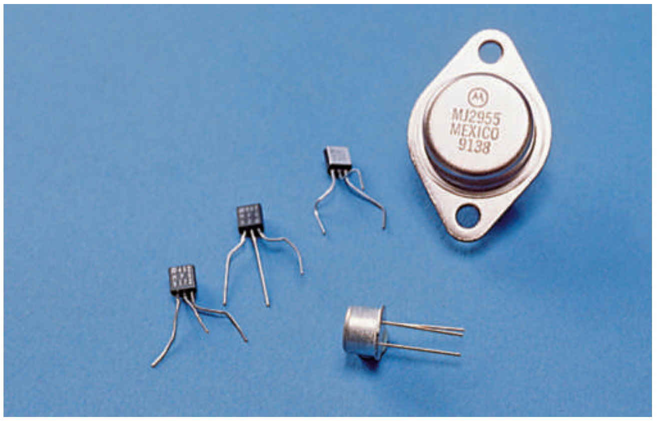


FIGURE 22-12 Typical transistors.

Transistors

A transistor is produced by joining three sections of semiconductor materials. Like the diode, it is used as a switching device, functioning as either a conductor or an insulator. **Figure 22–12** shows some examples of transistors; there are many different sizes and types, depending on the application.

A transistor resembles a diode with an extra side. It can consist of two P-type materials and one N-type material or two N-type materials and one P-type material. These are called PNP and NPN types. In both types, junctions occur where the materials are joined. **Figure 22–13** shows a PNP transistor. Notice that each of the three sections has a lead connected to it. This allows any of the three sections to be connected to the circuit. The names for the legs are the **emitter**, **base**, and **collector**.

The center section is called the base and is the controlling part of the circuit or where the larger controlled part of the circuit is switched. The path to ground is through the emitter. A resistor is normally

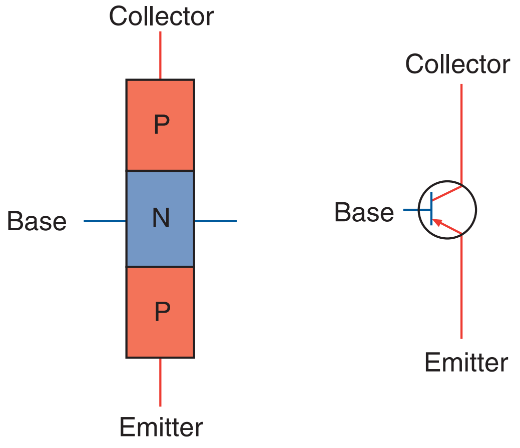


FIGURE 22–13 A PNP transistor and its schematical symbol.

in the base circuit to keep current flow low. This prevents damage to the transistor. The emitter and collector make up the control circuit. When a transistor is drawn in an electrical schematic, the arrow on the emitter points in the direction of current flow.

The base of a PNP transistor is controlled by its ground. Current flows from the emitter through the base, then to ground. A negative voltage or ground must be applied to the base to turn on a PNP transistor. When the transistor is on, the circuit from the emitter to the collector is complete.

An NPN transistor is the opposite of a PNP. When positive voltage is applied to the base of an NPN transistor, the collector-to-emitter circuit is turned on **(Figure 22–14)**.

Transistors can also function as a variable switch. By varying the voltage applied to the base, the completeness of the emitter and collector circuit will also vary. This is done simply by the presence of a variable resistor in the base circuit. This principle is used in light-dimming circuits.

Electronic Relays Electronic relays use a transistor or some other type of semiconductor as the main switching element in the relay. They have many uses: detecting and isolating faults, logic functions, and time delay functions. The different types of electronic relays are defined by the system used to activate them.

Opto-couplers are not electrical relays; however they operate in the same way and accomplish the same thing. They rely on a light-emitting diode that sends its signal to a phototransistor which operates the contacts. Solid state relays can also make use of a light sensor, but they have no moving parts. They operate quickly, last long and emit a highly reduced level of electromagnetic interference.

Piezoelectric relays use a piezoelectric substance instead of a magnet to act upon the relay's contact. Thermo-electric relays operate by heat; incoming energy heats a bimetal element in the relay that mechanically motivates the contacts.

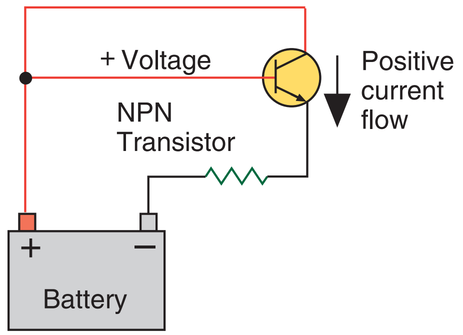


FIGURE 22–14 When positive voltage is applied to the base of an NPN transistor, current flows through the collector and the emitter.

Integrated Circuits

The ability of one transistor or diode is limited in its ability to do complex tasks. However, when many semiconductors are combined in a circuit, they can perform complex functions.

An integrated circuit is simply a large number of diodes, transistors, and other electronic components mounted on a single piece of semiconductor material **(Figure 22–15)**. This creates a very small package capable of performing many functions. Because of the size of an integrated circuit, many transistors, diodes, and other solid-state components can be installed in a car to make logic decisions and issue commands to other areas of the engine. This is the foundation of computerized engine control systems.

Computer Basics

Computers control nearly all of the systems in an automobile. Systems that once were controlled by vacuum, mechanical, and electromechanical devices are now controlled and operated by electronics. These are electronic control systems. They are made up of sensors, outputs, and a central processing unit, sometimes called a **microprocessor**. Electronic controls are designed to allow a system to operate in the most efficient way it can. They also provide for many driver conveniences. Although today's vehicles have several computers, they have two main computers—the powertrain control module (PCM) and body control module (BCM).

In addition to controlling various systems, the PCM and BCM continuously monitor operating

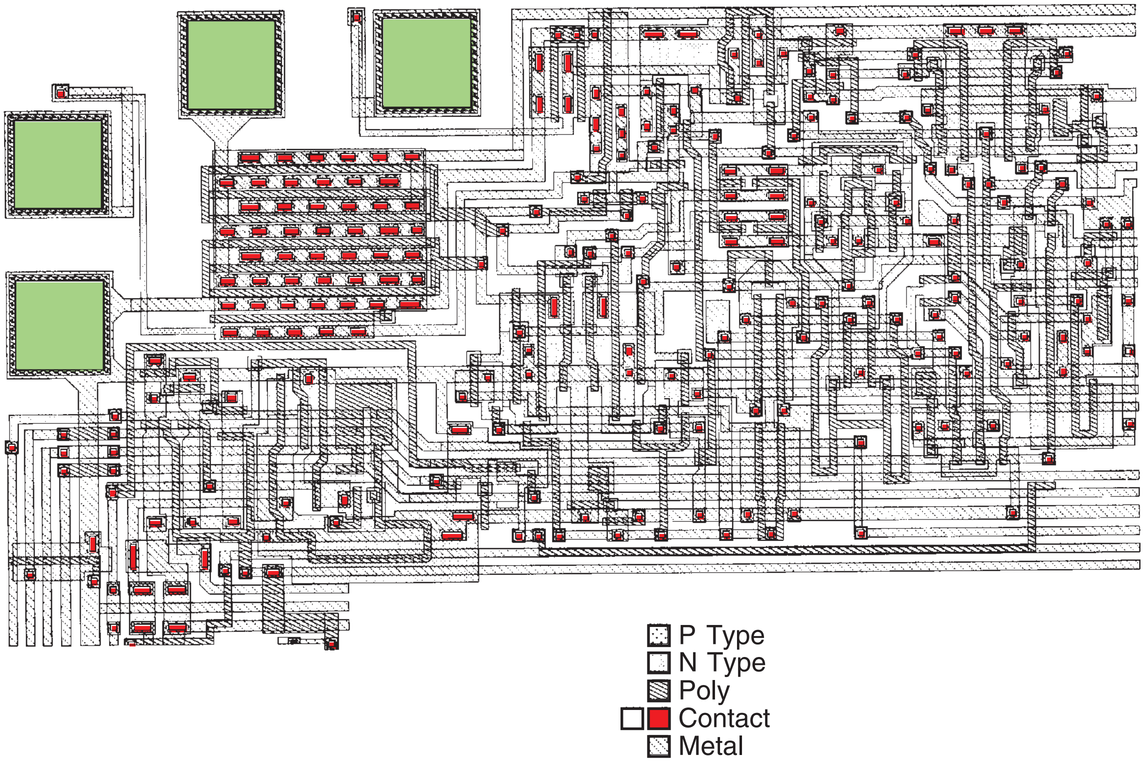


FIGURE 22–15 An enlarged illustration of an IC (chip) with thousands of transistors, diodes, resistors, and capacitors. The actual size of this chip can be less than ¼ of an inch square.

conditions for possible system malfunctions. The computers compare system conditions against programmed parameters. If the conditions fall outside of these limits, the computers will detect the malfunction. A trouble code will be stored in the computers' memory to indicate the portion of the system at fault. A technician can access this code to aid in diagnosis.

The central processing unit (CPU) is basically thousands to millions of transistors placed on a small chip. The CPU moves information in and out of the computer's memory **(Figure 22–16)**. Input information is processed in the CPU and checked against the programs stored in its memory. The CPU also checks for all other pertinent information held in memory. The CPU takes all of this information and uses computer logic to determine what should or should not happen. Once these decisions are made, the CPU sends out commands to make the required corrections or adjustments to the system.

A computer is an electronic device that stores and processes data. It relies on semiconductors and

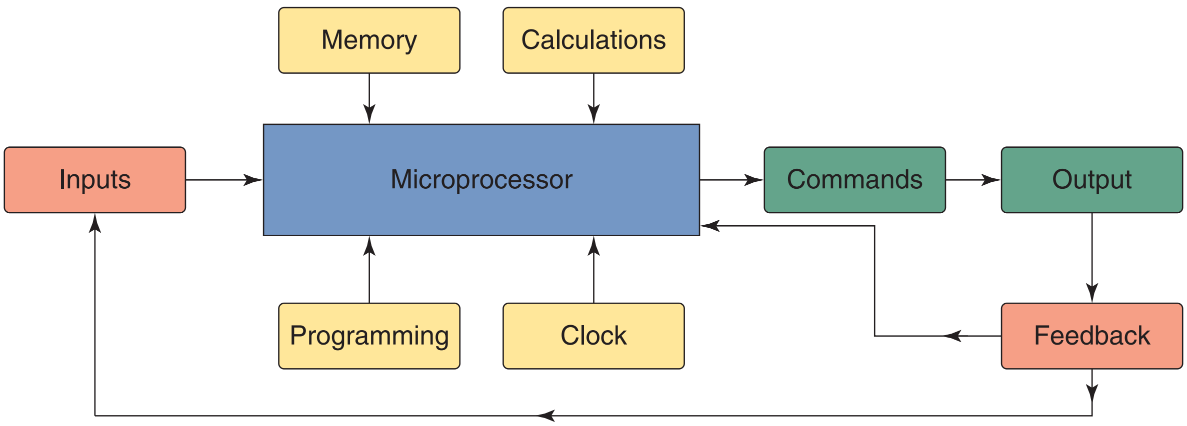


FIGURE 22–16 The basic information flow for a computer.

is really a group of integrated circuits. The four basic functions of a computer are:

1. Input: A signal sent from an input device. The device can be a sensor or a switch activated by the driver, technician, or a mechanical part.
2. Processing: The computer uses the input information and compares it to programmed instruction. This information is processed by logic circuits in the computer.
3. Storage: The program instructions are stored in the computer's memory. Some of the input signals are also stored for processing later.
4. Output: After the computer has processed the inputs and checked its programmed instructions, it will issue commands to various output devices. These output devices may be instrument panel displays or output actuators. The output of one computer may also be an input to other computers.

Inputs

The PCM receives inputs that it checks against programmed values. Depending on the input, the computer controls the actuator(s) until the programmed results are obtained. The inputs can come from other computers, the driver, the technician, or through a variety of sensors.

Driver input "on" signals are usually provided by momentarily applying a ground through a switch. The computer receives this signal and performs the desired functions. For example, if the driver wishes to reset the trip odometer on a digital instrument panel, a reset button is depressed. This switch provides a momentary ground that the computer receives as an input and sets the trip odometer to zero.

Switches can be used as inputs for any operation that only requires a yes-no, or on-off, condition. Other inputs include those supplied by means of a sensor and those signals returned to the computer in the form of **feedback**. Feedback means that data concerning the effects of the computer's commands are fed back to the computer as an input signal.

If the computer sends a command signal to actuate an output device, a feedback signal may be sent back from the actuator to inform the computer that the task was performed. The feedback signal confirms both the position of the output device and the operation of the actuator. Another form of feedback is for the computer to monitor voltage when a switch, relay, or other actuator is activated. Changing positions of an actuator should result in predictable changes in the computer's voltage sensing circuit. The computer may set a diagnostic code if it does not receive the correct feedback signal.

All inputs have the same basic function. They detect a mechanical condition (movement or position), chemical state, or temperature condition and change it into an electrical signal that is used by the computer to make decisions. Each sensor has a specific job to do (e.g., monitor throttle position, vehicle speed, and manifold pressure).

In addition to variable resistors, another commonly used reference voltage sensor is a switch. By opening and closing a circuit, switches provide the necessary voltage information to the computer so vehicles can maintain the proper performance and driveability.

Voltage-Generating Sensors Although many sensors are variable resistors or switches, **voltage-generating sensors** are commonly used. These sensors include speed sensors, Hall-effect switches, oxygen sensors, and knock sensors. These are capable of producing an input voltage signal for the control system. This varying voltage signal allows the computer to monitor and immediately adjust the operation of a system to meet the current needs.

GO TO Chapter 25 for more information on sensors.

Communication Signals

Voltage does not flow through a conductor; current flows while voltage is the pressure that pushes the current. However, voltage can be used as a signal; for example, difference in voltage levels, frequency of change, or switching from positive to negative values can be used as a signal.

A computer is capable of reading voltage signals. The programs used by the CPU are "burned" into IC chips using a series of numbers. These numbers represent various combinations of voltages that the computer can understand. The voltage signals to the computer can be either analog or digital. Analog means a voltage signal is infinitely variable, or can be changed, within a given range. Digital means a voltage signal that is in one of two states—either on-off, yes-no, or high-low. Digital signals produce a **square wave**. The wave represents the immediate change in the voltage signal. It is called a square wave because the digital signal creates a series of horizontal and vertical lines that connect to form a square-shaped pattern on a scope **(Figure 22–17)**.

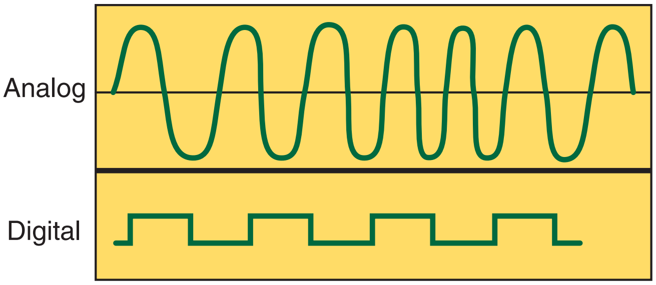


FIGURE 22-17 Analog signals can be constantly variable. Digital signals are either on/off or low/high.

In a digital signal, voltage is represented by a series of digits, which create a binary code.

Most input sensors produce a constantly variable voltage signal. For example, the voltage signal from an ambient temperature sensor never changes abruptly. The signal corresponds with a gradual increase or decrease in temperature and is therefore an analog signal.

A computer can only read a digital binary signal. To overcome this communication problem, all analog voltage signals are converted to a digital format by a device known as an analog-to-digital converter **(A/D converter)**. The A/D converter **(Figure 22–18)** is located in the processor.

The A/D converter changes a series of signals to a binary number made up of 1s and 0s. Voltage above a given value converts to 1, and zero voltage converts to 0 **(Figure 22–19)**. Each 1 or 0 represents a bit of information. Eight bits equal a **byte** (sometimes referred to as a *word*). All communication between the CPU, the memories, and the interfaces is in binary code, with each information exchange in the form of a byte.

Schmitt Trigger In addition to A/D conversion, some voltage signals require amplification before they can be processed by the computer. To do this, an input conditioner known as an amplifier is used to strengthen weak voltage signals. This is especially important for signals from Hall-effect switches. When the signal voltage leaves the sensor, it is a weak analog signal. The signal is amplified and

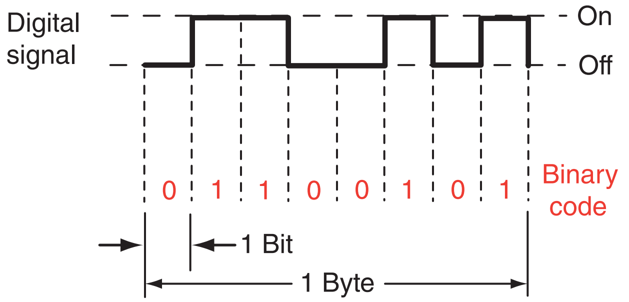


FIGURE 22-19 Each zero (0) and one (1) represents a bit of information. When eight bits are combined in specific sequence, they form a byte or word that makes up the basis of a computer's language.

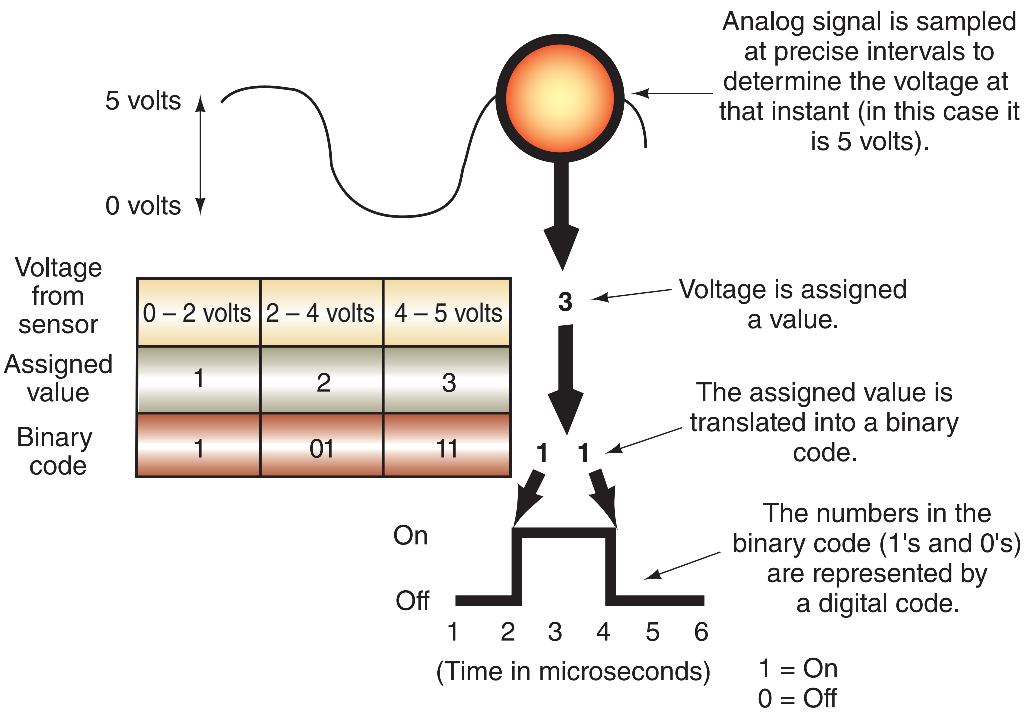


FIGURE 22-18 The A/D converter assigns a numeric value to input voltages and changes the numeric value to a binary code.

inverted. It is then sent to a **Schmitt trigger**, which is a type of A/D converter, where it is digitized and conditioned into a clean square wave. The signal is then sent to a switching transistor that turns on and off in response to the signal and sets the frequency of the signal.

Clock Rate After an input signal has been generated, conditioned, and passed along to the computer, it is ready to be processed for performing some work and displaying information. The computer has a crystal oscillator or clock that delivers a constant time pulse. The crystal vibrates at a fixed rate when current, at a certain voltage level, is applied to it. The vibrations produce a very regular series of voltage pulses. The clock maintains an orderly flow of information throughout the computer's circuitry by transmitting one bit of binary code for each pulse. The clock enables the computer to know when one signal ends and when another begins.

Communication Rates The amount of information processed by a computer is dependent on its speed or **baud rate**. Baud rate is the speed of communication and is roughly equal to the number of bits per second a computer can process.

Memories

A computer's memory holds the programs and other data, such as vehicle calibrations, which the CPU refers to while making calculations. The program is a set of instructions or procedures that it must follow. Included in the program are **look-up tables** that tell the computer when to retrieve an input (based on temperature, time, etc.), how to process it, and what to do with it after it has been processed. Look-up tables are sets of instructions and there is one for every possible condition the computer may detect.

The microprocessor works with memory in two ways: It can read information from memory or change information in memory by writing in or storing new information. To write information in memory, each memory location is assigned a number (written in binary code also) called an address. These addresses are sequentially numbered, starting with zero, and are used by the microprocessor to retrieve data and write new information into memory. During processing, the CPU often receives more data than it can immediately handle. In these instances, some information has to be temporarily stored or written into memory until the microprocessor needs it.

When ready, the microprocessor accesses the appropriate memory location (address) and is sent a copy of what is stored. By sending a copy, the memory retains the original information for future use.

Basically, three types of memory are used in automotive CPUs today **(Figure 22–20)**: read-only memory, programmable read-only memory, and random-access memory.

Read-Only Memory (ROM) Permanent information is stored in **read-only memory (ROM)**. Information in ROM cannot be erased, even if the system is turned off or the CPU is disconnected from the battery. As the name implies, information can only be read from ROM.

When making decisions, the microprocessor is constantly referring to the stored information and the input from sensors. By comparing information from these sources, the CPU makes informed decisions.

Programmable Read-Only Memory (PROM) The **programmable read-only memory (PROM)** differs from the ROM in that it plugs into the computer and may be reprogrammed or replaced with one containing a revised program. It contains program information specific to different vehicle model calibrations. The PROM in some computers is replaceable and can serve as a way to upgrade the system.

Electrically erasable PROM (EEPROM) allows changing the information electrically one bit at a time **(Figure 22–21)**. Some manufacturers use this type of memory to store information concerning mileage, vehicle identification number, and options. A "flash" EEPROM may be reprogrammed through the system's DLC.

Random-Access Memory (RAM) The **random-access memory (RAM)** is used during computer operation to store temporary information. The CPU can write, read, and erase information from RAM in any order, which is why it is called random. One characteristic of RAM is that when the ignition key is turned off and the engine is stopped, information in RAM is erased. RAM is used to store information from the sensors, the results of calculations, and other data that are subject to constant change.

There are currently two other versions of RAM in use: volatile and nonvolatile. A volatile RAM, usually called **keep-alive memory (KAM)** has most of the features of RAM. Information can be written into KAM and can be read and erased from KAM. Unlike RAM, information in KAM is not erased when the ignition key is turned off and the engine is stopped.

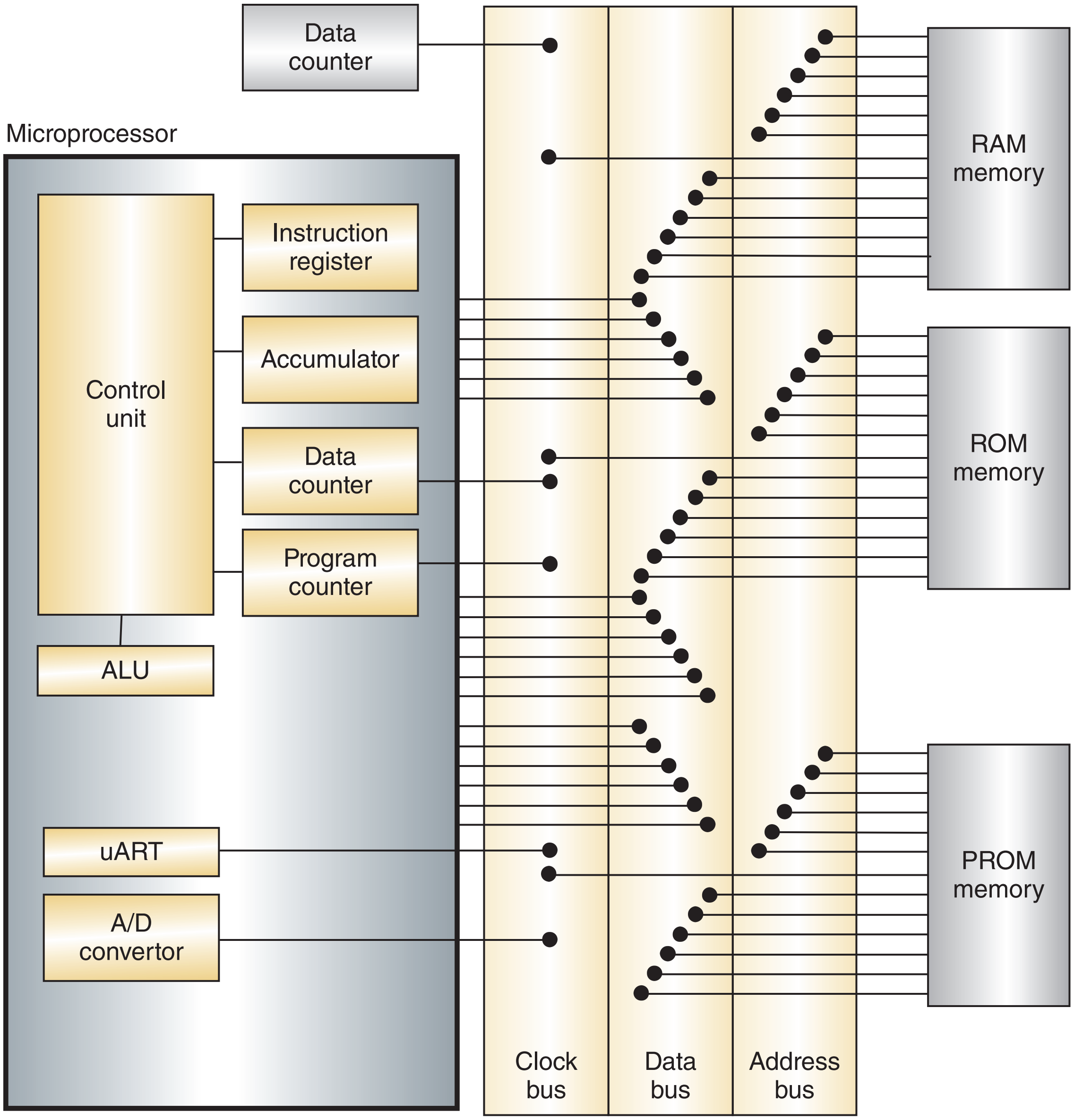


FIGURE 22–20 A schematic showing how the three types of memory are connected to a microprocessor.

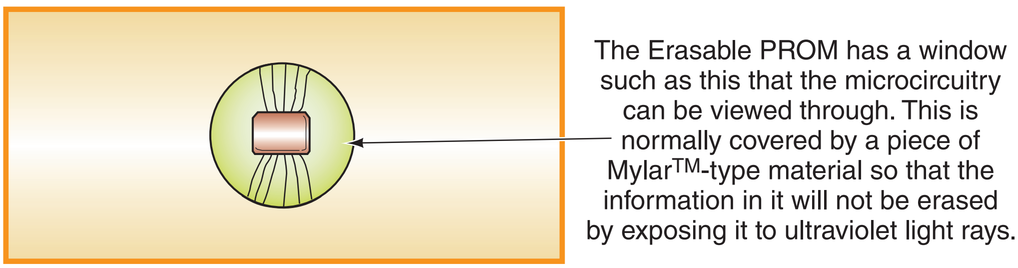


FIGURE 22–21 EEPROM memory is erased when its circuitry is exposed to ultra-violet light.

However, if battery power to the processor is disconnected, information in KAM is erased.

A **nonvolatile RAM (NVRAM)** does not lose its stored information if its power source is disconnected. Vehicles with digital display odometers usually store mileage information in nonvolatile RAM.

Actuators

Once the computer's programming determines that a correction or adjustment must be made in the controlled system, an output signal is sent to control devices called **actuators**. These actuators, which are

solenoids, switches, relays, or motors, physically act on or carry out the command sent by the computer.

Actually, actuators are electromechanical devices that convert an electrical current into mechanical action. This mechanical action can then be used to open and close valves, control vacuum to other components, or open and close switches. When the CPU receives an input signal indicating a change in one or more of the operating conditions, the CPU determines the best strategy for handling the conditions. The CPU then controls a set of actuators to achieve a desired effect or strategy goal. For the computer to control an actuator, it must rely on a component called an **output driver**.

The output driver applies either the power or the ground circuit of the actuator. Either can be applied steadily if the actuator must be activated for a selected amount of time, or it can be pulsed to activate the actuator in pulses.

Output drivers operate by the digital commands issued by the CPU. Basically, the output driver is nothing more than an electronic on-off switch used to control a specific actuator. On a wiring diagram, an output driver is often shown as a transistor inside a component or module **(Figure 22–22)**.

To illustrate this relationship, let us suppose the computer wants to turn on the engine's cooling fan. Once it makes a decision, it sends a signal to the output driver that controls the cooling fan relay (actuator). In supplying the relay's ground, the output driver completes the power circuit between the battery and cooling fan motor and the fan operates. When the fan has run long enough, the computer signals the output driver to open the relay's control circuit (by removing its ground), thus opening the power circuit to the fan.

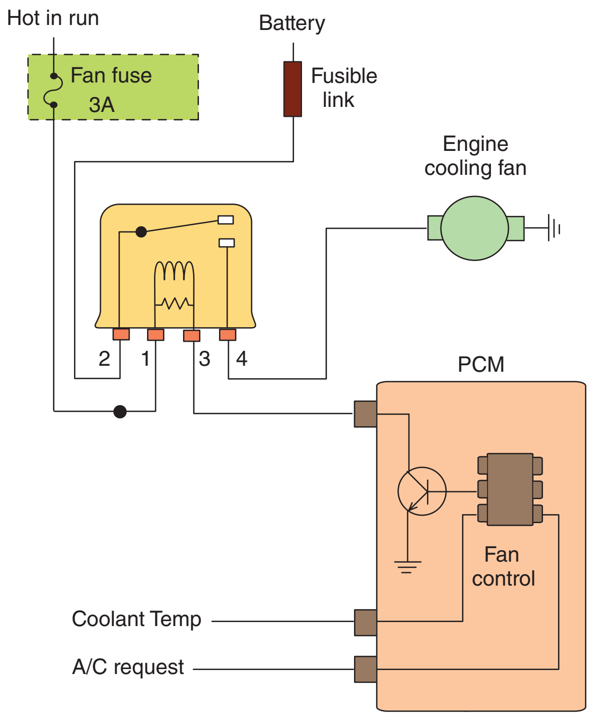


FIGURE 22–22 Transistors are shown as output drivers in many wiring diagrams.

> **SHOP TALK**
> Normally a computer will control an actuator with a low-side driver. These drivers complete the ground for the output device. Many newer systems use high-side drivers that control the outputs by varying the power to them. Most high-side drivers are metal oxide field effect transistors (MOSFET) controlled by another transistor. High-side drivers are used in circuits where a quick response to opens, shorts, and temperature changes is desired. Because a circuit's behavior depends on the driver being used, it is important to check the service information before diagnosing the system.

For actuators that cannot be controlled by a digital signal, the CPU must turn its digitally coded instructions back into an analog signal. This conversion is completed by the A/D converter.

Displays can be controlled directly by the CPU. They do not require digital-to-analog conversion or output drivers because they contain circuitry that decodes the microprocessor's digital signal. The decoded information is then used to indicate such things as vehicle speed, engine rpm, fuel level, or scan tool values.

Duty Cycle versus Pulse Width Often the computer controls the results of the output by controlling the duty cycle or pulse width of the actuator. Duty cycle is a measurement of the amount of time something is on compared to the time of one cycle and is measured in a percentage. When measuring duty cycle, you are looking at the amount of time something is on during one cycle. Pulse width is similar to duty cycle except that it is the exact time something is turned on and is measured in milliseconds **(Figure 22–23)**.

Power Supply

The CPU also contains a power supply that provides the various voltages required by the microprocessor and internal clock that provides the clock pulse, which in turn controls the rate at which sensor readings and

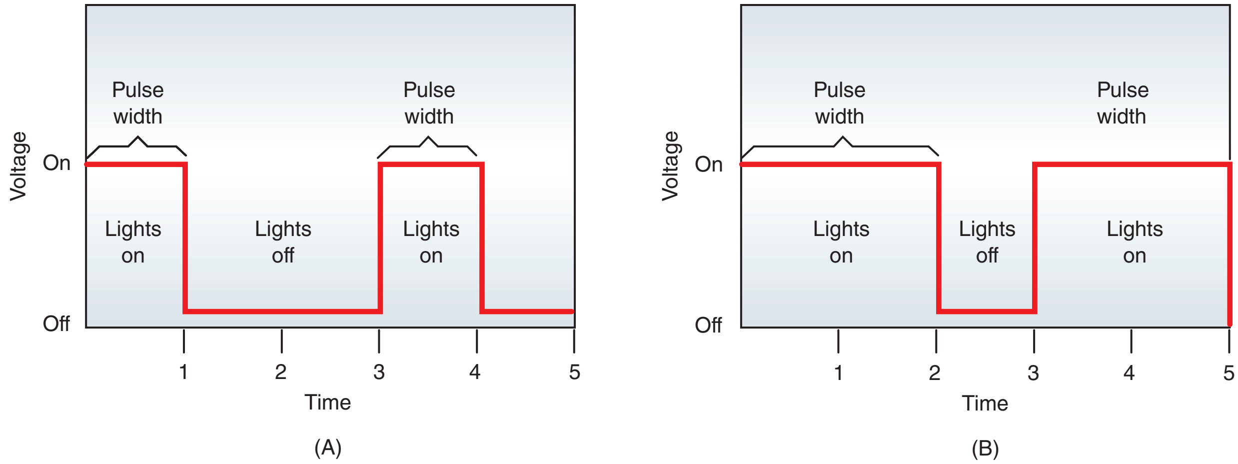


FIGURE 22-23 A pulse-width modulated output signal.

output changes are made. Also contained are protection circuits that safeguard the microprocessor from interference caused by other systems in the vehicle and diagnostic circuits that monitor all inputs and outputs and signal a warning light if any values go outside the specified parameters. This warning light is called the malfunction indicator lamp (MIL).

Awake/Sleep Modes

The control modules are able to control or perform all of their functions in the awake mode. They enter a sleep mode when normal control or monitoring of the system functions has stopped and a time limit has passed. There is still some activity during the sleep mode; what occurs depends on the system. Basically, during the sleep mode only enough power is used to maintain memory and for periodic monitoring of some systems. Once normal computer activity is called for, the computer wakes up and resumes its normal functions.

By-Wire Technology

One of the things that has become a reality because of the high-powered computers used in today's vehicles is by-wire technology. Currently this technology has eliminated the mechanical connection from the throttle pedal and the fuel injection system **(Figure 22–24)**. This unit is called the electronic throttle control unit **(Figure 22–25)**. Shift-by-wire technology is also used. It is also being used by a few manufacturers in parking brake systems and adaptive cruise control. Nissan has a steer-by-wire

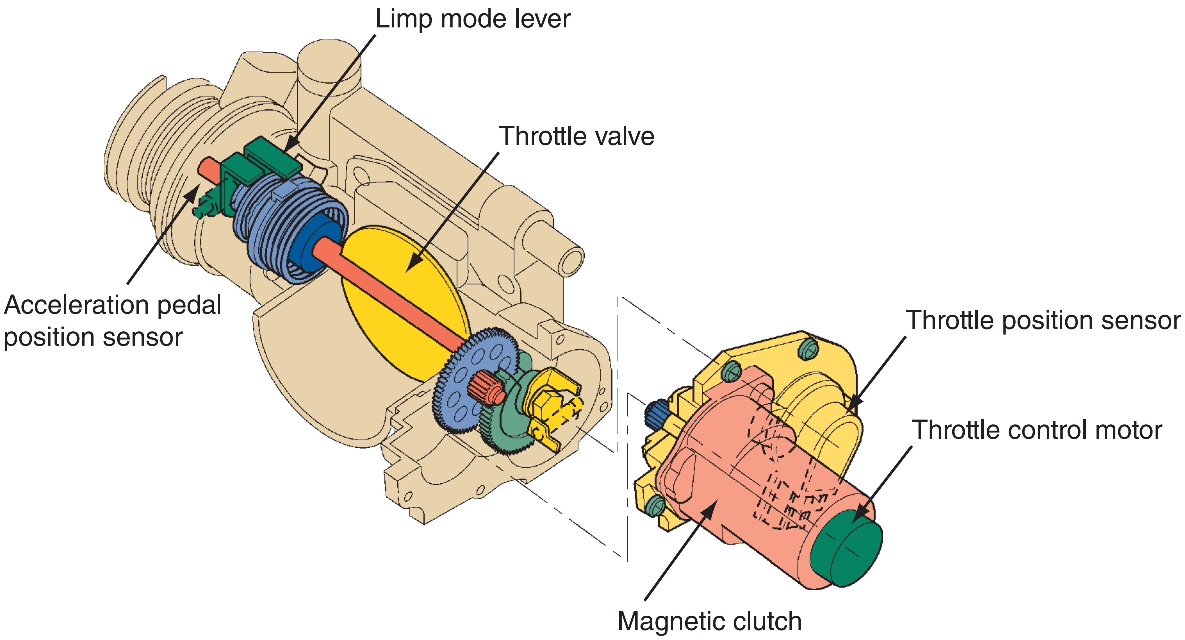


FIGURE 22-24 This electronic throttle control unit eliminates the need for a mechanical linkage between the throttle pedal and the fuel injection system.

FIGURE 22–25 An electronic throttle control assembly at the throttle body.

system that uses sensors and the electric steering rack for vehicle steering control. There is a mechanical backup in the event of a problem with the electronic system. If the steer-by-wire technology proves reliable and acceptable by consumers, expect more manufacturers to introduce similar systems.

Drive-by-wire systems use sensors to translate the movement of pedals, the steering wheel, and other parts into electronic signals. The vehicle's computer receives these signals and commands electric motors to perform the function ordered by the driver. These systems respond much quicker than mechanical linkages and can send feedback to the computer as they operate. Another factor involved in using by-wire systems is the mandate that vehicles be equipped with stability control systems. By using numerous inputs and by-wire systems, the on-board computer can intercede in vehicle operation during driving events that warrant the application of stability control. This is discussed in more detail in Chapter 53.

Multiplexing

Today's vehicles have hundreds of circuits, sensors, and other electrical parts. In order for the control systems to operate correctly, there must be some communication between them. Communication can take place through wires connecting each sensor and circuit to the appropriate control module. If more than one control module is involved, additional pairs of wires must connect the sensor or circuit to the other modules. The result of this communication network is miles of wires and hundreds of connectors. To eliminate the need for all of these wires, manufacturers are using multiplexing **(Figure 22–26)**.

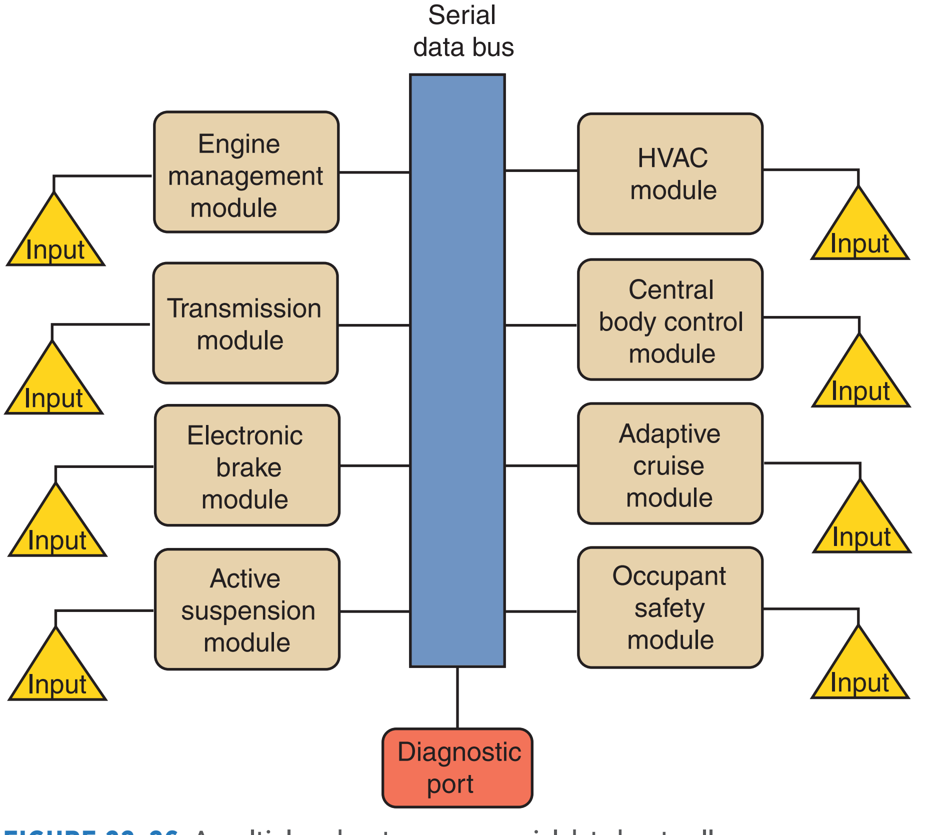


FIGURE 22–26 A multiplexed system uses a serial data bus to allow communications between the various control modules.

Multiplexing, also called in-vehicle networking, provides efficient communications between vehicle systems. Multiplexing relies on communication over one or two wires that allows many systems to communicate instead of using many wires. An example of multiplexing is cable TV. A multiplex wiring system uses a **serial data bus** that connects different computers or control modules together. Each module can transmit and receive digital codes over the serial data bus, allowing one module to share information with other modules. For example, the signal relating to engine speed may be required by the engine control, transmission control, electronic brake control, and suspension control modules. Rather than have separate engine speed inputs for each module, the serial data bus carries the information, as well as other information, to all of the control modules.

Each sensor is wired directly to the control module that relies heavily on the sensor's signal. That control module sends the information to the serial data bus. Each control module has an address or identifier on the network and a code-reading device or chip that reads and sends messages on the serial data bus. Some chips can only send or only receive, depending on their purpose. All information on the serial data bus is available for all control modules. However, the chip of each device compares the coded message to its memory list to see whether the information is relevant to its own operation.

The chip is also used to prevent the signals from overlapping by allowing only one signal to be transmitted at a time. Each digital signal is preceded by an identification code that establishes its priority. If two modules attempt to send a message at the same time, the signal with the higher priority code is transmitted first. Because a control module processes only one input at a time, it orders the signals as it needs them. When one input is being received, the others are disregarded. Although it may appear to cause a time lapse, realize that the communication rate for most computers is between 10,000 and 1,000,000 bits per second (1 Mbit/s). Newer vehicles can have data bus speeds of 10 Mbit/s and higher depending on the type of network.

Keep in mind that data are conveyed in binary numbers and therefore must be interpreted by some type of data processing before they become information. The stream of data across the bus is called serial data. It is essentially data that are transferred to and from a computer, one bit at a time. On many vehicles, serial data can be monitored with a scan tool connected to the vehicle's DLC. Monitoring serial data allows technicians to diagnose the various control modules and to check for DTCs.

The serial data bus is typically made of two wires making a twisted pair: a signal low and a signal high wire. These wires are twisted together to reduce magnetic interference, which can cause false information. A low-speed system may use a single wire and a very high-speed system can use fiber optic cable.

Advantages

Multiplexing offers many advantages over traditional wiring:

- The need for redundant sensors is eliminated because sensor data, such as vehicle speed and engine temperature, are available on the serial data bus where they can be used by several control modules.
- Accessories and vehicle features can be easily added to the vehicle through software changes.
- Fewer wires are required for the operation of each system, which means smaller wiring harnesses, lower cost and weight, and improved serviceability, reliability, and installation. Without multiplexing, it is necessary to add a ground, a power source, and control wires whenever an electronic component is added to the vehicle.
- Improved communications between control modules allows for more accurate recording and reporting of faults, which helps in locating and solving problems.
- As the electrical content of today's vehicles continues to increase, the need for networking is even more evident.

Communication Protocols

A protocol is the name for the language that computers speak when they are talking to each other. The differences in protocol are based on the speed and the technique used. The SAE has classified the different protocols by their speed and operation.

- Class A (low-speed communication): This is used for convenience systems, such as audio, trip computer, seat controls, windows, and lighting. Most Class A functions require inexpensive, low-speed communication and use a generic universal asynchronous receiver/transmitter (UART). These functions are proprietary and have not been standardized by the industry. Class A systems are no longer commonly used due to the adoption of CAN and LIN systems and the need for high-speed data transfer with newer systems.

- Class B (medium-speed communication): Class B multiplexing is used primarily with the instrument cluster, vehicle speed, and emissions data recording. Contained within this classification are different standards, designated by a number. The most commonly used is the SAE J1850 standard. Further, these standards are divided by their operation. One is a variable pulse width (VPW) type that uses a single bus wire. Another is a pulse width modulation (PWM) type that uses a two-wire differential bus.
- Class C (high-speed communication): This high-speed protocol is for communication with powertrain, vehicle dynamics, brake-by-wire, and other systems. This protocol can use a twisted pair, but shielded coaxial cable, Category 5 (Cat 5) network cable, or fiber optics may be used for less noise interference. The predominant class C protocol is CAN 2.0 (controller area network version 2.0) can transmit up to 500 kbits/s. CAN assigns a unique identifier to every message. The identifier classifies the content of the message and the priority of the message being sent. Each module processes only those messages whose identifiers are stored in the module's acceptance list.
- LIN Bus: The local interconnect network (LIN) is a single wire serial data network with a master and up to 16 slave modules. LIN is used primarily for low speed (under 20 kbits/s) non-safety-related systems such as power windows and locks, lighting, wipers, and seat controls. An individual switch may be used as a module on a LIN bus to communicate an input request, such as turning on a heated seat.
- FlexRay: FlexRay is a high-speed (10 Mbits/s) hardware and data bus system used for vehicle dynamics and safety-related components, including engine control, ABS, electronic steering, and electronic suspension systems.
- MOST Bus: The media-oriented systems transport bus is a high-speed system, up to 150 Mbits/s, and is used in GPS, multimedia, and infotainment systems. The MOST bus can carry real-time audio and video over plastic fiber optic transmission lines. Up to 64 modules can be connected to a MOST system, but typically only between 5 and 10 modules are used in automotive MOST networks. A MOST network is configured in a loop or a ring, each module can send and receive data **(Figure 22–27)**.

It is common to find a variety of the different classes of multiplexing in a single vehicle **(Figure 22–28)**. Some systems, such as powertrain control and vehi-

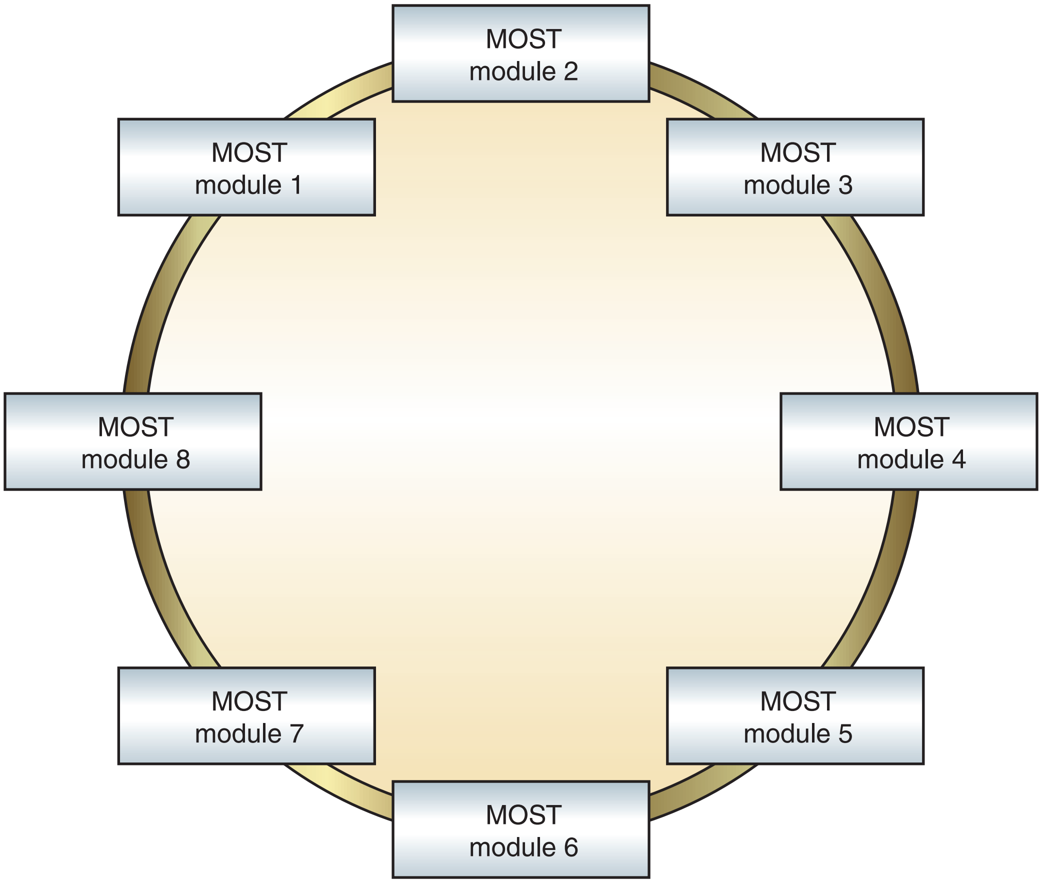


FIGURE 22-27 A MOST bus configuration. MOST networks are typically used for infotainment systems with the radio acting as a gateway module.

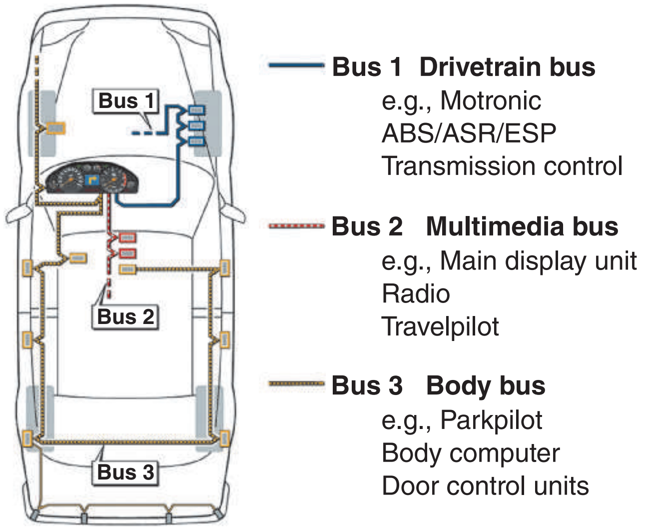


FIGURE 22-28 It is common to find a variety of protocols in a single vehicle.

cle dynamics, require high-speed communications, whereas other systems do not.

Early multiplexed systems were often based on proprietary serial buses using generic UART or custom devices. This called for dedicated and specific scan tools, each with the ability to work only on specific systems. OBD II called for standardized diagnostic tools, which meant standard protocols had to be implemented. Starting in 2008, Class C communications is the mandated protocol for diagnostics.

CAN Buses

The total network in most vehicles comprises three to six CAN buses. Each of these networks may operate at different speeds. The different CAN buses are identified by a prefix or suffix. For example, a medium-speed bus may be called CAN B or MS-CAN. Likewise, a high-speed bus can be called CAN C or HS-CAN. Manufacturers are not consistent with these labels, so there are a variety of them.

Low- or medium-speed CANs are typically used for body functions, such as:

- Interior and exterior lights
- Horn
- Locks
- Windshield wipers
- Seats
- Windows
- Basic sound systems

A high-speed bus is used for real-time functions such as:

- Engine management
- Antilock brake systems
- Transmission control
- Tire pressure monitoring systems
- Vehicle stability systems
- Air bag and safety systems

These networks are integrated through the use of a gateway. A **gateway** module allows for data exchange between the different buses. It translates a message on one bus and transfers that message to another bus without changing the message **(Figure 22–29)**. The gateway interacts with each bus according to that bus's protocol. This is an important function; some information must be shared. For example, when the driver turns the climate control settings to "cold" and turns on the air conditioning, a request is made by the HVAC control head to the climate control module. The climate control system is likely on a low-speed CAN or LIN network and unable to directly request or turn on the air conditioning compressor. Instead, the request is received by the gateway module. In many vehicles the BCM serves as the gateway for the different buses. On some newer vehicles, the DLC is the gateway module. The BCM sends the HVAC request for cooling to the ECM to engage the A/C compressor over

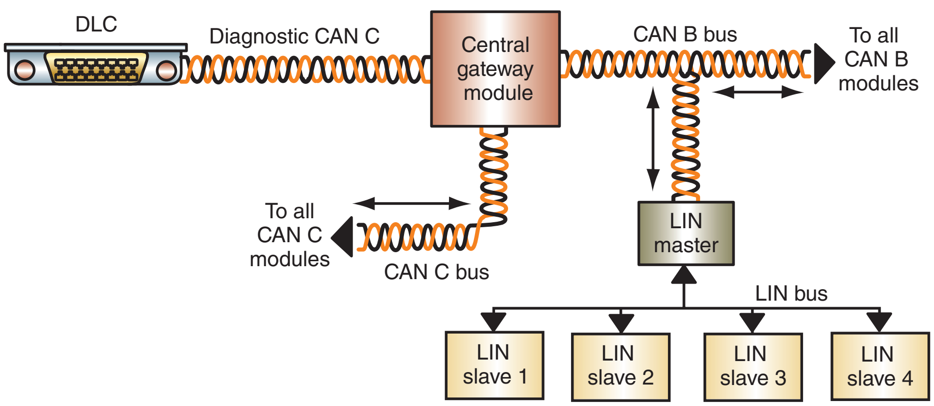


FIGURE 22-29 A basic look at a CAN communication system.

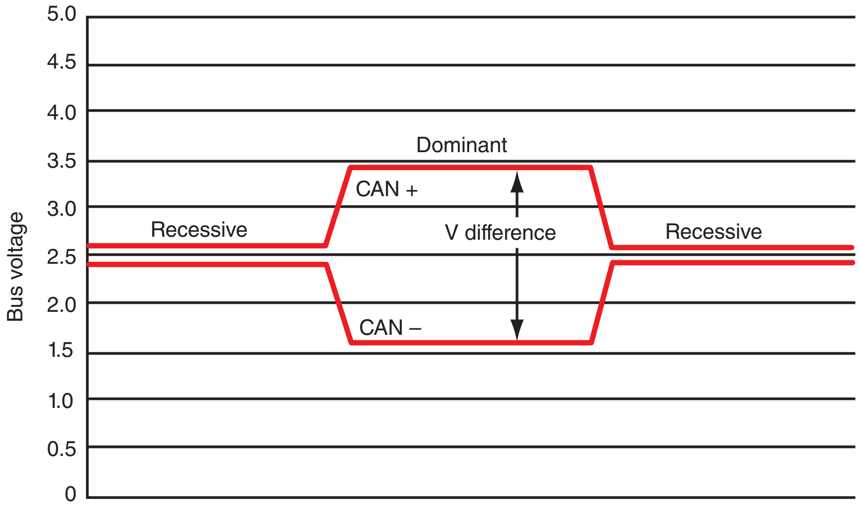


FIGURE 22–30 In order for a message to be transmitted, the drivers are energized to pull up the bias on the + bus and pull down on the – bus. There must be a voltage differential between the wires.

> **SHOP TALK**
>
> Although the BCM is designated as a body system, a vehicle may not start if the BCM is not operating correctly. This is due to its role as the gateway. If there is no communication between the security or antitheft system and the engine control system, the engine will not start. The PCM needs to know that it is okay to run the engine.

the high-speed CAN. The ECM and BCM communicate to confirm if the compressor is active and the BCM and climate control module communicate to maintain the desired temperature.

Each network bus may carry a different voltage **(Figure 22–30)**, such as a 5-volt or 7-volt communication signal with a 10- or 12-volt wake-up signal. CAN bus communication uses two wires, Bus + (positive) and a Bus – (negative). Both wires carry 2.5 volts when idle or not communicating. During communication, the positive wire signal switches from 2.5 to 3.5 volts and the negative wire drops from 2.5 to 1.5 volts **(Figure 22–31)**.

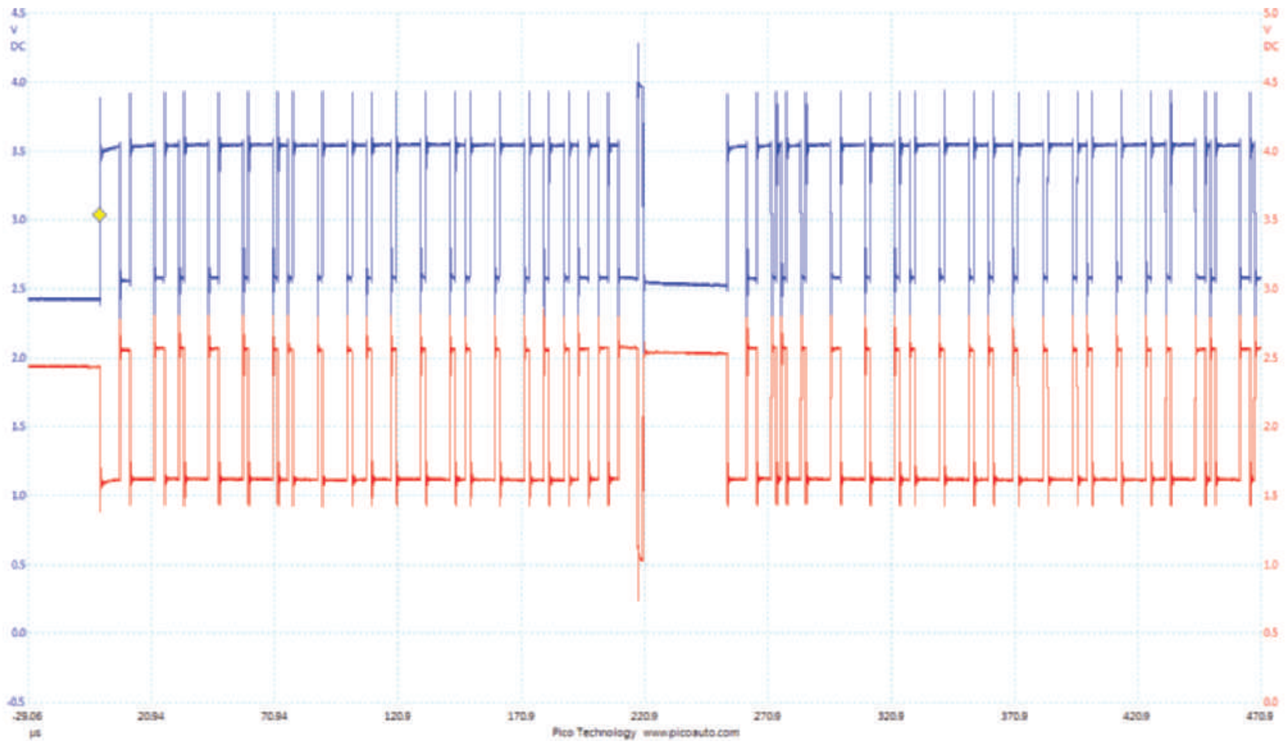


FIGURE 22–31 An example of a HS-CAN communication signal.

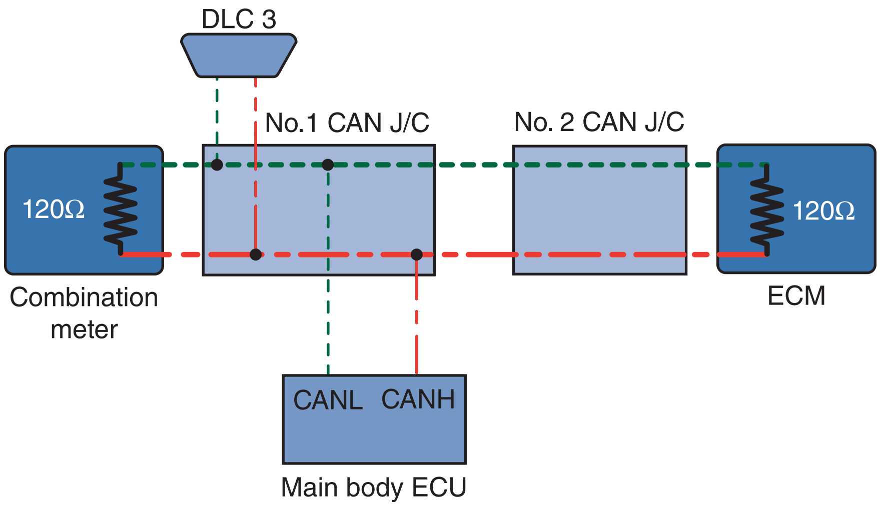


FIGURE 22–32 To eliminate potential voltage spikes and noise, two 120 Ω terminating resistors are connected in parallel across the ends of the main CAN bus wires.

The signals mirror each other to eliminate electrical noise and reduce communication errors. The difference between the two signals is 2 volts. Even the slightest change in voltage can affect the operation of one or more systems; therefore, all potential for voltage spikes, electrical noise, or induction must be eliminated. Twisting the wires eliminates the possibility of voltage being induced in one wire as current flows through the other. To eliminate other potential spikes and noise, two 120Ω resistors are connected in parallel across the ends of the main CAN bus wires. These are called terminating resistors **(Figure 22–32)**. The location of the resistors varies. One may be located in the fuse block, and others can be internal to the ECM or PCM and the BCM.

Protecting Electronic Systems

The last thing a technician wants to do when a vehicle comes into the shop is create problems. This is especially true when it comes to electronic components. You should be aware of the ways to protect electrical systems and electronic components during storage and repair. Keep the following in mind at all times:

- Vehicle computer-controlled systems should avoid giving and receiving jump-starts due to the possibility of damage caused by voltage spikes.
- Do not connect or disconnect electronic components with the key on.

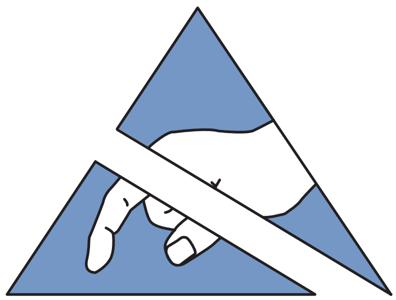


FIGURE 22–33 GM's electrostatic discharge (ESD) symbol warns technicians that a part or circuit is sensitive to static electricity.

- Never touch the electrical contacts on any electrical or electronic part. Skin oils can cause corrosion and poor contacts.
- Be aware of any part that the manufacturer has marked with a code or symbol to warn technicians that it is sensitive to electrostatic discharge **(Figure 22–33)**.
- Before touching a computer, always touch a good ground first. This safely discharges any static electricity. Static electricity can generate up to 25,000 volts and can easily damage a computer.
- Tool companies offer static-proof work mats that allow work inside the vehicle without the fear of creating static electricity.
- Tool companies also have grounding wrist straps. A wire connects the wrist strap to a good ground.
- Never allow grease, lubricants, or cleaning solvents to touch the end of the sensor or its electrical connector.

- Be careful not to damage connectors and terminals when removing components. This may require special tools.
- When procedures call for connecting test leads, or wires, to electrical connections, use care and follow the manufacturer's instructions. Identify the correct test terminals before connecting the test leads.
- Do not connect jumper wires across a sensor unless indicated in the service information to do so.
- Never apply 12 volts directly to an electronic component unless instructed to do so.
- Never use a testlight to test electronic ignition or any other computer-controlled system unless instructed to do so.
- Accidentally touching two terminals at the same time with a test probe can cause a short circuit.
- The sensor wires should never be rerouted. When replacing wiring, always check the service information and follow the routing instructions.
- Disconnect any module that could be affected by welding, hammering, grinding, sanding, or metal straightening.

Diagnosing Modules and Networks

Before troubleshooting a system operated by a control module, check the service information to identify any special procedures or precautions. When testing a system, you are basically trying to isolate a problem in one of the basic functions of the computer and its system.

The gateways, network, and other modules are continuously monitored for possible system malfunctions. For example, the BCM is often a gateway module. It compares system conditions against programmed parameters, such as the number and type of modules on a network. If the conditions fall outside of these limits, such as the radio module stops responding, it detects a malfunction and sets a trouble code that indicates the portion of the system that has the fault.

If the malfunction causes improper system operation, the computer may minimize the effects of the malfunction by using fail-safe action. During this the computer will control a system based on programmed values instead of the input signals. This allows the system to operate on a limited basis instead of shutting down completely.

Trouble Codes

There are as many ways to perform diagnostics as there are automobile manufacturers. Nearly all vehicles require a scan tool to retrieve DTCs. The scan tool is plugged into the diagnostic connector for the system being tested. The technician chooses the system to be tested through the scan tool. Once the DTCs are retrieved, follow the appropriate diagnostic chart to isolate the fault. It is important to check the codes in the order recommended by the manufacturer. Remember, the trouble code does not necessarily indicate the faulty component; it only indicates the circuit of the system that is not operating properly. To locate the problem, follow the diagnostic procedure in the service information for the code received.

Diagnosis should continue with a good visual inspection of the circuit involved with the code. Check all sensors and actuators for physical damage. Check all connections to sensors, actuators, control modules, and ground points. Check wiring for signs of burned or chafed spots, pinched wires, or contact with sharp edges or hot exhaust parts.

Communication Checks

Performing diagnostic checks on vehicles with a multiplex system should begin with a communications check. First, locate the **data link connector (DLC)**. On 1996 and newer OBD II vehicles, the DLC is located on the driver's side under the dash area. Connect the scan tool and power it on and turn the vehicle's ignition on to the RUN position. Program the scan tool to the vehicle using the VIN as necessary. Once the scan tool is installed, try to communicate with every module that could be in the vehicle. If an option is not there, the scan tool will display "No Comm" for that control module. That same message will appear if the module is present but not communicating. Therefore, always refer to the service information to identify what modules should be present before coming to any conclusions.

The scan tool may have a network or module test function. This allows you to "ping" or communicate with each system and its modules. However, a nonresponding module may not show on the list due to the scan tool not knowing if the module is part of the vehicle or not. For example, a vehicle may be equipped with an upgraded entertainment system that contains a video display unit for the rear seats. If the module failed, it may not respond to a network or module test. The scan tool would not flag the module as nonresponding because the scan tool does not know if the vehicle is equipped with that

particular module. However, there should be DTCs present in other modules for a communication failure with the video module.

If the scan tool will not communicate with the vehicle, you will need to diagnose the communication network. There are several possible causes for a lack of communication, including an open or shorted data circuit and a faulty module. Before attempting to diagnose the vehicle, refer to the manufacturer's service information for specific testing procedures. Also, check for aftermarket components, especially stereo systems. If an aftermarket stereo is installed and you cannot communicate with the vehicle, disconnect the stereo and retry.

In general, if the scan tool powers up but there is no communication with a vehicle or network, test the DLC signal ground circuit at pin 5. If this circuit is open, shorted or has high resistance, the scan tool will not be able to communicate with the network. If the HS-CAN network is down, a quick check of the data bus circuit is to test the resistance between DLC pins 6 and 14, which are the CAN + and CAN – terminals. If the circuit is complete, a reading of 60 ohms should be obtained. An open in the bus will cause a reading of 120 ohms. A resistance reading less than 60 ohms indicates a short in the data bus.

Because there may be more than one bus available at the DLC, try to communicate with a different network when diagnosing a network or communication issue. If the HS-CAN is down, try the body or HVAC network. If the scan tool can talk to a low- or medium-speed network, you may be able to get communication DTCs to help diagnose the fault. And if the scan tool will not communicate with the vehicle at all, try the tool on a different vehicle to make sure the scan tool is working properly.

The system periodically checks itself for communication errors. The different buses send messages to each other immediately after it sends a message. The message between messages checks the integrity of the communication network. All of the modules in the network also receive a message within a specific time. If the message is not received, the control module will set a DTC stating that it did not receive the message.

There are four types of DTCs used by CAN buses:

- *Loss of communication.* Loss of communication (and Bus-off) DTCs are set when there is a problem with the communication between modules. This could be caused by bad connections, wiring, or the module. Note: In most cases, a lost communication DTC is set in modules other than the module with the communication problem.
- *Signal error.* The control modules can run diagnostics on some input circuits to determine if they are operating normally. If a circuit fails the test, a DTC will set.
- *Internal error.* The modules also run internal checks. If there is a problem, it will set an internal error DTC.
- *Bus open or shorted.* The communication bus itself is monitored for faults and DTCs will set if bus voltage moves beyond preset limits, indicating a short to power or to ground.

Bus Wire Service

If the bus wire needs repair due to an open, short, or high resistance, it must not be relocated or untwisted. The twisting serves an extremely important purpose **(Figure 22–34)**. After a bus wire has been repaired by soldering, wrap that part of the wire with vinyl tape. Never run the repair wire in such a way that it bypasses the twisted sections. CAN bus wires are likely to be influenced by noise if you bypass the twisted wires.

Reprogramming Control Modules

Before going deeply into diagnosing an electronic control circuit, it is wise to check all TSBs that may relate to the problem. Often there will be one that recommends reprogramming of the computer. This is typically called "flashing" the computer. When a computer is flashed, the old program is erased and a new one written in. Reprogramming is often necessary when the manufacturer discovers a common concern that can be solved through changing the system's software. New programs are downloaded into the scan tool and then downloaded into the computer through a dedicated circuit.

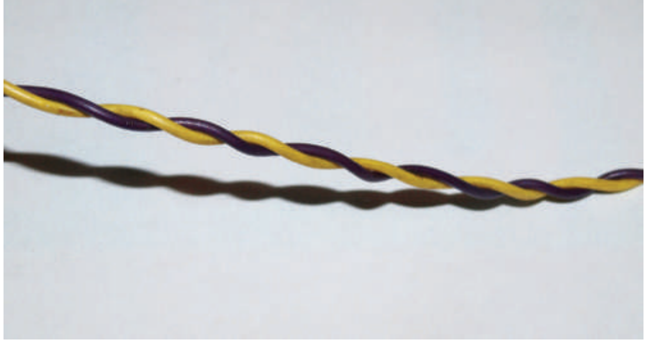


FIGURE 22–34 Network systems use specially shielded wires or twisted pairs of wires for protection from unwanted induced voltages that can interfere or change voltage signals.

Each type of scan tool has a different procedure for flashing. Always follow the manufacturer's instructions. Some scan tools are connected to a PC and the software is transferred from a CD or a website. Photo Sequence 20 shows a typical procedure for flashing a BCM.

It is important to know that any interruption in the flash process can ruin a new module. Connect a clean battery charger (one rated for programing functions) to the vehicle and maintain correct battery voltage during the flashing procedure. If battery voltage drops too low or rises too high, reprogramming will likely fail. In addition, check for the installation of any aftermarket components, such as stereos, before starting to update a module. The presence of aftermarket accessories can corrupt the reprogramming process.

Testing Electronic Circuits and Components

Most electronic circuits can be checked in the same way as other electrical circuits. However, only high-impedance meters should be used. A lab scope is a valuable tool for diagnosing electronic circuits. The scope is primarily used to measure voltages, pulse, and duty cycle.

The scope displays voltage over time and the increments for voltage and time can be modified to provide a good look at the circuit's activity. The time periods show the frequency of a voltage signal. *Frequency* is a term that describes how often a signal performs a complete cycle and is measured in hertz. To determine the frequency of something, divide the length of time it takes to complete one cycle into 1.

Whenever using a scope on a circuit, always follow the meter's instruction manual for hookup and proper settings. Most service manuals have illustrations of the patterns that are expected from the different electronic components. If the patterns do not match those in the manual, a problem is indicated. The problem may be in the component or in the circuit. Further testing is required to locate the exact cause of the problem.

Measuring Changing Voltages

A DMM may have AC selection modes for voltage and amperage. These modes are used to measure voltages and amperages that change polarity or levels very quickly. Most meters display the average voltage or current in an AC circuit. Some meters display root-mean-square (RMS) readings, which are very close to being average readings; however, there may be slight differences as this scale compensates for extreme fluctuations in voltage and current flow.

Testing Actuators

Each manufacturer may prescribe a specific procedure for checking an actuator and these checks will depend on the type of actuator. The tests may rely on the use of scan tool or lab scope. When checking an output, pay attention to the commands of the BCM and the response of the actuator. **Figure 22–35** shows a typical scan tool display of the operation of the control side of an actuator.

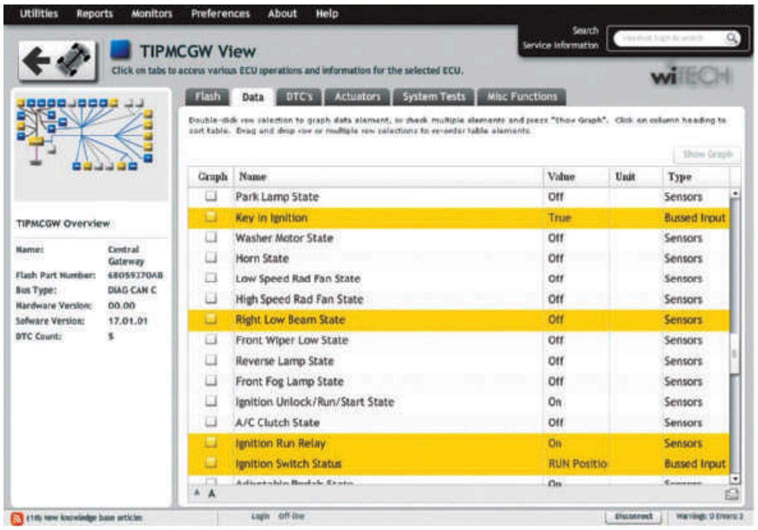
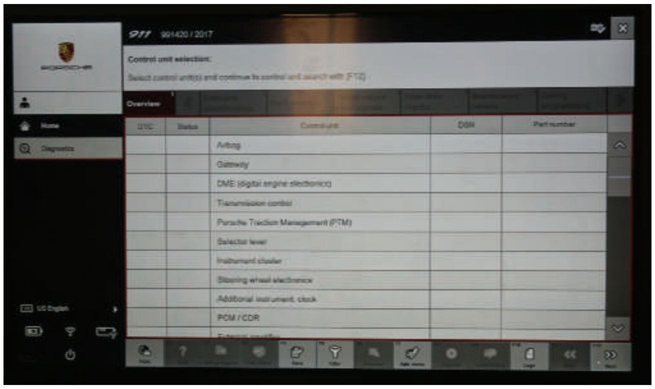


FIGURE 22–35 A look at the control side of an actuator with a scan tool.

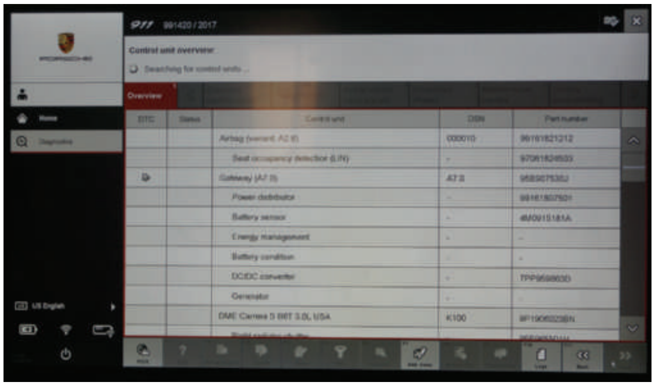
PHOTO SEQUENCE 19

Flashing a BCM

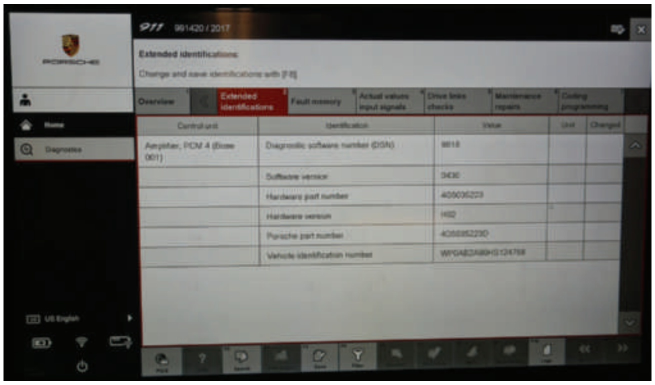
P19-1 Connect the vehicle interface of the scan tool or J-2534 pass-through device to the vehicle's DLC. Be sure to read and follow all manufacturer's guidelines for module programing.



P19-2 Navigate the software to locate the module you need to program.

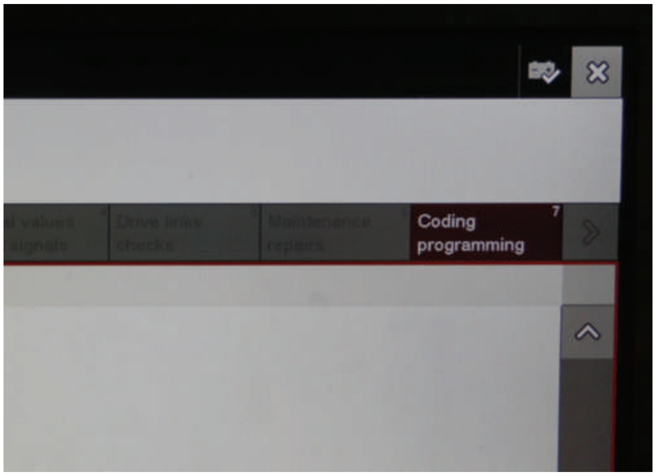


P19-3 You typically need to determine the part number and software version of the module before performing any programing to ensure the correct software is used. Many OEMs do not allow overwriting the current program or reinstalling older versions of the software.

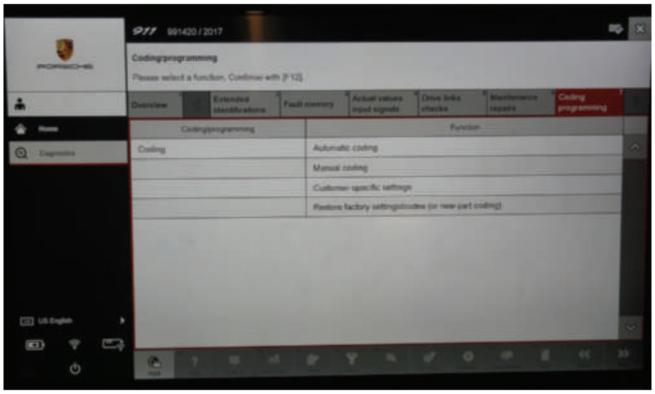


P19-4 Verify that all the module information is correct before starting the programing.

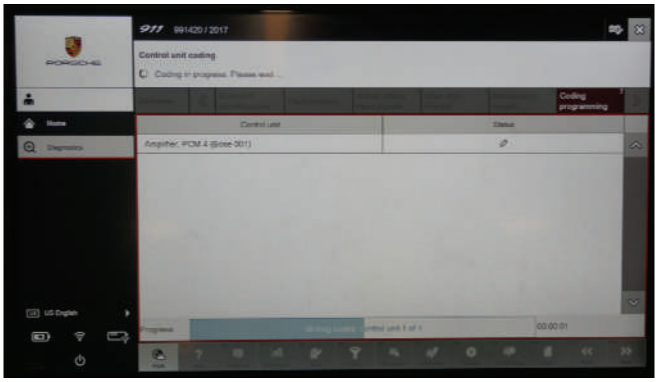
Flashing a BCM *(continued)*



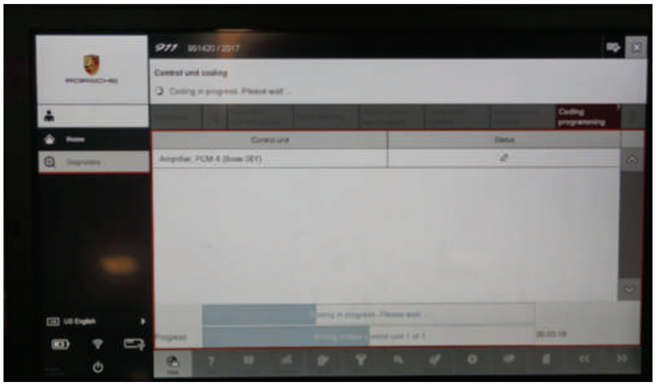
P19-5 Select the programing function in the software.



P19-6 If necessary, select the type of programing function to perform.



P19-7 Begin the programming function.



P19-8 Depending on the module and other factors, programing may take a few minutes to several hours. Keep checking the software to see if any actions are required during the process.

P19-9 Once programming is complete, the ignition is usually cycled on and off to reboot the modules. When finished, recheck for any DTCs and confirm correct system operation.

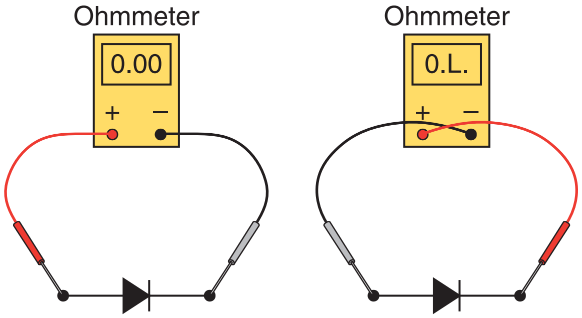


FIGURE 22–36 Testing a diode with an ohmmeter.

Checking Diodes

Multimeters can be used to check diodes, including zener diodes and LEDs. Regardless of the bias of the diode, it should allow current flow in one direction only. Connect the meter's leads across the diode. Observe the reading on the meter. Then reverse the meter's leads and again observe the reading. The resistance in one direction should be very high or infinite and close to zero in the other direction **(Figure 22–36)**. If any other readings are observed, the diode is bad. A diode that has low resistance in both directions is shorted. A diode that has high resistance or an infinite reading in both directions is open.

You may run into problems when checking a diode with a high-impedance DMM. Because many diodes will not allow current flow through them unless the voltage is at least 0.6 volt, a digital meter may not be able to forward bias the diode. This will result in readings that indicate the diode is open, when in fact it may not be. Because of this problem, many multimeters are equipped with a diode testing feature. This allows for increased voltage at the test leads. The meter displays the voltage drop across the diode during the test. This test can also be used to check the operation of an LED.

Diodes can also be tested with a voltmeter. Using the same logic as when testing with an ohmmeter, test the voltage drop across the diode. The meter should read low voltage in one direction and higher voltage in the other direction. Most automotive diodes will drop 500 to 650 mV.

Caution! To avoid possible damage to the meter or to the part being tested, disconnect the circuit's power and discharge all high-voltage capacitors before testing.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2005	**Make:** VW	**Model:** Beetle	**Mileage:** 113,902	**RO:** 18047
Concern:	Customer states the check engine light stays on. Stopped at auto parts store to have light checked, part store could not read codes.			
The technician verifies the concern and then checks the power and ground at the DLC. Both are present but the scan tool will not communicate with any system or module. He then checks the service information for how to diagnose the scan tool not communicating with the vehicle. The service information says to inspect the vehicle for any installed aftermarket accessories. Finding an aftermarket stereo system installed, the technician unplugs the stereo from the factory wiring harness.				
Cause:	Found aftermarket stereo installed and shorting audio circuit of the body control system. Disconnected stereo and retrieved DTC for EVAP system leak.			
Correction:	Because the customer did not want to replace the installed radio with a factory unit, the aftermarket stereo was reinstalled once repairs were complete.			

KEY TERMS

A/D converter
Actuator
Base
Baud rate
Byte
Capacitance
Capacitor
Clamping diode
Collector
Data link connector (DLC)
Electrically erasable PROM (EEPROM)

Electrically inert materials
Emitter
Farad (F)
Feedback
Forward bias
Gateway
Impurities
Keep-alive memory (KAM)
Look-up tables
Microprocessor
Multiplexing
Nonvolatile RAM (NVRAM)
Output driver
Programmable read-only memory (PROM)
Random-access memory (RAM)
Read-only memory (ROM)
Reverse bias
Schmitt trigger
Serial data bus
Square wave
Trimmers
Voltage-generating sensors
Zener diode

SUMMARY

- All basic laws of electricity apply to electronic controls.
- A capacitor is used to store and release electrical energy.
- A diode allows current to flow in one direction but not in the opposite direction. It is formed by joining P-type semiconductor material with N-type semiconductor material.
- A transistor resembles a diode with an extra side. There are PNP and NPN transistors. They are used as switching devices. A very small current applied to the base of the transistor controls a much larger current flowing through the entire transistor.
- Computers are electronic decision-making centers. Input devices called sensors feed information to the computer. The computer processes this information and sends signals to controlling devices.
- Most input sensors are reference voltage sensors or voltage-generating sensors.
- Computers work digitally; therefore, they must receive digital signals or convert analog signals to digital signals before processing them.
- A typical electronic control system is made up of sensors, actuators, a microcomputer, and related wiring.
- The microcomputer and its processors are the heart of the computerized engine controls.
- There are three types of computer memory used: ROM, PROM, and RAM.
- Output sensors or actuators are electromechanical devices that convert current into mechanical action.
- On-board diagnostic capabilities are incorporated into a vehicle's computer to monitor virtually every component that can affect emission performance. Each component is checked by a diagnostic routine to verify that it is functioning properly.
- Multiplexing provides communications between vehicle systems. It uses a serial data bus that connects different computers or control modules together.
- Controller area network (CAN) is the most commonly used network protocol in today's vehicles.
- Static electricity can generate up to 25,000 volts and do damage to components. Precautions for static discharge must be taken when handling electronic components.
- Communication between the various control modules in a vehicle is critical to the vehicle's overall operation.
- There are three types of DTCs used by CAN buses: loss of communication, signal error, and internal error.
- At times the manufacturer will recommend that a control module be reprogrammed; this is often called flashing the computer.
- Most electronic circuits can be checked in the same way as other electrical circuits. However, only high-impedance meters should be used.

REVIEW QUESTIONS

Short Answer

1. Explain the three types of memory used in the computer system.
2. ___ signals resemble a square pattern.
3. ___ signals can have varying voltage levels.
4. ___ means that data concerning the effects of the computer's commands are fed back to the computer as an input signal.
5. The type of memory that contains specific information about the vehicle and can be replaced or reprogrammed is called ___.

6. A ___ is the simplest type of semiconductor.
7. What is meant by the term *pulse width?*
8. Explain how transistors can be used in automotive electronics.
9. How should you test a diode with a multimeter?
10. What is the name of the module that allows the different serial buses in a multiplexed system to communicate with each other?
11. What is the major difference between ROM and RAM memory in a microprocessor?

True or False

1. *True or False?* Look-up table's are a type of information stored in ROM.
2. *True or False?* In a high-speed CAN system, a serial data bus is used to allow communication between the various control modules in a vehicle.

Multiple Choice

1. Which of the following is not made of semiconductor material?
   a. Zener diode
   b. Thermistor
   c. PM generator
   d. Hall-effect switch
2. Which of the following is a basic function of a computer?
   a. To store information
   b. To process information
   c. To send out commands
   d. All of the above

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that when positive voltage is present at the base of an NPN transistor, the transistor is turned on. Technician B says that when an NPN transistor is turned on, current flows through the collector and emitter of the transistor. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. While checking an A/C compressor clutch coil clamping diode with a DMM, the meter shows infinite resistance when the diode is measured in both directions: Technician A says that the diode is open. Technician B says that all diodes should behave this way until a specified voltage is applied to them. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. Technician A says that some types of voltage sensors provide input to the computer by modifying or controlling a constant, predetermined voltage signal. Technician B says that a coolant temperature sensor is a voltage-generating sensor. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. Technician A says that multiplexing is a way to increase data communication without increasing the weight of the vehicle. Technician B says that multiplexing uses data buses to share information. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Technician A says that when a diode is placed in a circuit with the positive side of the circuit connected to the positive side of the diode and the negative side of the circuit connected to the negative side of the diode, the diode is said to have reverse bias. Technician B says that the diode's P material is repelled by the positive charge of the circuit and is pushed toward the N material and that the N material is pushed toward the P. Who is correct?
   a. Technician A
   b. Both A and B
   c. Technician B
   d. Neither A nor B
6. Technician A says that a capacitor always discharges with the same voltage it was charged with. Technician B says that current only flows through a capacitor when it is charging or discharging. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

7. While discussing multiplex system protocols: Technician A says that CAN communications are based on variable pulse widths carried on a single bus wire. Technician B says that Class B communications offer real-time communications over a twisted pair of wires. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. Technician A says that the signal from a Hall-effect switch needs to pass through a Schmitt trigger before the computer can process it. Technician B says that a Hall-effect switch produces an analog signal. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. While diagnosing a network communication failure: Technician A checks for communication codes in the problem network. Technician B checks for DTCs in all networks and modules. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. Technician A says that only the gateway module contains the terminating resistors in a HS-CAN system. Technician B says that MOST networks do not require terminating resistors. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER 23

ELECTRICAL ACCESSORIES

OBJECTIVES

- Explain the basic operation of electric windshield wiper and washer systems.
- Inspect and diagnose concerns with windshield wiper and washer systems.
- Explain the operation of power door locks, power windows, and power seats.
- Understand how cruise or speed control operates and the differences of various systems.
- Inspect and diagnose cruise control systems.
- Identify the components of typical audio and video systems.
- Identify and diagnose video and sound concerns.
- Diagnose problems with power door lock, power window and seat systems.
- Understand the operation of the various security systems.

Electrical accessories make driving safer, easier, and more pleasant for the driver and passengers. This chapter covers many of the common accessories. Other automotive electric and electronic equipment, such as passive seat belts and air bags, are described elsewhere in this book. Most accessories are controlled by the BCM or other module and after the verification of a problem, diagnostics begin with retrieving DTCs and observing data on a scan tool.

GO TO Chapter 22 for a discussion on and the procedures for connecting and using a scan tool on a BCM.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2017	**Make:** Kia	**Model:** Soul	**Mileage:** 446	**RO:** 18214
Concern:	Customer states the Apple CarPlay doesn't work.			
History:				
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

Windshield Wiper/ Washer Systems

Both rear and front windshield wiper systems can be found on many vehicles **(Figure 23–1)**. Headlight wipers and washers are also available and work in unison with the windshield wipers. Windshield wiper motors can have electromagnetic fields or permanent magnetic fields. Most often, the motors use permanent magnets.

Permanent Magnet Motor Circuits

In motors with permanent magnet fields, motor speed is controlled by the placement of the brushes on the commutator. Three brushes are used: common, high speed, and low speed. The common brush carries current whenever the motor is operating. The low-speed brush and high-speed brush are placed in different locations. The most commonly used motor has the low-speed and common brushes opposing each other and the high-speed brush is either centered between the two or offset from the two **(Figure 23–2)**. Other motors have the high-speed and common brushes opposing each other, with the low-speed brush offset from the two **(Figure 23–3)**.

The placement of the brushes determines the number of armature windings connected in the circuit.

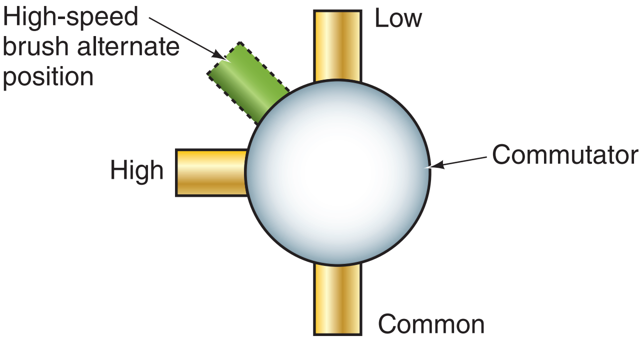


FIGURE 23–2 The most common brush arrangement has the low-speed brush opposing the common brush.

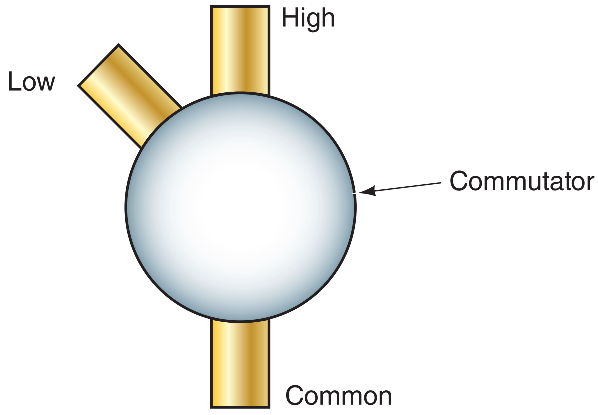


FIGURE 23–3 In this brush arrangement, the high-speed and common brushes oppose each other and the low-speed brush is offset from the two.

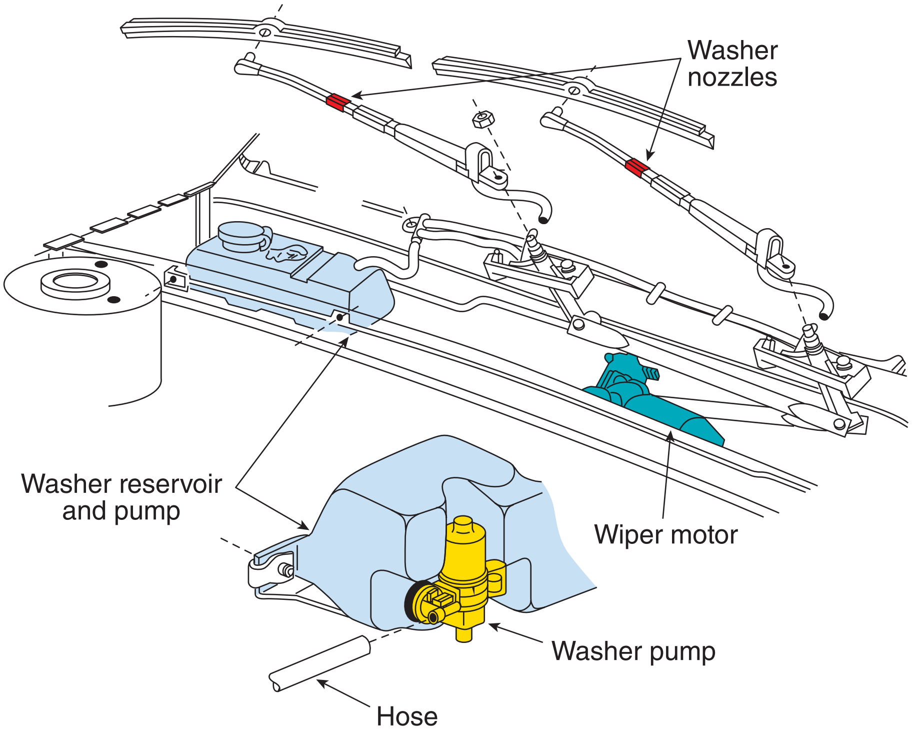


FIGURE 23–1 Parts of a windshield wiper and washer assembly.

When battery voltage is applied to fewer windings, there is less magnetism and less counter-EMF (CEMF). With less CEMF, armature current is higher. This high current results in higher motor speeds. When more windings are energized, the magnetic field around the armature is greater and there is more CEMF. This results in lower current flow and slower motor speeds.

Park Switch A park switch is incorporated into the motor. It operates off a cam or latch arm on the motor's gear **(Figure 23–4)**. The switch supplies voltage to the motor after the wipers have been turned off with their switch. This allows the motor to continue running until it reaches the park position.

When the wiper control is in the high-speed position, voltage is applied through the switch to the high-speed brush **(Figure 23–5)**. Wiper 2 moves with wiper 1 but does not complete any circuits. When the switch is moved to the low-speed position, voltage is applied through wiper 1 to the low-speed brush. Wiper 2 also moves but does not complete any circuits.

When the switch is moved to the off position, wiper 1 opens. Voltage is applied to the park switch and wiper 2 allows current to flow to the low-speed brush. When the wiper blades reach their lowest position, the park switch is moved to the park position. This opens the circuit to the brush and the motor shuts off.

Depressed Park Wiper Systems Systems with a depressed park mode have a second set of contacts with the park switch. The contacts allow current to flow to the low-speed brush, rather than the common brush. The ground for the motor is established by the common brush **(Figure 23–6)**. This causes the wiper motor to rotate in reverse for about 15 degrees after the wipers have reached the normal park position, causing them to recess.

Electromagnetic Field Motor Circuits

Some two-speed and all three-speed wiper motors use two electromagnetic field windings rather than a permanent magnet. The speed of the motor depends on the strength of the magnetic fields. The two field coils are wound in opposite directions so that their magnetic fields oppose each other. The field is wired in series with the brushes and commutator. The shunt field forms a separate circuit off the series circuit to ground.

A ground side switch controls the path of current and speed of the motor. One current path to ground is through the field coil and the other is through a resistor. When the switch is placed in the low-speed position, the relay's contacts close and voltage is applied to the motor. The second wiper of the switch provides the path to ground for the shunt field. With no resistance in the shunt field coil, the shunt field is very strong and bucks the magnetic field of the series field. This results in slow motor operation.

When the switch is in the high-speed position, the shunt field finds its ground through the resistor.

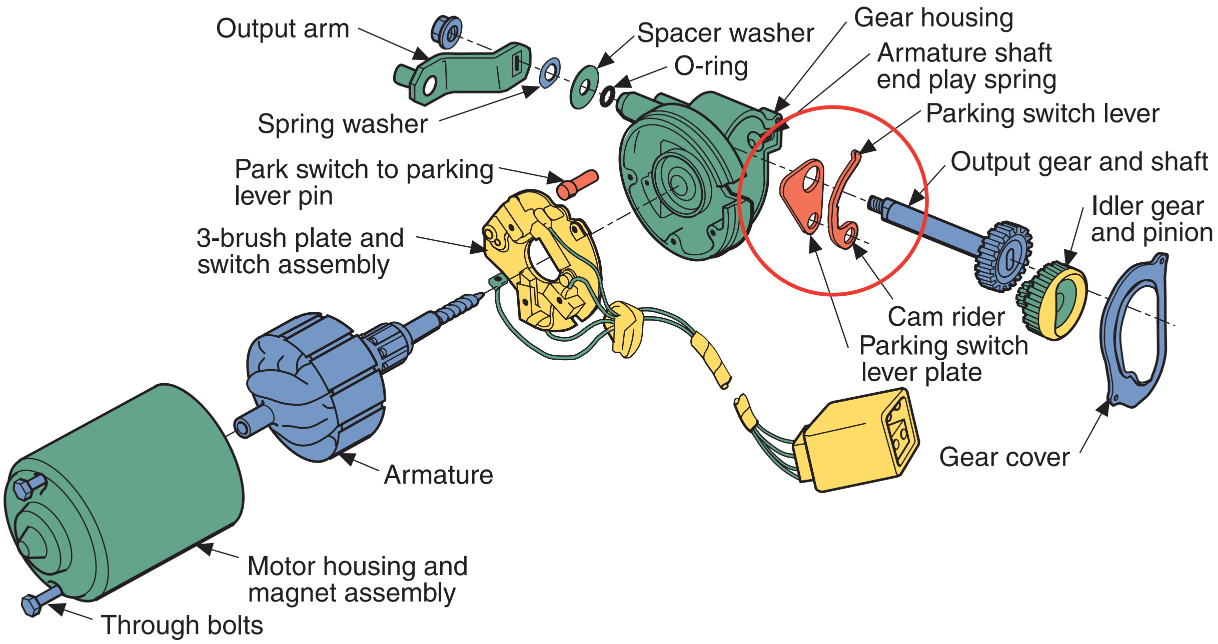


FIGURE 23–4 An exploded view of a wiper motor with a park mode.

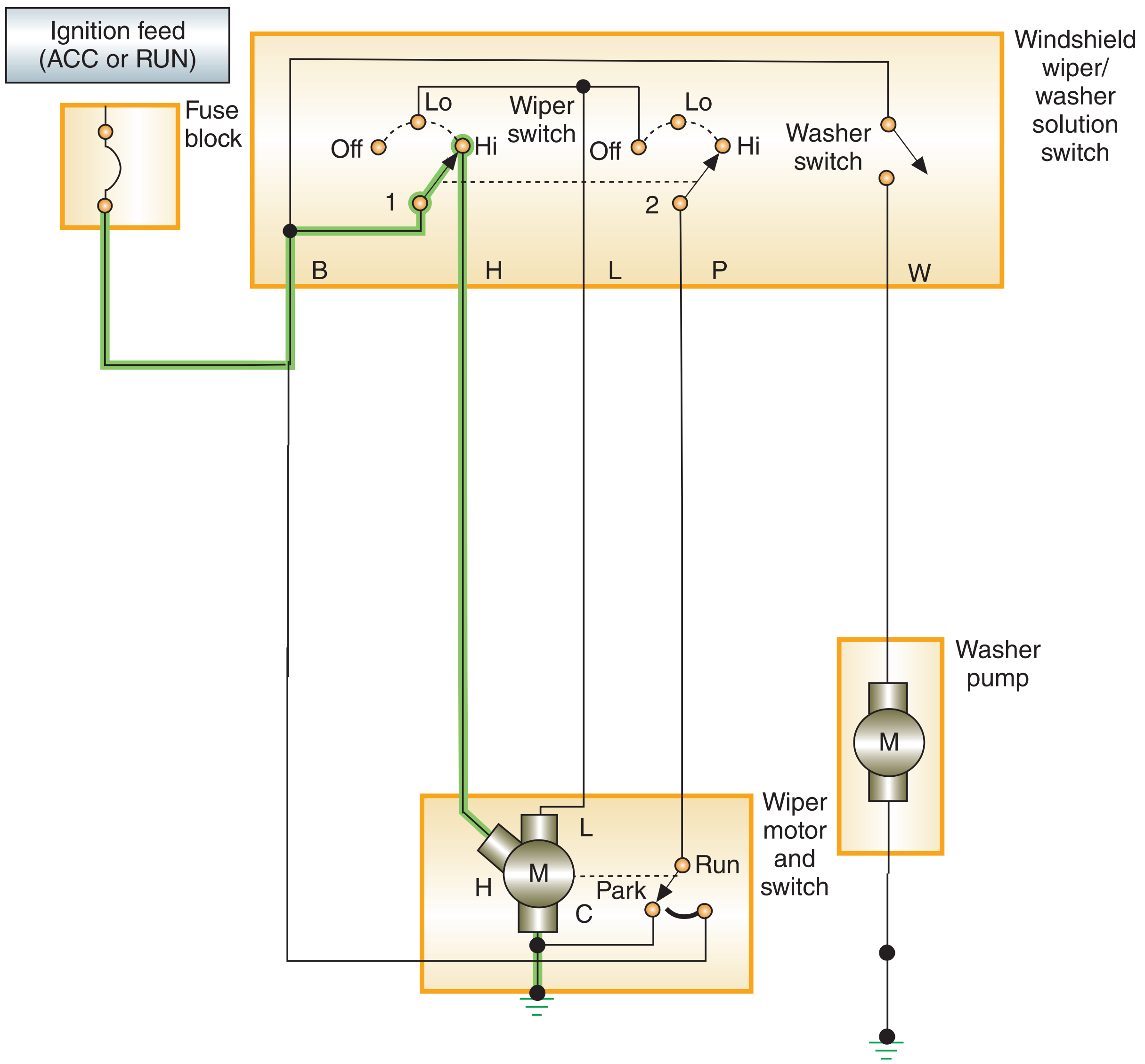


FIGURE 23–5 Current flow in the high-speed mode of a permanent magnet motor.

This results in low current and a weak magnetic field in the shunt coil; therefore, the armature turns at a higher speed.

Three-Speed Motors The control switch for a three-speed motor determines what resistors, if any, will be connected to the circuit of one of the fields **(Figure 23–7)**. When the switch is in the low-speed position, both field coils have the same amount of current flow. Therefore, the total magnetic field is weak and the motor runs slowly.

When the switch is in the medium-speed position, current flows through a resistor before going to the shunt field. This connection weakens the shunt coil and the motor's speed increases.

With the switch in the high-speed position, a resistor of greater value is connected to the shunt field. This connection weakens the magnetic strength of the coil and the motor runs faster.

Windshield Wiper Linkage and Blades Several arms and pivot shafts make up the linkage used to transmit the rotation of the motor to oscillate the windshield wipers. As the wiper motor runs, the linkage rotates the arms from left to right. The arrangement of the linkage causes the wipers' pivot points to oscillate. The wiper arms and blades are attached directly to the two pivot points.

A few wiper systems have two wiper motors that operate in opposite directions, thus creating the oscillation motion of the wipers. These systems also occupy less space in the engine's cowl area.

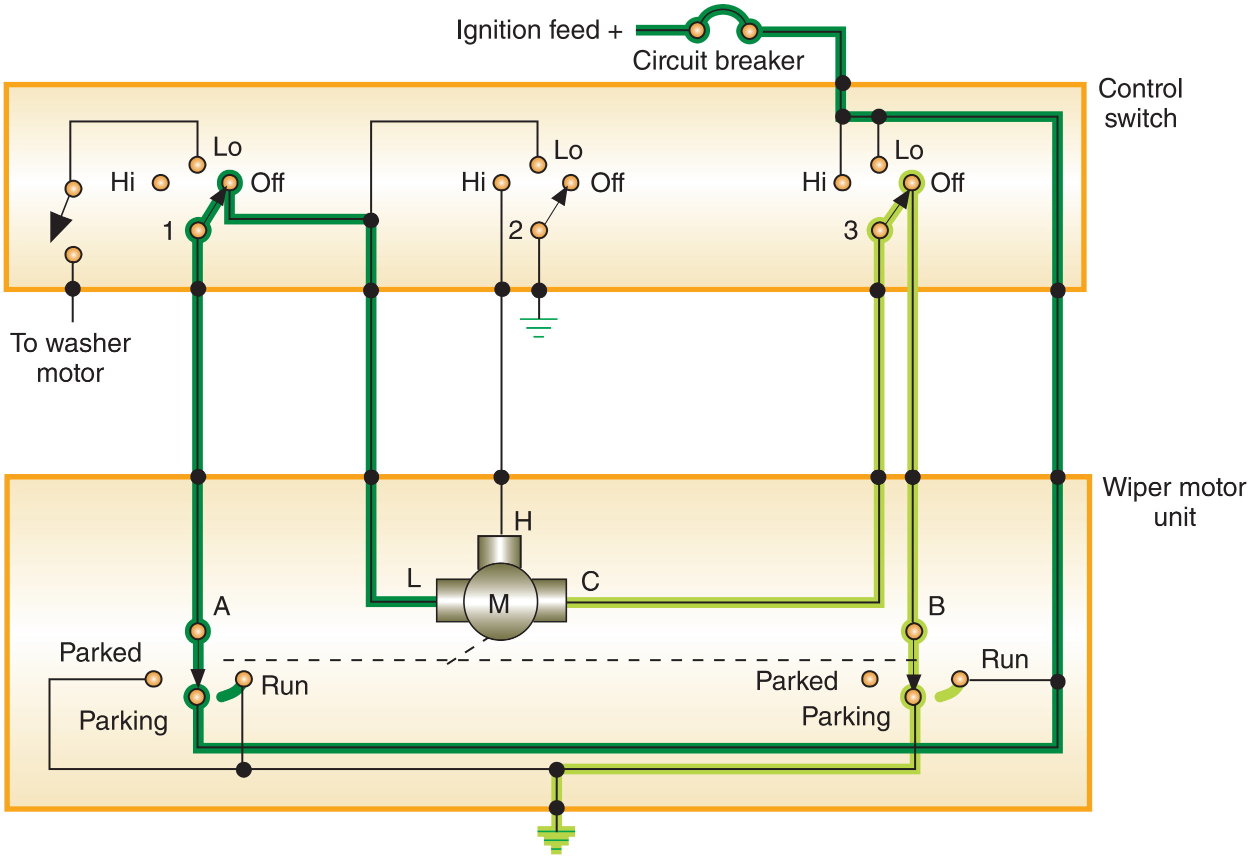


FIGURE 23–6 Circuit current flow when the wipers are parking and moving to the depressed position.

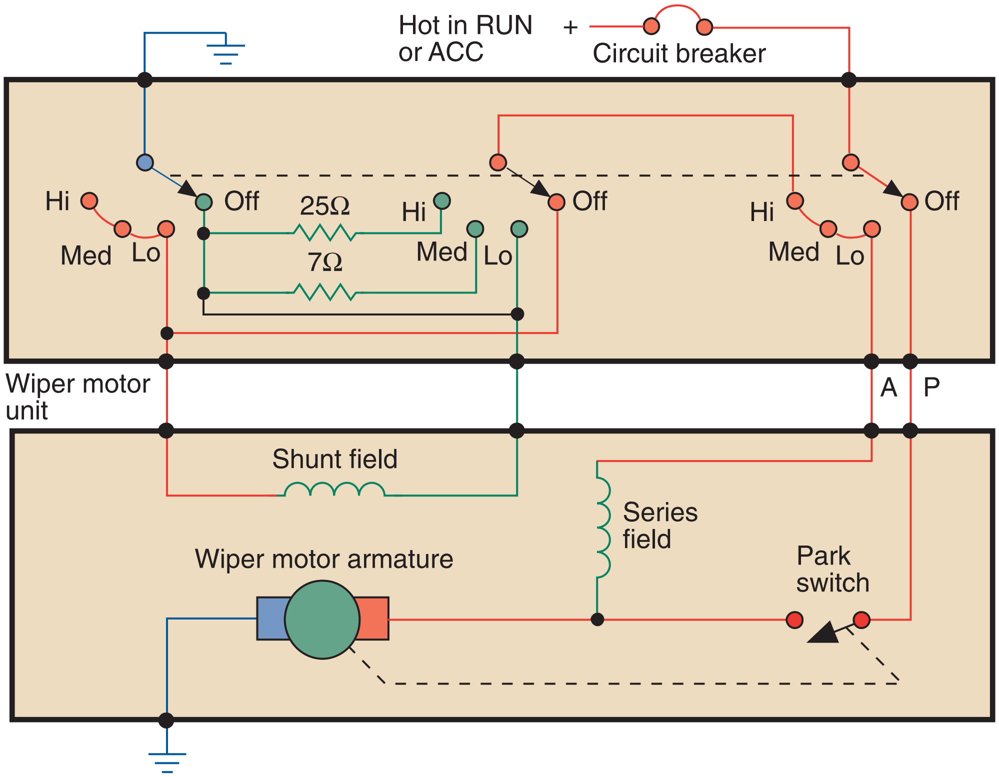


FIGURE 23–7 A three-speed wiper motor schematic.

GO TO Chapter 8 for the procedure for replacing wiper blades and arms.

Rear Window Wiper/Washer System This system is typically found on hatchbacks, vans, and SUVs **(Figure 23–8)** and has a separate switch to control the wiper motor. The parking function is completed within the rear window wiper motor and switch.

Intermittent Wiper Systems

Many wiper systems offer an intermittent mode that provides a variable interval between wiper sweeps. Many of these systems use a module, or governor, mounted near the steering column, or the system has a module connected to the BCM **(Figure 23–9)**.

The delay between wiper sweeps is controlled by a potentiometer. By rotating the intermittent control, the resistance value changes. The module contains a capacitor that is charged through the potentiometer. Once the capacitor is saturated, the electronic switch

FIGURE 23–8 A rear window wiper.

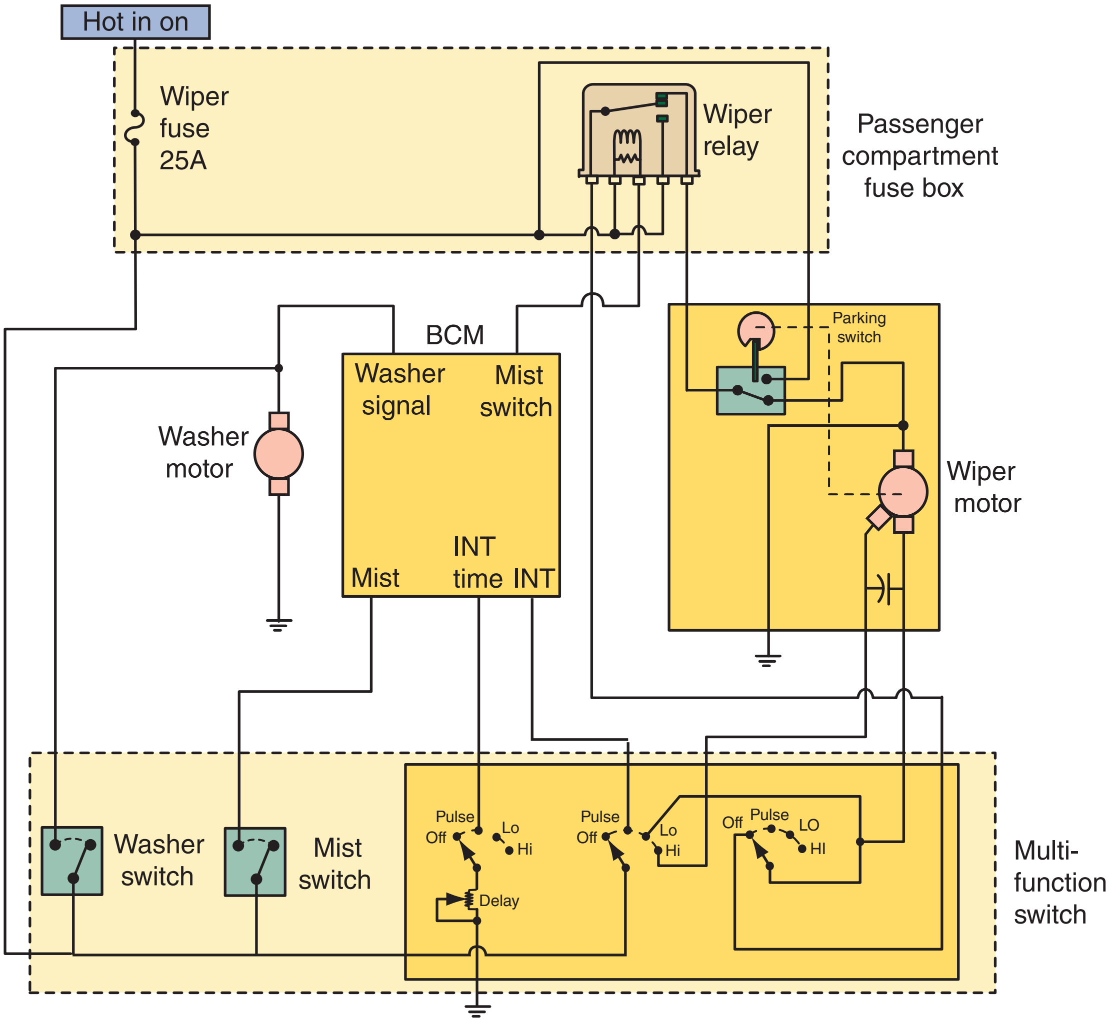


FIGURE 23–9 An intermittent wiper system.

is triggered and current flows to the wiper motor. The capacitor discharge is long enough to start the wiper operation and the park switch is returned to the run position. The wiper will continue to run until one sweep is completed and the park switch opens. The amount of time between sweeps is based on the length of time required to saturate the capacitor. As more resistance is added to the potentiometer, it takes longer to saturate the capacitor.

Rain-Sensing Wipers Some vehicles have a setting for windshield wiper operation that responds to water on the windshield. The sensor for these wipers is usually located in the center and at the top of the windshield behind the rearview mirror. The sensor transmits an infrared light onto the windshield's surface through a special optical element **(Figure 23–10)**. The system has a series of LEDs that shine at an angle onto the inside of the windshield and an equal number of light collectors **(Figure 23–11)**.

When the windshield is dry, all of the light from the LEDs is reflected back to the collectors. The windshield's ability to reflect light starts to change as soon as moisture begins to accumulate on the glass. Water refracts some of the light away from the collectors. This lower level of reflected light serves as an index indicating higher levels of moisture on the windshield's surface. The rain sensor uses all changes in reflected light as the basis for determining the intensity of the rain. In response, the number of sweeps made by the windshield wipers increases or decreases. The sensitivity level of this system can be adjusted by the driver.

On some vehicles, the rain-sensing wiper module data is used to automatically turn on the headlights. On some cars, the ABS applies a slight amount of pressure to the brake system to clean and dry the pads and rotors and pre-charge the system when it is wet outside.

FIGURE 23–10 A typical rain-sensing module mounted on the inside of the windshield so it can monitor the moisture on the outside of the windshield.

Speed-Sensitive Wipers Some vehicles have speed-sensitive wipers that vary the speed or intermittent intervals according to vehicle speed. This feature addresses the problem of excessive water accumulating on the windshield when the vehicle is moving fast. These systems are typically controlled by the BCM in response to inputs from the VSS.

Windshield Washers

Windshield washers spray a fluid onto the windshield and work in conjunction with the wiper blades to

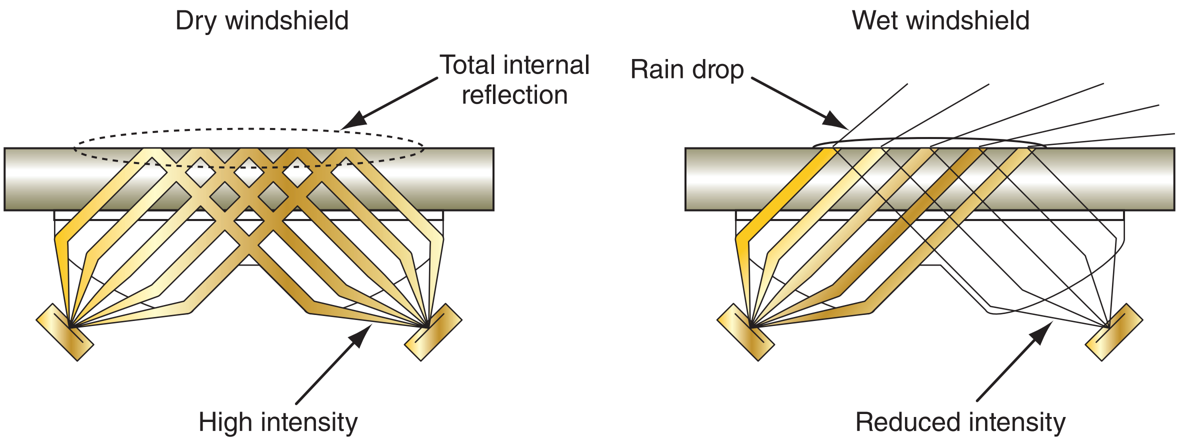


FIGURE 23–11 The basic operation of a rain sensor.

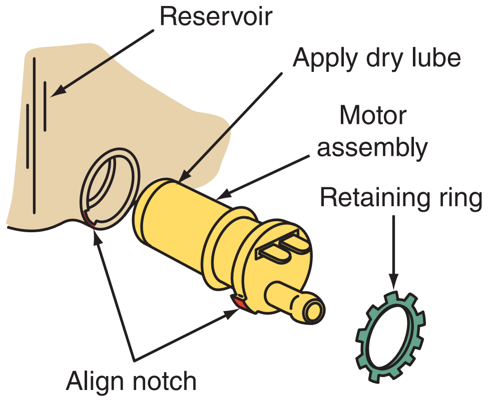


FIGURE 23–12 Installation of a washer pump and motor in a fluid reservoir.

clean the windshield. Most systems have the washer pump installed in the fluid reservoir **(Figure 23–12)**. A few older systems, such as some from GM, use a pulse-type pump that operates off the wiper motor.

Washer systems are activated by holding the washer switch. If the wiper/washer system also has an intermittent control module, a signal is sent to the module when the washer switch is activated. An override circuit in the module operates the wipers at low speed for a programmed length of time. The wipers either return to the park position or operate in intermittent mode, depending on the design of the system.

Some vehicles have wipers and washers that clean the headlights **(Figure 23–13)** and fog lights for maximum visibility. Headlight washer systems may operate from their own switch and pump or work along with the windshield washer system.

Wiper System Service

Customer complaints about windshield wiper operation can include poor wiping, no operation, intermittent operation, continuous operation, or wipers that do not park. Other complaints will be related to wiper arm adjustments, such as slapping the molding or one blade parks lower than the other.

When the wipers move as they should but do not wipe the glass surface the way they should or make noise while moving across the glass, the blades and/or arms should be replaced.

If the wipers work slower than expected, disconnect the wiper linkage at the motor **(Figure 23–14)**. Turn on the wiper system. If the motor runs properly, the problem is the linkage and is not electrical. If the motor runs slower than normal, check for excessive voltage drops in the circuit.

If the motor does not run at a particular speed or at all, the problem is electrical. Carefully inspect the motor, wires, connectors, and switch. On some late-model vehicles, wiper system inputs and operation can be monitored with a scan tool. Use the scan tool to check for DTCs and check the operation of the wiper switch while watching the data. Pay attention to the circuits that could cause the problem, not the entire wiper circuit. Test for voltage at the motor in the various switch positions. Also check the ground circuit. If the motor is receiving the right amount of voltage at the various switch positions and the ground circuits are good, the problem must be the motor. Wiper motors are replaced, not repaired or rebuilt.

If the wiper motor runs but the blades do not move, inspect the nuts securing the wiper arms to the posts. It is possible that nuts have loosened on the posts. If the wiper arms are splined to the posts and do not move, check for stripped splines on the posts and in the wiper arms. Also check the

FIGURE 23–13 Headlight wiper and washer systems may work directly with the windshield wipers or have a separate control.

FIGURE 23–14 Disconnecting the wiper linkage arms at the wiper motor.

wiper linkage. Many manufacturers use plastic ball sockets to connect components. These sockets tend to crack and break, causing the wiper motor to run but the arms to remain in place.

Warning! Most wiper motors are the permanent magnet type, which can be quite delicate. Do not throw the motor around or hammer on the case. Both of these actions can destroy the magnetic fields.

Washer System Service

Many washer problems are caused by restrictions in the fluid lines or nozzles. To check for restrictions, remove the hose from the pump and operate the system. If the pump ejects a stream of fluid, then the fault is in the delivery system. The exact location of the restriction can be found by reconnecting the fluid line to the pump and disconnecting the line at another location. If the fluid still streams out, the problem is after that new disconnect. If the fluid does not flow out, the problem is before where the hose was disconnected. Repeat this process until the problem is found.

If the pump does not spray out a steady stream of fluid, the problem is in the pump circuit. It should be tested in the same way as any other electrical circuit. Make sure it gets power from the switch when it should, then check the ground. If the power to the pump is good and there is a good ground, the problem is the pump. These are not rebuilt or repaired; they must be replaced. If a vehicle has repeated washer pump failures, make sure the fluid pickup in the reservoir is clear of dirt and debris. A clogged pickup can overwork the pump, causing premature failure.

Horns/Clocks/ Cigarette Lighter Systems

The purpose and operation of these systems are obvious and their circuits may vary from one model and year to another. However, the overall operation remains the same.

Horns

The electrical horn in automobiles operates on basic electromagnetic principles. When turned on, a diaphragm in the horn vibrates and emits a noise **(Figure 23–15)**. The diaphragm is a thin, flexible, circular plate mounted to an electromagnet. This diaphragm is only solidly attached to the outside of the horn assembly. This mounting allows the center of the diaphragm to flex. The electromagnet is moved by the magnetic field set up in the field windings. The circuit to the field windings is open when the electromagnet moves. After the electromagnet moves back to its static position, current is again sent to the field winding. This process continues several times per second as long as the horn button is depressed.

Horn switches are either installed in the center of the steering wheel or may be part of the multifunction switch (on some older models). With the switch in the center of the steering wheel, a clockspring is used to provide continuity, regardless of the position of the steering wheel, between switch (or button) and the steering column wiring harness. A clockspring is a winding of conductive material contained in a plastic housing **(Figure 23–16)**.

Most horn systems are controlled by relays. When the horn switch is depressed, the ground for the horn relay is completed and the contacts of the

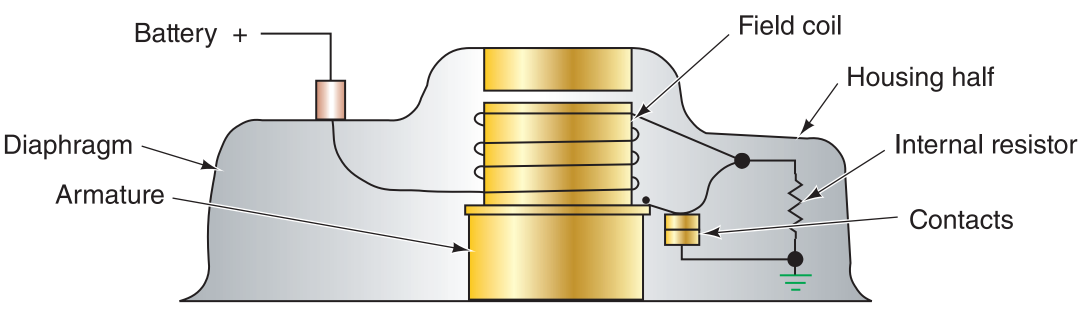


FIGURE 23–15 The basic construction of an automotive horn.

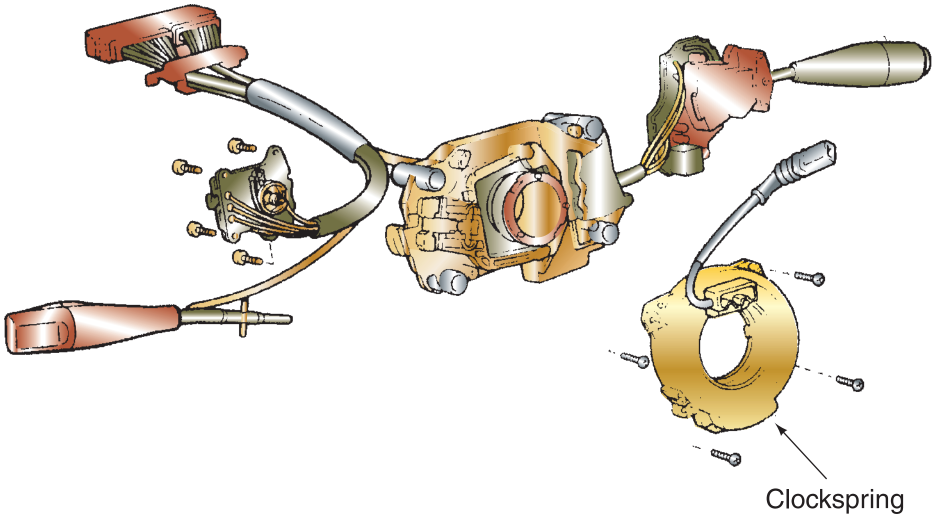


FIGURE 23–16 Nearly all vehicles use a clockspring to maintain contact between the steering wheel and the contacts for the air bag and other accessories.

relay close. This allows high current to be sent to the horn. By using a relay, only a low amount of current is present at the horn button.

Many current vehicles use a control module to operate the horn. The module is used to handle several different tasks, depending on the controls available on the steering wheel. The position and status of all of those controls is sent to the steering column module and is shared with other vehicle systems.

Most vehicles have two horns wired in parallel with each other and in series with the switch. Each horn has a different shape and design to a different tone **(Figure 23–17)**. The two horns provide a fuller

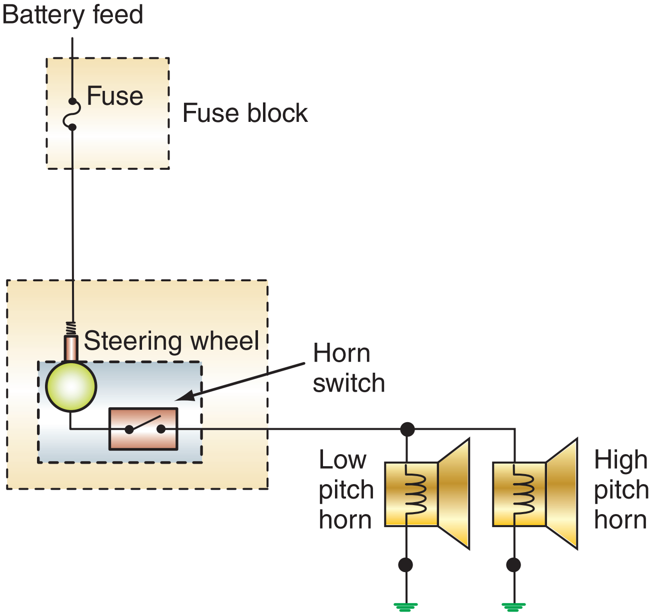


FIGURE 23–17 A basic schematic for a horn circuit that uses a power switch to control the operation of the horns.

FIGURE 23–18 The horn pitch of a horn can be adjusted with a screw on the horn.

sound than one horn can. Adjustments to either of the horns can be made by turning a screw on the outside of the horn **(Figure 23–18)**.

Horn Diagnosis If the horn does not work, start your diagnosis at the relay. Press the horn button or remotely activate the horn if possible and listen for the relay to click. If the relay clicks, the control side of relay and its coil are good. Check for power to the horn itself. If power is present, the horn or its ground is the problem. No power to the horn may be from an opening in the power wire or the relay switch may be faulty. If the relay does not click, check the fuse. If the fuse is bad, check the relay and the horn circuit from the relay. The relay is checked with a DMM. A shorted relay coil, horn, or wire to the horn can cause the fuse to open.

If the relay is good, the horn switch circuit should be checked. Connect a DMM or testlight to battery

positive and the horn switch terminal at the relay. Press the horn button. If the switch circuit is complete to ground, the DMM will show battery voltage or the testlight will glow brightly. If no power is present, either the switch or the circuit to the switch is open.

Clock

The clock receives power directly from the fuse panel or is part of the DIC or infotainment system. Some clocks have additional functions. These are explained in the owner's guide for the particular vehicle.

Cigarette Lighter/Power Outlet

The cigarette (cigar) lighter is a heating element that automatically releases itself from the pushed-in position when the appropriate heat level is reached. Most vehicles have replaced the higher-amperage lighter with a lower-amperage accessory power outlet.

For an inoperative system, first check the fuse(s). If the fuse is good, make certain that power is present at the lighter receptacle. If power is present, the lighter unit is probably bad. Power outlets are typically only powered with the key, although some remain hot at all times. Refer to the service information for additional troubleshooting information.

Cruise (Speed) Control Systems

Cruise control systems are designed to allow the driver to maintain a constant speed (usually above 30 mph or 48 km/h) without applying continual pressure on the accelerator pedal. Selected speeds are easily maintained and can be easily changed. When engaged, the system sets the throttle position to the desired speed. The speed is maintained unless heavy loads and steep hills interfere. The cruise control switch is often located near the center or sides of the steering wheel **(Figure 23–19)**.

FIGURE 23–19 The cruise control switch is used to set or increase speed, resume speed, or turn the system off and on.

Vacuum Systems

Older cruise control systems relied on engine vacuum and mechanical linkages. The following are the common components in these systems **(Figure 23–20)**:

- When the system is turned on, the **transducer** senses vehicle speed and controls the amount of vacuum applied to a vacuum servo.
- The servo unit is connected to the throttle by a rod or linkage, chain, or cable. It maintains the desired speed by receiving a controlled amount of vacuum from the transducer. Variations in vacuum change the position of the throttle. When a vacuum is applied, the servo spring compresses and the throttle is positioned correctly. When vacuum is released, the servo spring is relaxed and the system does not operate.
- When the pedal is depressed, the brake release switch disengages the system, at the same time a vacuum release valve disengages the system.

Electronic Cruise Control Systems

Late-model vehicles have electronic cruise control systems. These systems rely on an electronic control module or BCM to operate a vacuum servo unit or control an electric stepper motor. If the system is vacuum based, the servo is controlled by supply and vent solenoid valves. The stepper motor moves a strap attached to the cruise control cable to move the throttle linkage. The control switch provides a ground circuit through some resistors; these vary the amount of voltage to the control module. The system also has brake and clutch switches that send a signal to the control module to stop control of the throttle.

Engines with electronic throttle control (throttle-by-wire) do not need a separate cruise control module, stepper motor, or cable to control engine speed. The PCM has full control of the throttle and, therefore, the circuitry of the PCM operates the cruise control system.

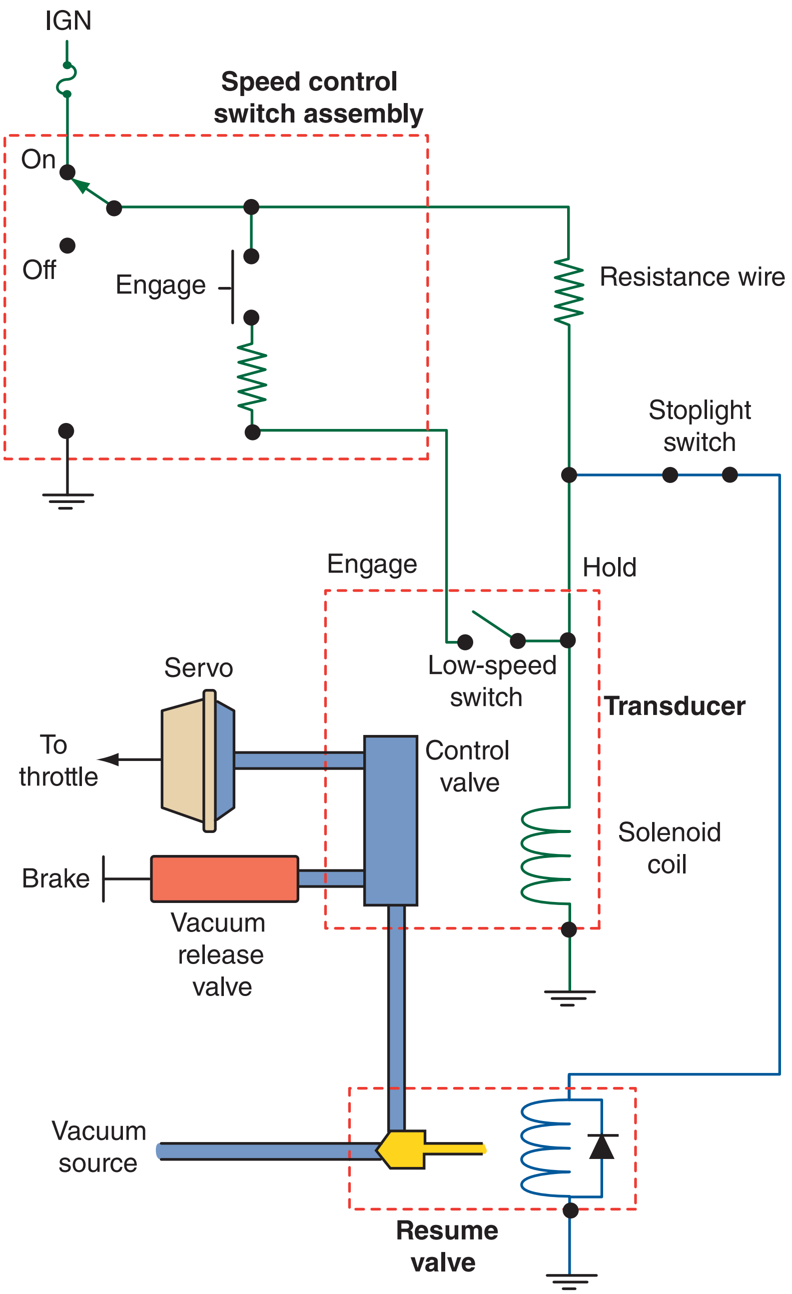


FIGURE 23–20 A cruise control circuit with vacuum and electrical circuits.

A vehicle speed sensor (VSS) is used to monitor vehicle speed. The module has several other inputs to help control the operation of the system **(Figure 23–21)**. The BCM monitors the signals from the cruise control on/off, set/coast, resume/accelerate, and cancel switches to detect when the driver wants to change the current cruise control operation. It sends the status of the switches to the engine control module (ECM) as serial data. The ECM uses this information to set and maintain the selected speed by controlling the stepper motor. The ECM will disengage cruise control operation if the system is turned off or the brake and/or clutch pedal is depressed.

Cruise control can operate only if certain conditions exist, such as the vehicle's speed is within a prescribed range, the BCM does not detect a problem in the system, and system voltage is within a prescribed range.

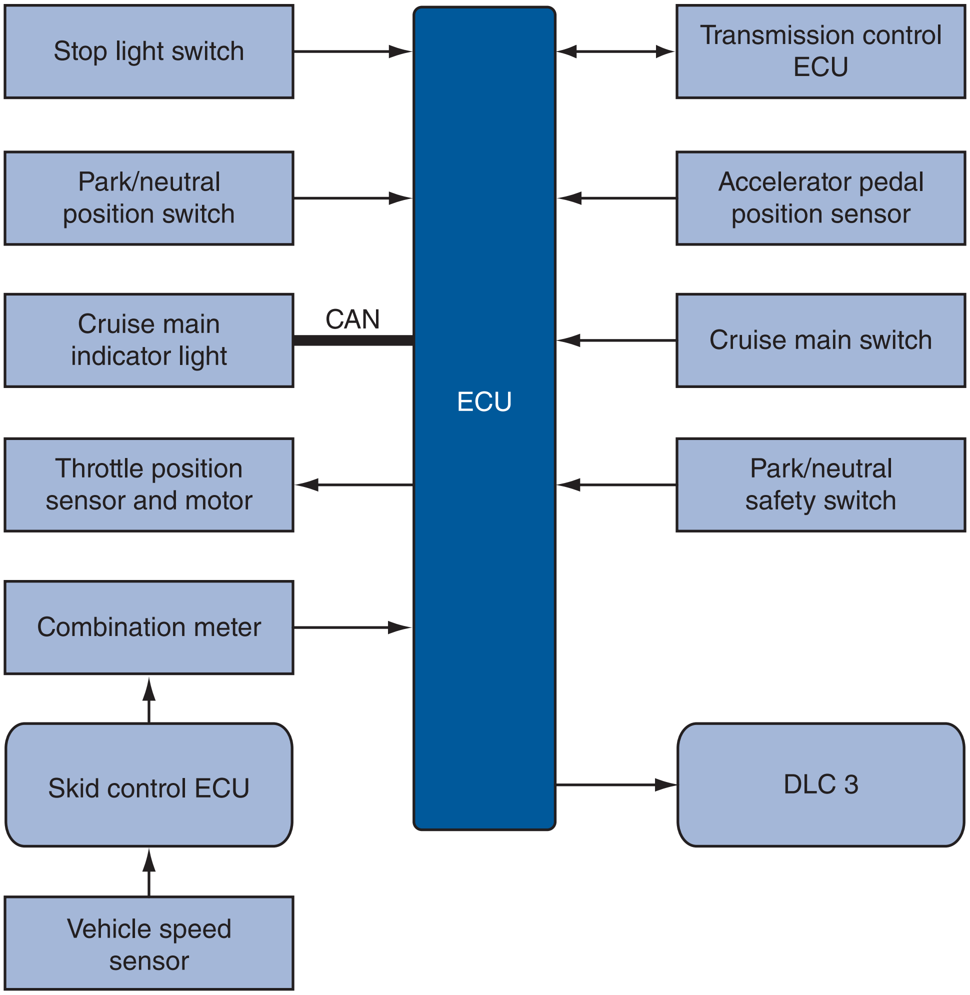


FIGURE 23–21 The main components of an electronic cruise control.

Adaptive Cruise Control

Like other cruise control systems, adaptive cruise control automatically maintains the desired speed of the vehicle, but it also maintains a safe distance between vehicles. The desired distance between vehicles is set by the driver. The system also adjusts the speed of the vehicle to mirror that of a slower vehicle in front of it, and then maintains that speed.

A laser or radar sensor **(Figure 23–22)** mounted near the front bumper serves as the eyes for the system. Other vehicles traveling within the sensor's range reflect the radar waves **(Figure 23–23)**, and the sensor picks up the returning signals. From this, the control unit can determine the position and speed of the preceding vehicle. When the system

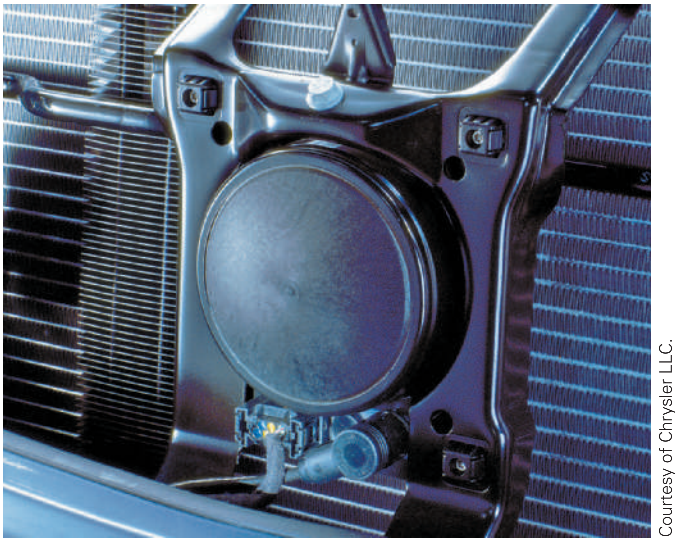


FIGURE 23–22 The distance sensor for an intelligent or adaptive cruise control system.

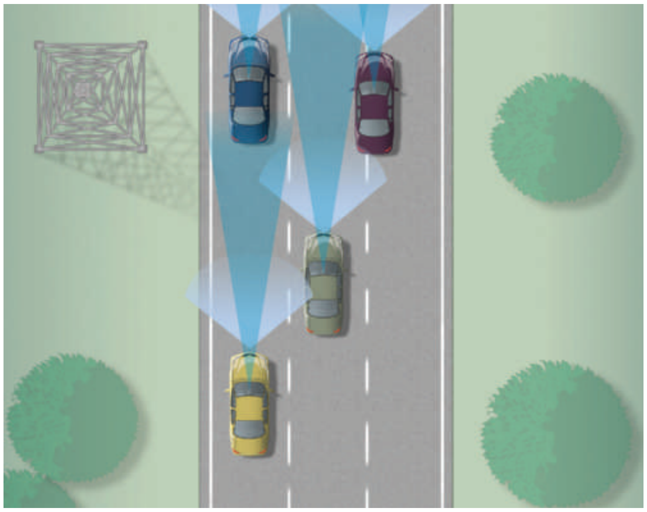


FIGURE 23–23 The response of an adaptive cruise control system.

SHOP TALK

As with any concern, first verify the complaint. Due to the increased sophistication of today's onboard systems, a complaint about the cruise control not working may be due to the customer not fully understanding the system. For example, the adaptive cruise control systems may automatically disengage or simply not work if the sensors are covered in enough dirt or if the windshield wipers are set to high speed.

detects a slower moving vehicle in the same lane, it reduces the throttle or gently applies the brakes to reduce speed. The vehicle then follows behind the preceding vehicle at the speed required to maintain a predefined distance. As soon as the vehicle in front has moved, increased speed, or the driver moves into an open lane, the system will accelerate the vehicle back up to the set and desired speed. This technology is available for the full speed range; including stop and go functionality.

Cruise Control System Service

Most cruise control systems are controlled by the BCM and work with the electronic throttle control system. Diagnosis of these cruise systems is the same as for any other electronic system. Diagnostic work is done with a scan tool and DMM. Typically, on most late-model vehicles, cruise control problems are caused by faulty circuits, sensors, and/or switches **(Table 23–1)**.

SHOP TALK

Most adaptive cruise control systems rely on radar and/or lidar sensors. Radar means "radio detection and ranging." Electromagnetic waves are transmitted from an antenna. When those waves contact another object, they bounce back to the antenna. A processor then determines the speed, location, density, and distance from the object sited within its range. The time it takes for the waves to return is used to determine how far away the object is. Lidar "light detection and ranging" is also often referred to as "laser radar." This works the same way as Radar, except light waves are used in Lidar.

Before connecting the scan tool, check the operation of the cruise indicator lamp. If it does not operate properly, test and repair that circuit before proceeding. If the light is blinking, the control module detects an electrical fault in the system. Also, check all of the system's accessible components for obvious damage. Then with the scan tool, verify that communication links on the CAN bus are good. Retrieve the DTCs and proceed with the recommended procedures for the codes.

The service information will give information on the expected scan tool data readings and voltage values at various points in the system. It will also list acceptable resistance readings through the switches. If the resistance across any switch is not within the listed values, the control assembly should be replaced. Also, the brake light circuit must be functioning correctly; if the brake lights are not working or there is a problem with the brake light switch, the cruise may be disabled.

Radar/Laser Sensor Calibration

If the cruise control sensor is replaced or becomes out of alignment, an adjustment procedure must be performed. The tools and steps vary depending

SHOP TALK

Repair any brake system problems before performing this diagnostic check.

TABLE 23–1 COMMON CRUISE CONTROL PROBLEMS AND THEIR PROBABLE CAUSES

Symptom	Likely Problem Area
Pushing the ON-OFF button does not turn the system on.	■ Brake light switch ■ Clutch switch (M/T) ■ Vehicle speed sensor ■ Cruise control switch ■ Transmission range sensor ■ Control module
Vehicle speed cannot be set. (The CRUISE indicator is on.)	■ Cruise control switch ■ Vehicle speed sensor ■ Brake light switch ■ Transmission range sensor ■ Clutch switch ■ Control module
Cruise control stops during operation.	■ Cruise control switch ■ Vehicle speed sensor ■ Brake light switch ■ Transmission range sensor ■ Clutch switch ■ Control module
Cruise control cannot be manually canceled.	■ Cruise control switch ■ Control module
Cruise control is not canceled when vehicle speed drops below the low-speed limit.	■ Vehicle speed sensor ■ Control module
Depressing the brake pedal does not cancel cruise control.	■ Brake light switch ■ Control module
Depressing the clutch pedal does not cancel cruise control.	■ Clutch switch ■ Control module
Moving the shift lever does not cancel cruise control.	■ Transmission range sensor ■ Control module
Speed is not constant.	■ Vehicle speed sensor ■ Control module
CRUISE indicator is blinking.	■ Cruise control circuit ■ Control module

on the manufacturer but generally include the following:

1. Park the vehicle on a level section of floor. Use an angle gauge and level to measure the slope of the floor.

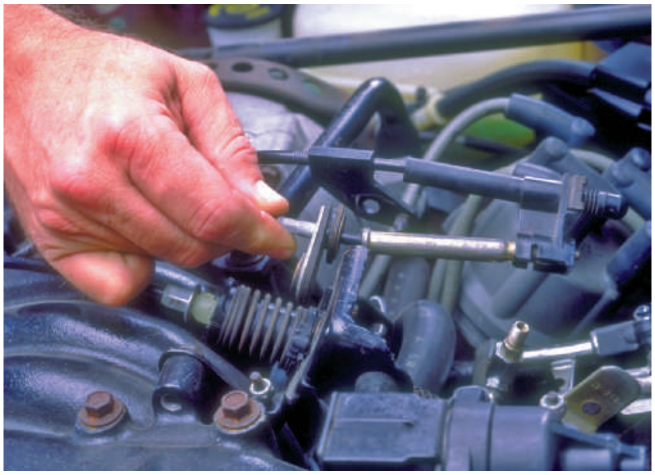


FIGURE 23–24 Check the linkage if the vehicle surges while cruise is activated.

2. Measure the floor surface at the locations where the vehicle will be parked and determine if the floor is flat enough to proceed.
3. Install the sensor alignment gauge and reflector target(s).
4. Place the sensor in alignment/adjustment mode with the scan tool and perform the calibration.

Vacuum Systems Troubleshooting vacuum systems should begin with a thorough inspection. Check the system's fuses. Check all vacuum hoses for disconnects, pinches, loose connections, and so on. Inspect all wiring for tight and clean connections. Check and adjust the linkage according to specifications.

If the cruise control does not work, apply the brake pedal and verify brake light operation. If the lights do not work, repair them and see if this was the cause of the problem. If the vehicle has a manual transmission, check the clutch switch.

If the system does not keep a constant speed, disconnect the vacuum hose between the check valve and the servo. Apply 18 inches of vacuum to the check valve. The valve should hold the vacuum. If it does not, replace it. Check the vacuum dump valve, servo, and speed sensor according to the procedures outlined in the service information. If everything checks out fine, replace the controller (amplifier).

If the vehicle surges while cruise is activated, check the actuator linkage **(Figure 23–24)**. It should move smoothly. Then, check the speedometer cable for proper routing.

Sound Systems

Today, a wide variety of sound systems are available and the complexity of each also varies from basic AM radio to more complex stereo systems **(Figure 23–25)**

FIGURE 23–25 Options now available for sound systems.

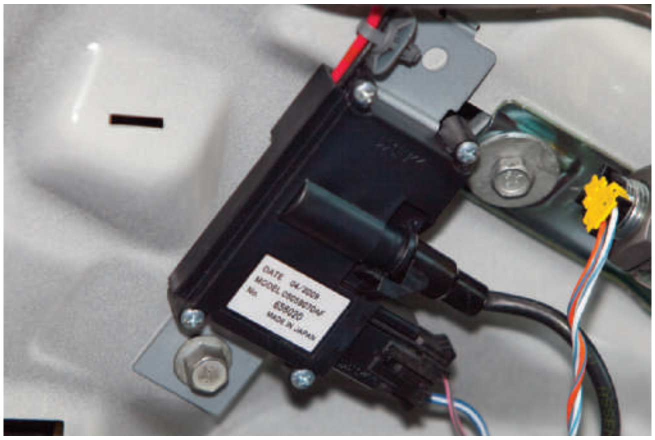


FIGURE 23–26 A rear window defogger and antenna module.

that include an AM/FM radio receiver, a stereo amplifier, CD and DVD players, MP3 player, equalizer, several speakers, and a power antenna system. Many models support streaming audio via Bluetooth, Android Auto, Apple CarPlay, Pandora, and other services.

A radio receives sound waves that are broadcast from radio station towers through an antenna. Amplitude modulation (AM) sound waves travel far but cannot be used to broadcast in stereo. Also, AM does not have as good of sound quality as that of frequency modulation (FM) sound waves. Nearly all FM broadcasts are in stereo, but the distance range for good reception is limited.

A recent addition to traditional radio is HD Radio. HD Radio broadcasts digital information in addition to standard analog AM and FM radio signals. To receive these broadcasts, a digital HD Radio receiver is required. This improves the sound quality produced by the receiver. In addition to music, HD Radio can also transmit song titles, artist, traffic, and stock information.

Antenna

An antenna collects radio waves for both AM and FM stations. Radio stations' broadcast towers transmit electromagnetic energy through the air and induce an AC voltage in the antenna. This AC signal is then converted, by the radio receiver unit, to an audio output.

Some vehicles incorporate the antenna into the rear window defogger grid. A window defogger/antenna module **(Figure 23–26)** separates the radio frequencies used by the radio from the current used by the defogger grid. When the radio is turned on, a 12-volt signal is sent to the defogger/antenna module. A coaxial cable from the module provides the radio with the radio waves.

Power Antennas Some vehicles are equipped with electrically operated antennas that extend when the radio is turned on and lower when it is turned off. These antennas are powered by a reversible electric motor. To keep them working properly, these antennas (even black-colored antennas) should be cleaned with chrome polish on a regular basis. Often when there is a problem, it is caused by dirt or a lack of lubricant on the telescoping mast.

Satellite Radio

To provide broadcast content (e.g., music, live sports, talk) that is not interrupted by distance, most vehicles can be purchased with satellite-based radio as a standard feature or an option. These radios pick up electromagnetic waves from satellites many miles above the earth and use terrestrial repeater networks in some limited markets to support sound transmission in areas blocked with a large number of high-rise buildings. Since the microwaves are transmitted by more than one satellite at all times, and each is in its own orbit or place within the orbit, the same radio station can be heard from coast to coast **(Figure 23–27)**. Although distance does not hamper the reception, the large U.S. geographic areas with satellite-only delivered microwaves cannot penetrate buildings, tunnels, or large groupings of trees. Select satellite radio content is also being offered through increased Internet and cellular connectivity paths such as mobile cellular and office/home Internet.

Courtesy of Delphi Corporation.

FIGURE 23–27 The reception of satellite radio systems is not affected by distance because the radio waves are transmitted by more than one satellite.

Satellite radio programs provide a wide variety of commercial-free music and talk show channels **(Figure 23–28)**. The satellite digital audio receiver (SDAR) is an audio receiver and is separate from the conventional radio receiver. A signal from a satellite is processed by the SDAR, which provides a signal to the conventional radio. The antenna for the SDAR is normally located on the centerline of the roof of the vehicle **(Figure 23–29)**.

Speakers

Sound quality depends on the basic system but especially on the quality of the speakers and their placement. Most systems are equipped with several speakers, each designed to produce a different range of sound. Matching speakers to the system is done by selecting speakers that have the same impedance as the rest of the system. The placement of the speakers is also critical to providing a good clean sound.

FIGURE 23–29 An antenna for satellite radio.

Sound waves from a speaker will bounce off anything they hit, including other sound waves. This bouncing of sound can cause noise or distortion. To achieve a high-quality sound system, the speakers must be placed so that all bouncing is minimized.

Since one speaker cannot reproduce the entire range of hearing frequencies (approximately 20 Hz to 20 kHz), speakers are designed to provide quality sound within a particular range.

Large speakers, called **woofers**, produce the low frequencies of midrange and bass better than smaller speakers, called **tweeters**. Woofers are typically placed toward the rear of the vehicle **(Figure 23–30)**. Tweeters produce high frequencies of treble better than woofers and are normally placed in each front and rear door of the vehicle. High/mid-range speakers are normally placed in the center of the front instrument panel. Additional high/mid-range speakers may be placed throughout the passenger compartment. Coaxial speakers or full-range speakers are also normally placed in the front and rear doors

FIGURE 23–28 The screen of a satellite digital audio receiver.

FIGURE 23–30 A woofer mounted in the rear of the vehicle.

and have two separate speakers combined into one unit and cover a broader frequency range. Subwoofer speakers can be coupled with a coaxial speaker, tweeter, or midrange speaker to cover a wider range of frequency while maximizing sound quality. Surround-sound systems may have full-range speakers set inside or near the seats' headrests.

CD Players

A compact disc (CD) player uses a laser pickup to read digital signals recorded on a compact disc. By converting the digital signals to analog, it can play music and other audio formats. CD players vary from being able to insert one or more CDs into the main unit to having an auxiliary unit where many CDs can be installed. The control unit allows the operator to select the CD of choice.

Newer vehicles may have ports that allow MP3 music files to be played from an SD card or USB flash drive **(Figure 23–31)**. Some also have connectors that allow full operation of an iPod through the sound system.

DVD Systems

Many vehicles have DVD players. Most of these display videos on a flip-down, roof-mounted monitor or on a monitor attached to back of the front seats **(Figure 23–32)**. In some cases, a DVD can be viewed on the navigation screen when the vehicle is not moving. The sound from the video is channeled to the vehicle's speakers through the radio, unless headphones are used. When the headphones are activated, the audio of the video can be heard through them while others in the vehicle can listen to the output of the normal sound system.

FIGURE 23–31 A variety of connections for different sound devices and storage media.

FIGURE 23–32 A DVD monitor located in the back of a front seat.

These systems are controlled by a rear-seat entertainment ECU that integrates some of the functions of the front-seat audio unit and the multi-information display.

Wireless headsets and remote controllers use infrared-emitting diodes to transmit signals. Wired headsets connect to the DVD player and allow for headset volume control. The DVD player may also have terminals that allow other audio/visual equipment, such as a video game player, to connect to the system.

Streaming Audio

Many vehicles now have the ability to stream content using Bluetooth technology. Bluetooth is a low-power short-range wireless communication standard that connects cell phones and other devices. By connecting or pairing a phone to a vehicle's infotainment system, audio can be streamed from the device, either from files stored on the phone or by using the cellular data network.

Self-Diagnostics The system performs self-diagnostics and stores DTC(s) if any faults are found. DTCs are retrieved by entering into the diagnostic mode by pressing the required series of keys on the control panel.

Amplifiers

Many optional sound systems have very a high wattage output and use several amplifiers. An amplifier increases the volume of a sound without distorting it. Amplifiers are typically rated by the maximum power (watts) they can put out. Amplifiers can be either remotely mounted or integrated in the speakers. Most remotely mounted amplifiers are connected to

a data bus and receive power through an amplifier relay. When the radio is turned on, 12 volts are sent to energize the relay.

Some sound systems have an automatic sound level system that adjusts the volume to compensate for changes in ambient noise and vehicle speed. Other vehicles feature a system that allows for fine-tuning the output based on the number and position of passengers in the vehicle. To provide these features, the outputs from the sound system are sent to the data bus where signals sensors are used to analyze the sound, and adjust the volume at each speaker accordingly.

Some new vehicles are incorporating active noise cancelation functions into the audio system. Active noise cancelation uses microphones to detect engine, wind, and tire noise and then programs the audio system to play back the noise 180 out-of-phase. This cancels the unwanted noise and allows for a quieter passenger compartment.

In addition to power and audio signal wires, some systems have a serial data wire that allows communication between the various components of the sound system. The controls of the sound system may be housed at the radio receiver unit, or have additional remote controls at the steering wheel or another location inside the passenger compartment. The switches can be either resistive multiplexed switches or use a supplementary bus system, such as the local interconnect network (LIN), sometimes called the infotainment network. The switches send different voltage signals to the controlling module, depending on which switch is pressed. In turn, the module responds by sending a request message via the data bus to the radio.

Diagnosis

If the radio system is not working, check the fuse. If the fuses are okay, refer to the service information and check the rest of the power and ground circuits for the radio. If you determine the radio is the problem, remove it and send it to a qualified shop or replace it. Refer to **Table 23–2** to view the possible causes of common sound system problems.

If the sound system has poor sound quality or poor radio reception, the circuit's wiring, the antenna, and the speakers should be checked. If reception is bad, use an ohmmeter to check the ground of the antenna. Also connect one lead of the ohmmeter to the antenna's mast and its case; there should be no continuity between the two.

Poor speaker or sound quality is usually caused by damaged speakers, wiring, bent sheet metal around the speaker opening, damaged or missing speaker mounting brackets, or missing or loose attaching hardware or speaker covers. Be careful not to overtighten the speaker hardware as this may bend or deform the speaker baskets, causing buzzes or distorted sound.

TABLE 23–2 COMMON SOUND SYSTEM CONCERNS AND THEIR POSSIBLE CAUSES

Symptoms	Possible Causes
Radio will not turn on.	■ Open power battery feed circuit ■ Open ignition feed circuit ■ Poor radio ground circuit ■ Loss of bus communications
Radio will not produce sound.	■ Open power battery feed circuit ■ Open ignition feed circuit ■ Poor ground connection ■ Defective radio ■ Open speaker circuit ■ Defective amplifier ■ Open power feed to amplifier ■ Poor amplifier ground circuit ■ Bus communications error ■ Stuck MUTE button
No sound in AM or FM mode. CD audio operates normally.	■ Faulty antenna connection ■ Poor antenna ground ■ Faulty radio
Excessive noise.	■ Faulty antenna connection ■ Poor antenna ground ■ Faulty engine to chassis ground ■ Interference from ignition system, neon lights or electrical power lines
Poor radio reception.	■ Faulty antenna connection ■ Poor antenna ground ■ Faulty radio
Poor sound quality.	■ Damaged speaker cones ■ Damaged speaker mountings ■ Damaged wiring

SHOP TALK

Antitheft audio systems have built-in devices that make the system useless, if stolen. If the power source for the system is cut, even if it is later reconnected, the system will not work unless its ID number is put in. When working on vehicles equipped with this system, before disconnecting the battery terminals or removing the audio system, ask the customer for the ID number so you can input it after service, or request that the customer input the ID after the repairs are completed. A memory saver or backup battery can be used to maintain the radio's code and settings during service.

Satellite Radio Reception Factors Several factors can affect satellite radio reception performance:

- Antenna obstructions including, ice, snow, and items on a roof rack
- Hills, mountains, tall buildings, bridges, tunnels, freeway overpasses, parking garages, dense tree foliage, and thunderstorms can interfere with reception.
- Station overload—a stronger signal may overtake a weaker one and result in an audio mute and a display of NO SIGNAL.

Telematics

Telematics is a technology that allows the transfer of data over a distance and from remote sources. It is best defined as the integrated use of telecommunications and Information Technology (IT). IT is a branch of engineering focused on the use of computers and telecommunications equipment to retrieve, store, sort, and transmit data. Telematics are used by NASA to control the flight of unmanned spacecraft while it is in flight.

Telemetry is widely used by NASA to transmit data and photos from space flights. Telemetry relates to the transmission of measurements from a remote location to another point where the data can be studied. Telemetry relies on remote sensors that measure electrical or physical data. These inputs are converted to voltage and a multiplexer combines the voltages and timing data, to form a single data stream. The signal is sent to a receiver that translates the data stream and the data is then displayed and processed. Telemetry commonly refers to wireless data transfer, but it also includes other ways of data transfer, such as telephone lines and computer networks. Telemetry is also used to transmit engine, chassis, and transmission data from race cars to a race team's pit area. Telemetry is used by many automotive systems, including TPMS, through LAN or radio waves.

Today, in the automotive world, telematics relies on wireless communication, but wires and optical links may be used. It is used to provide displays for:

- Navigation assistance
- Traffic information
- Satellite radio or video
- High speed Internet
- Automatic air bag deployment notification
- Vehicle tracking
- Vehicle conditions

Phone Systems

There are many different systems that provide for hands-free cell phone systems that allow for communication between a cell phone and vehicle's entertainment system and an on-board microphone. Most often, communication and entertainment systems are connected by Bluetooth technology or a standard USB port. Voice commands can dial or answer the phone and choose the entertainment media.

Bluetooth A technology available for bringing information, voice, and video into the passenger compartment is "Bluetooth." Although there are other methods for doing this, Bluetooth is the most commonly used. Bluetooth is a wireless connection that uses a 2.4 GHz frequency band. When Bluetooth is built into the radio receiver, a Bluetooth compatible cell phone can be connected to the main sound system through a wireless connection. This allows for hands-free operation of the phone without the need of a connector or cable to connect the phone **(Figure 23–33)**. Likewise, when the receiver is Bluetooth enabled, a compatible portable audio player can be connected through a wireless connection. This allows files stored in an audio player to be heard and the features of the audio

FIGURE 23–33 Phone controls on the steering wheel.

player, such as play/stop can be operated directly from the radio receiver assembly.

To connect a phone to an infotainment system, it must first be "paired" with the vehicle. The basic steps are as follows:

1. Initiate pairing on the infotainment system.
2. On the phone, select Bluetooth settings.
3. Select the infotainment system from the list of available devices.
4. Enter the pin sent by the vehicle.

Once connected, features such as streaming audio, call sending and receiving, contact information, and text messaging are often available.

Voice Activation System

Voice activation or control systems allow for the control and operation of some accessories with voice commands. The voice commands are in addition to normal manual controls. Voice activation is commonly used for cell phone operation but can be used on other controls. Voice activation systems recognize the driver's voice and can respond with answers in response to the driver's questions. Once the system has understood the driver's request, it responds by carrying out the desired function, such as changing the stations on the radio. The system works through the microphones located near the driver. The voice activation system can recognize up to 2,000 commands and numeric sequences.

The telematics transceiver sends power to the telephone microphone assembly, and the microphone sends signals to the display and navigation module display through the transceiver. The displays and microphone are connected to each other using microphone connection detection signal lines.

A microphone converts sound into an electrical signal. Most microphones use electromagnetic induction, capacitance change, piezoelectric generation, or light modulation to change mechanical vibrations into an electrical voltage signal. A microphone has a housing, a vibration sensitive transducer to send signals to other equipment, and an electronic circuit to adapt the output of the transducer to the receiver. A wireless microphone also contains a radio transmitter. In a vehicle, the microphone may be located in the instrument panel, the steering wheel, or the map light assembly.

USING SERVICE INFORMATION Inspection and diagnostic procedures for the microphone circuit can be found in the vehicle's service information.

Navigation Systems

Navigation systems use global positioning satellites (GPS) to help drivers make travel decisions. These global positioning systems set up a mathematical grid between the satellites and radio stations on the ground. The exact position of a vehicle can be plotted on the grid; therefore, the system knows exactly where the vehicle is **(Figure 23–34)**. A GPS antenna collects the signals for the control unit, which determines the vehicle's location according to latitude and longitude coordinates, and a gyroscope sensor that monitors the vehicle's direction by monitoring angular velocity. The processor compares the data from the global positioning satellites and gyro sensor to the information stored in its memory or to data found on a designated CD or DVD.

Two methods are used to determine the exact location of a vehicle, and both are used simultaneously. One is GPS navigation which detects the location of the vehicle using radio waves from a satellite. The current position is determined by measuring the

FIGURE 23-34 The screen of a typical navigational center.

time it took the radio waves from the satellites to reach the processor. The other method is autonomous navigation, which uses the gyro and speed sensors to monitors the vehicle's travel. The signals from these sensors are updated once per second and if they have changed, the screen is updated.

Usually map data, provided on a DVD, and navigation information are displayed on a TFT or LCD color screen. Many systems give turn-by-turn guidance either by voice, on-screen displays, or both. Many systems feature touch-screen technology and can display and control other systems, such as air-conditioning, heating, and sound systems. Touch screens have touch-sensitive switches. When a touch-sensitive switch is pressed, the outer glass bends to contact the inner glass at the pressed position. By doing this, the voltage ratio is measured and the pressed position is detected. Voice prompts can be sent through the audio system. Other systems allow watching a DVD while the vehicle is parked.

Most navigation systems can display the following:

- Current traffic information regarding traffic backups and show alternative routes so travel is not delayed.
- Display a road map marking the exact location of the vehicle.
- Plot out the best way of getting to a destination.
- The number of miles that have been traveled and how many remain before reaching a destination, as well the expected time of arrival.

Vehicle Tracking Systems

Vehicle tracking systems can identify the location of a vehicle if it has been stolen or lost. The system is based on the vehicle's navigational system and/or the driver's cell phone. When the cell phone is the identifier, the tracking system is triggered when the thief attempts to place a phone call. If the correct code is not entered into the phone, the satellite begins to track the vehicle. This tracking signal is then monitored by an operator who can call the police in the area where the vehicle is being tracked. When the system relies on GPS, a security or police officer can watch the movement of the vehicle on a remote computer screen.

Some systems automatically send a signal to the vehicle tracking operator if an air bag was deployed. This signal, in addition to the global positioning satellite network, allows the authorities to immediately know when and where a serious accident has occurred and the emergency squad can respond quickly.

Systems, such as GM's OnStar (a cell phone based system) and Ford's SYNC (an internal system co-developed by Microsoft), can also provide the driver with control over various systems, such as climate control. Every system provides different conveniences to the driver. Other things they provide are (please keep in mind that not all systems provide the same features):

- Turn-by-turn navigation
- 911 emergency assistance and advice
- Roadside assistance
- Remote diagnostics (while the vehicle is driven)
- Remote door unlocking
- E-mail
- Provide full cell phone features
- Total control of the audio system

SHOP TALK

As manufacturers continue to add accessories and equipment, the number of customer concerns arising from just being able to use the systems continues to increase. A significant number of customer concerns dealt with by technicians come from the customer not knowing how to use a feature or by his or her expectation of how it should perform. You should, also, learn the system so you can guide the customer and know when the system is not operating correctly.

Power Lock Systems

Although systems for automatically locking doors vary from one vehicle to another, the overall purpose is the same—to lock all outside doors at the same time. As a safety precaution against being locked in a car due to an electrical failure, power locks can be manually operated. When either the driver's or passenger's control switch is activated (either locked or unlocked), power from the fuse panel is applied through the switch to a reversible motor. A rod that is part of the lock assembly moves up or down to lock or unlock the door. On some models the signal from the switch is applied to a relay that, when energized, applies an activating voltage to the door lock actuator. The door lock actuator consists of a motor and a built-in circuit breaker. Since the motors are reversible, each does not have its own ground. The ground for the lock circuits is remotely at the master or door circuits **(Figure 23–35)**.

Today, most power door lock systems place the motor in the door latch assembly and are controlled by the BCM. This allows door lock/unlock functions from a remote control and allows for integration with

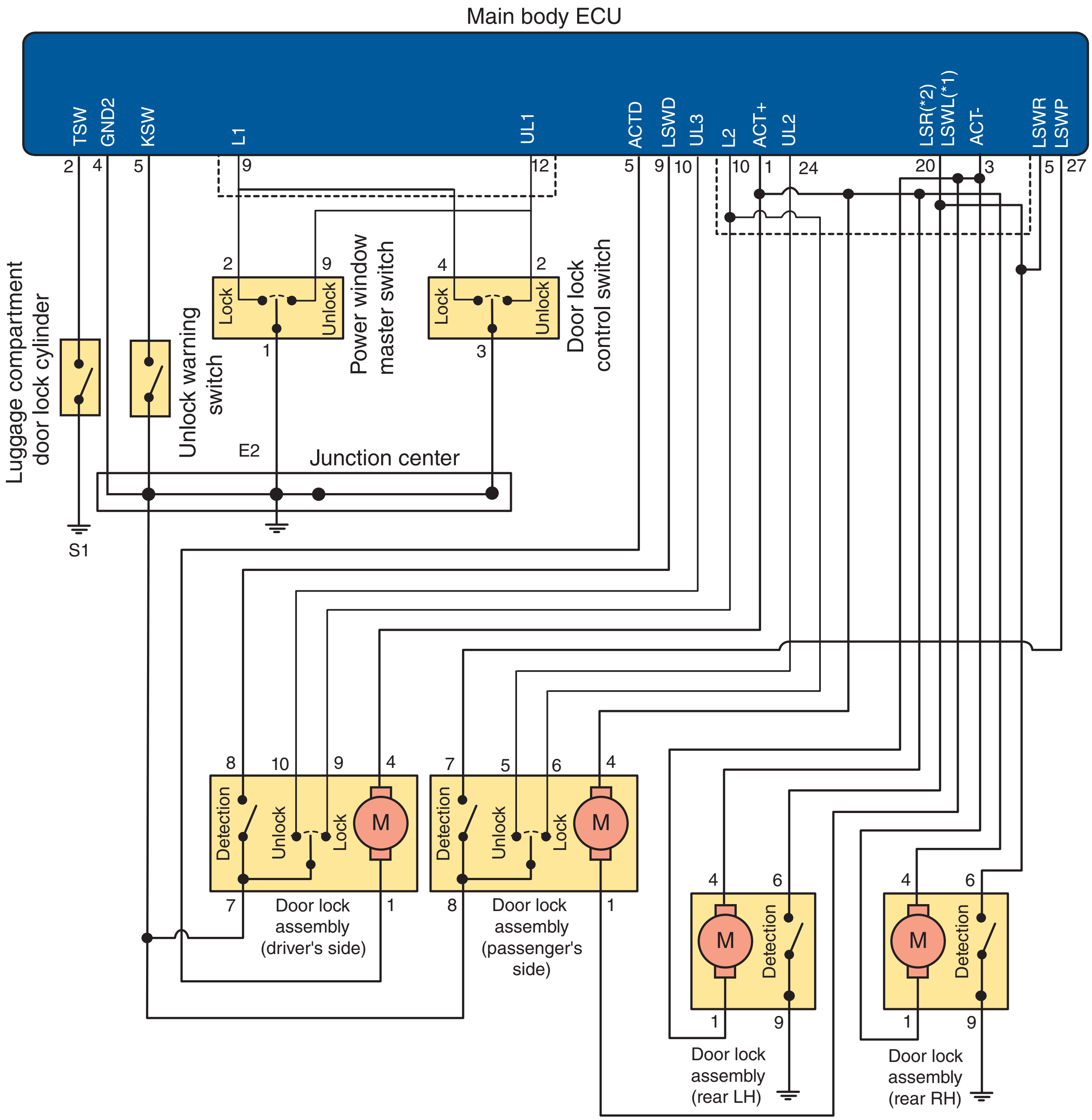


FIGURE 23–35 A wiring diagram for a power door lock system.

FIGURE 23-36 A central doorlock switch.

the vehicle's security system. These systems depend on many different components, including a remote control door lock receiver, door modules, individual door switches and relays, individual door latch assemblies, and LAN and/or LIN serial data.

Most models have a central control switch mounted in the door arm rest, instrument panel, or door trim panel **(Figure 23–36)**. This feature allows for internal and external door lock control. However, some models use switches controlled by the front door push button locks.

Automatic Door Locks Some vehicles have an Autolock or automatic door lock system. This provides for the automatic locking of all doors when the doors are closed, ignition turned ON, the transmission is shifted out of PARK, and the vehicle is moving more than 4 mph (7 km/h). Depending on the vehicle, configuration of when or if automatic door locks activate may be changed using a scan tool to suit customer preferences.

Child Safety Locks

To prevent accidental door opening by a child in the rear seats, nearly all vehicles have a child safety lock. When this lock is set, the rear doors cannot be opened from the inside. These doors can only be opened from the outside. The lock switch for this feature is normally located on the rear edge of the rear doors and must be set separately for each door.

Power Trunk Release

The power trunk release system is a relatively simple electrical circuit that consists of a switch and a solenoid. When the trunk release switch is pressed, voltage is applied through the switch to the solenoid. With battery voltage on one side and ground on the other, the trunk release solenoid energizes and the trunk latch releases to open the trunk lid.

Diagnosis

Power door lock or trunk release systems rarely give trouble. However, if all of the door locks are inoperative, begin by checking the circuit fuse. If the fuse is okay, look at the wiring diagram to determine the next best location for testing. If the system uses a remote key, test the door lock operation using the remote and the interior door controls. Vehicles with remote locks use a keyless entry module. The system may be tested with a scan tool. If so, locate the door lock circuit, test the switch and lock motor operation while monitoring the scan tool data. Key fob operation can often be checked using a TPMS tool.

A malfunctioning door latch can cause a door lock to not operate. Over time, the latches wear and may not lock or unlock during normal operation. Do not attempt to repair a latch; if faulty, the latch should be replaced. As door pins and hinges age, the door tends to drop causing the latch and striker to misalign. This often forces people to slam the door shut, which increases the likelihood of damage to the latch assembly.

Another common problem with door lock systems is that the plastic locking clips that hold the lock rods to the latch and handle will break, allowing the lock rod to fall off of the latch or handle. This is often evident by a door that will not open from one handle but works fine from the other handle. To check this, remove the door panel and inspect the lock rods and clips.

Power Windows

Obviously, the purpose of any power window system is to raise and lower the windows. The systems do not vary significantly from one model to another. The major components of a typical system are the master control switch, individual window control switches and control modules, and the window drive motors.

The master control switch provides overall system control. Power for the system comes directly from the fuse panel. Depending on the vehicle, there may be one fuse or circuit breaker for the system or a fuse for each door. Power for the individual window control switches comes through the master control switch **(Figure 23–37)**. When the master switch allows, the other windows can be controlled by the switches located on the associated doors.

Window Lockout Systems

A lock switch included on four-door master control switches is a safety device to prevent children from opening windows at the individual window switches

FIGURE 23–37 The master window switch located in the driver's door.

without the driver's knowledge. When the lockout switch is pressed, it briefly closes and sends a signal to the BCM via LAN serial data. The modules that are part of the network will prevent the passenger windows from being operated by their locally mounted switches. When the lockout function has been activated, the passenger door windows can still be operated from the driver door by using the central control switch.

Circuit Operation

Typically a permanent magnet motor operates each power window. Each motor raises or lowers the glass when voltage is applied to it. The direction the motor moves the glass is determined by the polarity of the supply voltage to the motor **(Figure 23–38)**. Today, most driver and front passenger doors have a motor with its own module. Each of the modules is controlled by the BCM. That signal can cause the window to move up or down and convey the action across the serial data network line to control the rear windows.

Voltage is applied to a window motor when the UP switch in the master switch assembly is activated. The motor is grounded through the DOWN contact. Battery voltage is applied to the motor in the opposite direction when any DOWN switch in the master switch assembly is activated. The motor is then grounded through the master switch's UP contact.

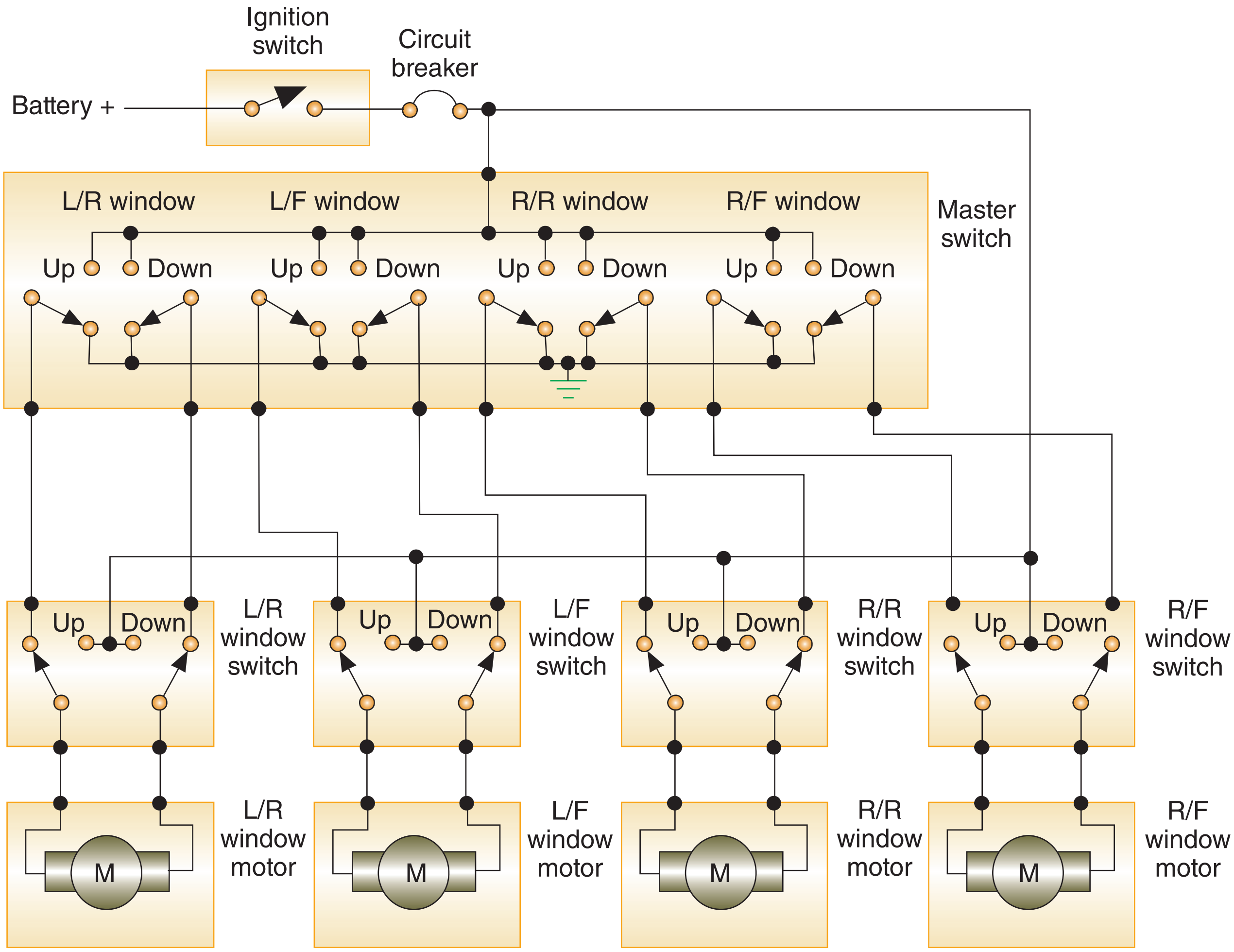


FIGURE 23–38 A typical power window circuit.

The operation of the individual window switches is much the same. When the UP switch is activated, voltage is applied to the window's motor. The motor is grounded through the DOWN contact at the switch and the DOWN contact at the master switch. When the DOWN switch in the window switch is activated, voltage is applied to the motor in the opposite direction. The motor is grounded through the UP contact at the window switch and the UP contact in the master switch. This runs the motor in the opposite direction.

Each motor is protected by an internal circuit breaker. If the window switch is held too long with the window obstructed or after the window is fully up or down, the circuit breaker opens the circuit.

Express Windows Some vehicles are equipped with an "express up/down" window feature. This feature allows the windows to be fully opened or closed by momentarily pressing the window switch for more than 0.3 second then releasing it. The window may be stopped at any time by depressing the switch. The express window option relies on an electronic module and a relay. When signaled, a control module energizes a relay, which completes the circuit to the motor. When the window is fully down, the module opens the relay, which stops the motor. The motor will also stop 10 to 30 seconds after the DOWN switch is depressed.

The express window circuit is part of the BCM and can be temporarily disabled if the battery is disconnected, if a fuse blows, or if parts are replaced. If this is the case, the system needs to be reinitialized. Follow the manufacturer's procedure for doing this.

Obstacle-Sensing Windows This feature prevents the window from closing if the system detects something, such as fingers, that are between the window glass and window frame. This detection causes the window to reverse its direction. These systems typically rely on infrared sensors. When the light beams are broken by an obstacle, the window will reverse and go down.

Diagnosis

The first step in diagnosing a power window system is to determine whether the whole system or just one or two windows are not working correctly. If it is the whole system, the problem can be isolated to fuses, circuit breakers, or the master control switch. If only a portion of the system does not work, check the components used in the portion that is not working. Removing the door trim allows access to the motor and linkage. Photo Sequence 20 shows a typical procedure for replacing a power window regulator.

To carefully remove the door panels, a special tool is needed, these will reduce the chance of damaging the panel and its retaining clips or rivets. Once the panel is removed, there is access to the mechanisms for the power door locks, windows and mirrors, as well as the speaker in the door.

Guidelines Basic logic will help identify probable causes for window problems.

- When all windows do not operate, check the fuse and the wiring to the master switch, including the ground.
- When one window does not operate, check the wiring to the individual switch, the switch, and the motor. Also check the window for binding in its tracks.
- Many systems can be tested using a scan tool to check switch inputs and command the window motors **(Figure 23–39)**.

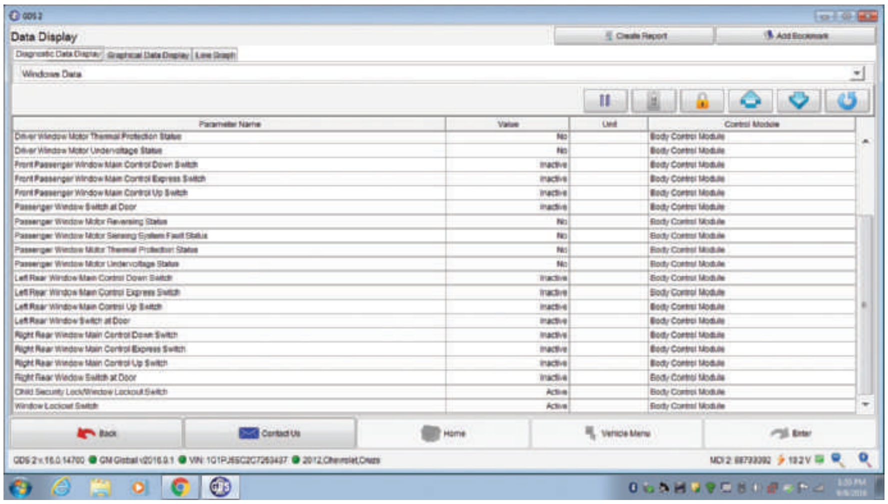


FIGURE 23–39 Using a scan tool to check power window switch operation.

PHOTO SEQUENCE 20

Typical Procedure for Replacing a Power Window Motor

P20-1 Begin by examining the door panel for screws and other fasteners that need to be removed. Once visible screws are removed, carefully move the door latch assembly to gain access to the actuator rod.

P20-2 To separate the latch rod, carefully pull the retaining clip away from the rod. Once unhooked, pull the rod from the clip and latch.

P20-3 Using a door panel clip tool, carefully separate the panel from the door frame by prying on the panel at each plastic clip. Disconnect any wiring for speakers, lights, and other components and remove the panel.

P20-4 Once the panel is removed, carefully peel the vapor barrier from the door to gain access to the motor and regulator.

P20-5 Remove the bolts holding the window to the regulator.

P20-6 Carefully remove the glass from the door and place it in a safe location.

P20-7 Locate and remove the bolts holding the window regulator in place. Remove the regulator through the opening in the door frame.

P20-8 Install the new regulator and reinstall the window glass.

P20-9 After testing the new regulator for proper operation, reinstall the door panel and install all fasteners.

- When both rear windows cannot be operated by their individual switches, check the lockout and master switch.
- When one window moves in one direction only, check the wiring between the master switch and the individual switch.
- A common source of power window and door lock concerns is broken wiring in the harness going through the driver's door jamb. Because the driver's door is opened and closed thousands of times, the movement of the door stresses and breaks the wires. When checking power window and door lock concerns, try gently pulling on the wiring in the door jamb while operating the circuits.

Power Seats

Power seats allow the driver or passenger to adjust the seat to the most comfortable position. The major components of the system are the seat control and the motors.

Power seats generally come in these configurations: four-way, six-way, and nine-way. However, some vehicles allow the seats to be adjusted in up to twelve directions. In a four-way system, the whole seat moves up or down, or forward and rearward. A six-way system **(Figure 23–40)** has the same adjustments, plus the capability to adjust the height of the front and rear of the seat. Generally, a four-way system is used on bench seats and a six-way system is used on split-bench and bucket seats. Some units also control the tilt, rear/forward movement, height, and angle of the seat back. The adjuster for the seat back may also control the height of the head rest or restraint.

Two motors are typically used on four-way systems, while three are used on a six-way system. Many newer systems rely on a horizontal motor, front vertical motor, rear vertical motor, and recline motor. The names of the motors identify their function. To raise or lower the entire seat on a six-way system, both the front height and the rear height motors are operated together. The motors are

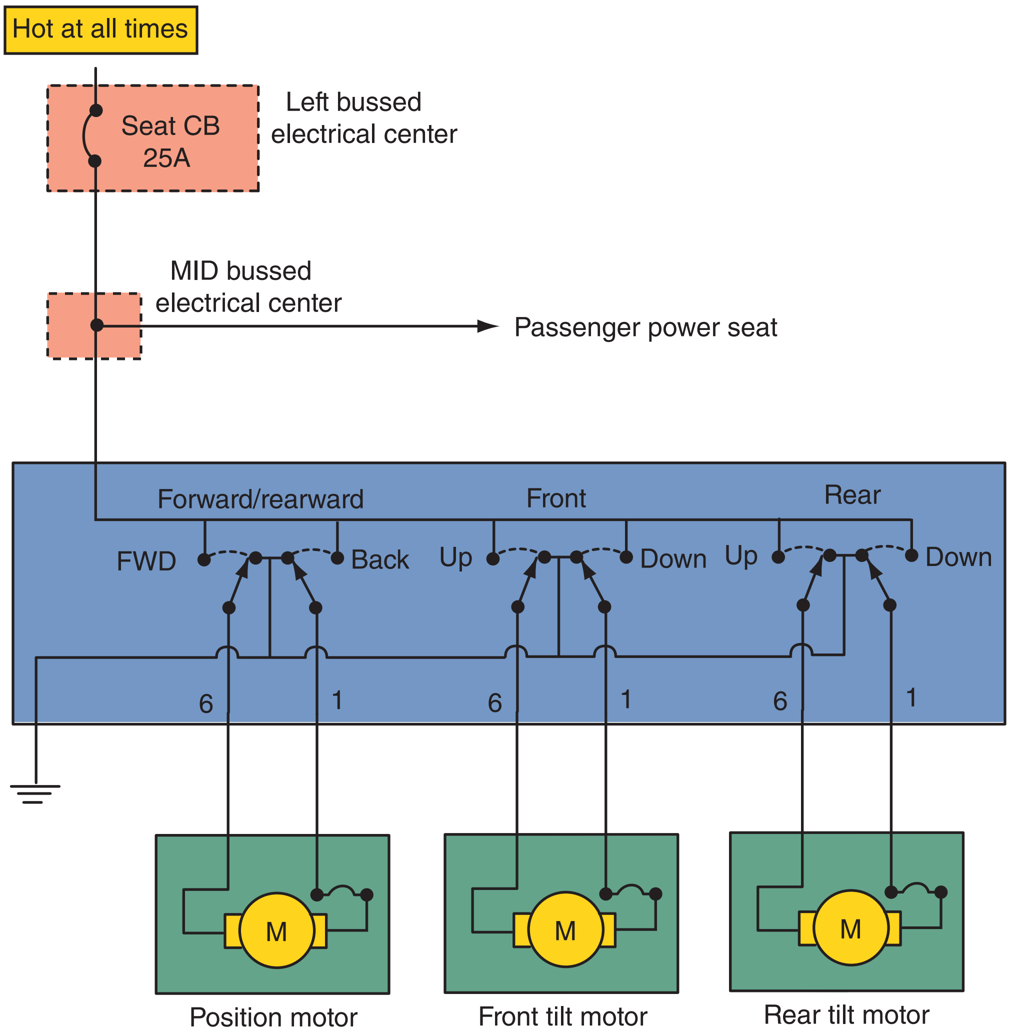


FIGURE 23–40 A power seat circuit.

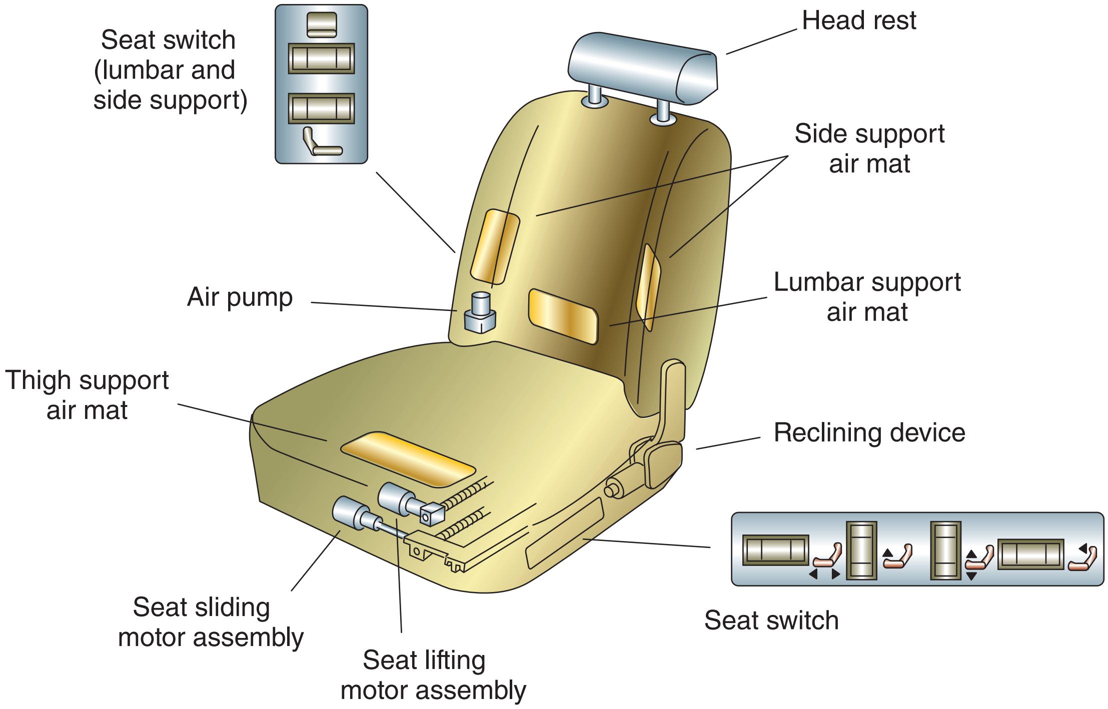


FIGURE 23–41 Seat adjustments can improve driver and passenger comfort.

generally two-directional motor assemblies that include a circuit breaker to protect against circuit overload if the control switch is held in the actuate position for long periods **(Figure 23–41)**.

Climate Control Seats

Many vehicles have an option that warms up the seats, an especially nice feature in cold climates. The system relies on heating coils in the seat cushion and back controlled by relays and switches **(Figure 23–42)**. Some systems offer a heat function at the front seats and others also offer heated seats in the rear of the vehicle. Each seat is controlled by a separate switch. Many of these circuits are controlled by the BCM that receives inputs from various temperature sensors. The heated seat system is designed to warm the seat cushion and seat back to approximately 107.6 °F (42 °C) when in the high position, 103 °F (39.5 °C) when in the medium position, and 98.6 °F (37 °C) when in the low position.

FIGURE 23–42 This heated seat became very hot because of a shorted heating coil.

In addition to warming the seats in cold weather, some vehicles allow the seats to cool by passing cooled air through them during warm weather **(Figure 23–43)**. In most vehicles, the air is cooled by a **Peltier element** and a fan in the seat cushion pad and seatback. The air moves to the surface of the seat by passing through grooves in the surface of the seat pads. Typically the fan is operated by a climate control seat switch located on the seat. This switch can have seven modes: three cooled air modes, three heater modes and one ventilation mode.

Peltier devices can be used for heating or for cooling, although they are most commonly used for cooling. When operated as a cooler, voltage is applied across the device, which creates a difference in temperature between the two sides of the device. The difference in heat creates a cool output at the seats when ambient temperatures are high. Normally, the maximum temperature difference between the hot side and cold side of the device is about 160 °F (70 °C).

Courtesy of the BMW of North America, Inc.

FIGURE 23–43 This seat features ventilation, heating, and multiple position adjustments, including the headrest and lumbar support; the small round things are fans.

FIGURE 23–44 Air vents at the top of the seats to add comfort for the driver and passengers.

Other systems offer air vents positioned at the top of the seats to provide warm or cool air **(Figure 23–44)**. These are especially nice when a driver of a convertible is out with the top down when the weather is either cool or hot.

Other Seat Options

Many different options are available for the seats of a vehicle. Some of the following features are available on vehicles with manual seats; others are only available with the power seat option.

Power Lumbar Supports A power lumbar support allows the driver to inflate or deflate a bladder located in the lower seat back. Adjusting this support improves the driver's comfort and gives support at the lower lumbar region of the spinal column.

Memory Seats The memory seat option allows for automatic positioning of the driver's seat to different, often up to three, programmable positions **(Figure 23–45)**. This feature allows different drivers to have their desired seating position automatically adjusted by the system. It also allows an individual driver to set different positions for different driving situations.

Some systems with a remote key fob can be programmed to move the seat to its memory position whenever the unlock button of the key fob is depressed. Each driver can have his or her own key fob and their desired seat position will be selected when the door is unlocked. Also, other systems automatically adjust the power mirrors to a setting for each driver.

Adaptive and Active Seating Adaptive seating, a feature that moves the seat slightly as the driver shifts positions, is offered in some luxury vehicles. Moving the seat improves the driver's comfort and support while driving for a long time. Active seating stimulates the spine and surrounding muscles with continuous yet virtually imperceptible motion. This type of seating is designed to prevent the driver from getting saddle sore while sitting without moving for a long time. The right and left halves of the seat cushion move up and down at cyclical intervals. To do this, two pillows are integrated within the seat's upholstery. A hydraulic pump alternately inflates the two cavities with a mixture of water and glysantine.

FIGURE 23–45 Seat adjustment controls, memory, and heat controls.

Massaging Seats To help reduce driver fatigue, groups of air bags or bladders fill with air and then release the air. In many cases this sensation moves up and down the seat back when activated. The air bags alternately inflate and deflate to create a "kneading" sensation on the backs of the driver and occupants. A seat massaging or vibration system normally uses an air pump (located in the seat back or trunk), solenoid valves to control the air flow in and out of the air bags, and a control switch. Depending on the system, the control may adjust the intensity, speed, and placement of the air bags' activity.

The actual system and its operation varies widely. The number of air bags and their placement in the seat back greatly differs with each design. Simpler systems have a simple on/off switch, while others offer as many as twenty-five different control settings. In the very controllable systems, there may be up to ten bladders placed strategically in the seat back. Some simpler systems have five rows of two bladders and the placement of those bladders work the shoulders and back of the occupant, however there is only one control setting.

Diagnosis

Before testing a power seat system, determine if the seats are BCM controlled or directly controlled. If the seats are controlled by the BCM, use a scan tool to check the system. In both cases, do a visual inspection of the wires and connectors in the system. Two types of problems affect power seats: One is a tripped or constantly tripping circuit breaker and the other is the inability of the seat to move in a direction.

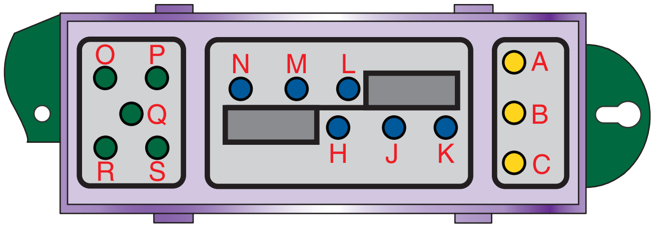
The resettable circuit breaker should protect the system from a short circuit or from high current due to an obstructed or stuck seat adjuster. The circuit breaker must be replaced if it is faulty. Before testing the circuit breaker, make sure the seat tracks are not damaged and that nothing is physically preventing the seat from moving.

When a seat does not move in a particular direction, turn on the dome light, then move the power seat switch in the problem direction. If the dome light dims, the seat may be binding or have some physical resistance on it. Check under the seat for binding or obstructions. If the dome light does not dim, test the system.

Disconnect the negative terminal at the battery. Remove the power seat switch from the seat or door armrest. Check for battery voltage to the switch. If there is no voltage and the circuit breaker is okay, check for an open in the power feed circuit. If voltage is present, check for continuity between the ground connection at the switch and a good ground. If there is no continuity, repair the ground circuit. If there is continuity, the switch must be tested. Use an ohmmeter to test the continuity of the switch in each position. Check the service information for the expected continuity between the various terminals of the switch **(Figure 23–46)**. If the switch checks out, test the motor. If the switch is bad, replace it.

Test each motor by connecting it to a power source and a good ground. If, while doing this, the motor stops running, immediately disconnect the power source. If the front up-down motor, rear up-down motor, or slide motor does not run or does not run smoothly, replace the motor.

If the massaging seats do not work properly, the controls, air hoses, electrical wiring, sensors, and pump should be checked.



Terminals shown as viewed from rear of switch

Power seat switch position	Continuity between
Off	→ B-N, B-J, B-M, B-E, B-L, B-K
Vertical	
up	→ A-E, A-M, B-N, B-J
down	→ A-J, A-N, B-M, B-E
Horizontal	
forward	→ A-L, B-K
aft	→ A-K, B-L
Front tilt	
up	→ A-M, B-N
down	→ A-N, B-M
Rear tilt	
up	→ A-E, B-J
down	→ A-J, B-E
Lumbar	
off	→ O-P, P-R
up (inflate)	→ O-P, Q-R
down (deflate)	→ O-R, P-Q

FIGURE 23–46 The terminals of a power seat switch identified for continuity checks.

SHOP TALK The slide motor is normally not available as a separate unit because it is assembled into the seat track.

Power Mirror System

The power mirror system consists of a joystick-type control switch and a dual motor drive assembly located in each mirror assembly. The driver's door switch assembly has two switches assembled as a single unit. One switch selects which side mirror, left or right, is to be adjusted. The other switch adjusts that mirror.

Rotating the power mirror switch to the left or right position selects one of the mirrors for adjustment. Moving the joystick control up and down or right and left moves the mirror to the desired position. The dual motor drive assembly is located behind the mirror glass. The position of the mirrors may be tied to the memory power seats and will automatically adjust when a seating position is selected.

A typical power mirror circuit **(Figure 23–47)** is an independent circuit unless it is tied to the convenience memory system. In that case, the BCM controls the mirrors along with the seats. The BCM in a few vehicles automatically tilts the passenger-side outside mirror downward whenever the transmission is placed into reverse. This allows the driver to see the area directly next to the vehicle.

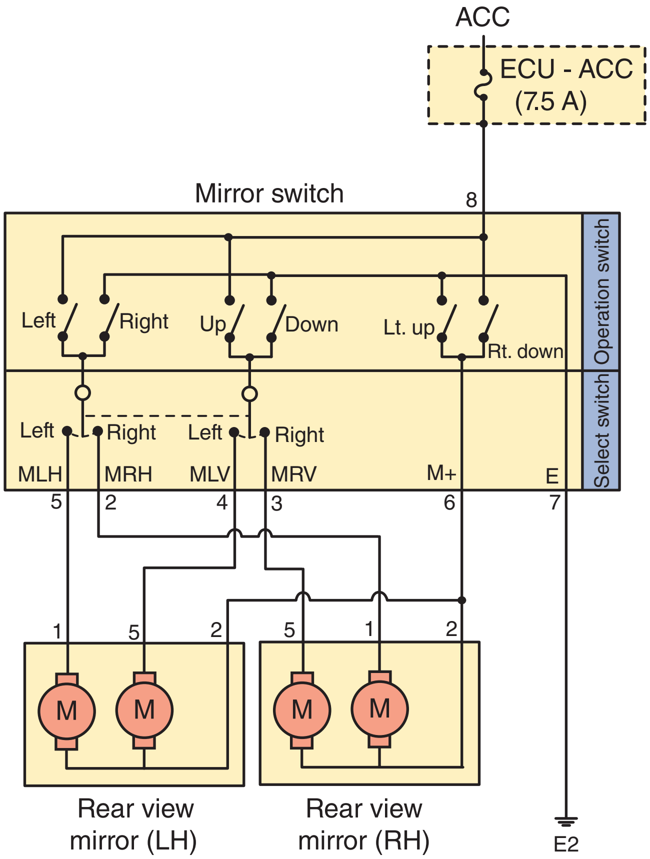


FIGURE 23–47 A wiring diagram for a power mirror circuit.

On some cars the right side exterior mirror will tip inward/downward when the vehicle is placed into reverse. This allows the driver to have a view of the immediate area around the right rear. Once the car is placed into drive, the mirror moves to its normal position.

Electrochromic Mirrors Many new vehicles are being equipped with electrochromic outside mirrors. These mirrors automatically adjust the amount of reflection based on the intensity of the light striking the mirror's surface. These mirrors use photo sensors to sense the light. When glare is heavy, the mirror darkens fully (down to 6 percent reflectivity). When glare is mild, the mirror provides 20 percent to 30 percent reflectivity. When glare subsides, the mirror changes to its clear daytime state.

Inside Mirrors

Some automatic day/night inside rearview mirrors use a thin layer of electrochromic material between two pieces of conductive glass. A switch located on the mirror allows the driver to turn the feature on or off. When it is turned on, the mirror switch is lighted by an LED. The self-dimming feature is disabled whenever the transmission is placed into reverse.

When the mirror is turned on, two photocell sensors monitor external light levels and adjust the reflection of the mirror **(Figure 23–48)**. The ambient photocell sensor detects the light levels outside and in front of the vehicle. The headlamp photocell faces rearward to detect the level of light coming in from the rear of the vehicle. When there is a difference in light levels between the two photocells, the mirror begins to darken.

On some vehicles the electrochromic feature of the driver's outside rearview mirror is controlled by the inside rearview mirror. The inside mirror supplies a signal to the outside mirror and causes it to darken along with the inside mirror.

The automatic day/night mirror cannot be repaired. If it is faulty, it must be replaced.

Some rearview mirrors are fitted with a directional compass display. The readings on the compass appear on the mirror's reflective surface, normally in the lower left corner. The mirror may also contain a small backup camera display, a curb view from a camera in the passenger outside mirror, or even project the rear view as seen by the backup camera instead of the reflected view of the mirror itself.

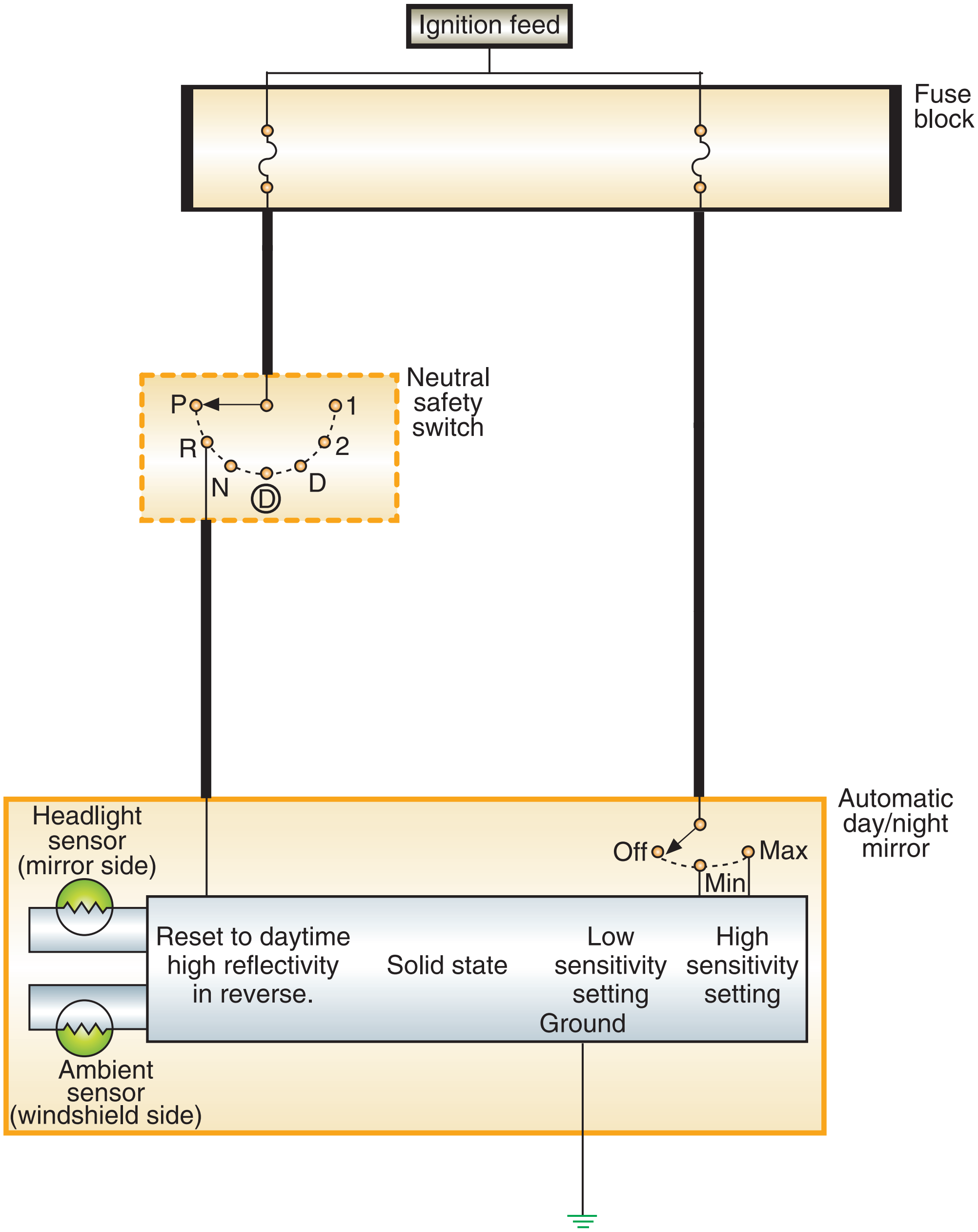


FIGURE 23–48 An automatic day/night mirror.

Power Folding Mirrors

Some vehicles, especially large pickup trucks, have power folding mirrors. This feature allows the driver to retract the outside mirrors to a fully folded position, where they fold in toward the door's windows. The mirrors can also be extended to the fully unfolded position for normal use. The operation of the folding mirrors is accomplished by a switch and an additional power folding mirror motor.

This feature is now on many newer cars and SUVs. When the vehicle is parked, the outside mirrors rotate in towards the doors. This is to reduce the chance of someone walking into and damaging the mirror.

Rear-Window Defrosters and Heated Mirror Systems

The rear-window defroster (also called a defogger or deicer) heats the rear-window surface to remove moisture and ice from the window. On some vehicles, the same control heats the outside mirrors. The major components of a rear-window defroster include a switch, relay assembly, and the heating elements on the glass surface **(Figure 23–49)**.

FIGURE 23–49 A typical rear window defogger grid.

Pressing the rear-window defroster switch momentarily energizes the relay. Battery voltage is then applied through closed contacts of the relay to the rear-window defroster grid. On models with a heated mirror, current also flows through a separate fuse to the mirror's heated grid.

After about 10 minutes, a time-delay circuit opens the ground path to the relay's coil and the coil de-energizes, shutting off power to the grids. The time-delay circuit prevents the system from remaining on during periods of extended driving. The system can also be manually turned off.

Diagnosis

One of the most common problems with rear-window defrosters is damage to the grids on the window. Damage can be caused by hard objects rubbing across the inside surface of the glass or by using harsh chemicals to clean the window. When a segment of the grid breaks, it opens the circuit. Often the customer's complaint is that the unit does not defrost the entire window. Normally one or two lines of the grid are open. The open can be found by using a testlight. With the defroster turned on, voltage should be present at all points of the grid. If part of the grid does not have voltage, move the probe toward the positive side of the grid. Once voltage is present, you know the open is between those two points. Opens can be repaired by painting a special compound over the open. The correct procedure for doing this is shown in Photo Sequence 21.

If none of the grids heat up, check for voltage at the connection to the grids, and then check the ground circuit. If no voltage is present at the grids, examine a wiring diagram to determine where to check the circuit. If the switch and relay work correctly, there is likely an open in wiring to the grid.

Other Electronic Equipment

Vehicles are being equipped with many electrical and electronic features. Examples of some of the more common newer accessories are discussed here.

Adjustable Pedals

Shorter drivers normally must move their seat very close, sometimes uncomfortably and unsafely close, to the steering wheel. By moving the pedals toward the driver, drivers may be able to adjust their seat position away from the steering wheel and still comfortably reach and use the pedals. An electric motor at the brake pedal **(Figure 23–50)**, with a cable connection to the accelerator pedal, moves both pedals back and forth (up to 3 inches). A switch on the dash controls the motor. This feature may also be part of the seat memory system so the driver can quickly bring both the seat and pedals to the most comfortable position.

Heated Windshields

Heated, or self-defrosting, front windshield systems work like rear-window defrosters, heating the glass directly. However, instead of using a wire grid that could hinder the driver's vision, a microthin metallic

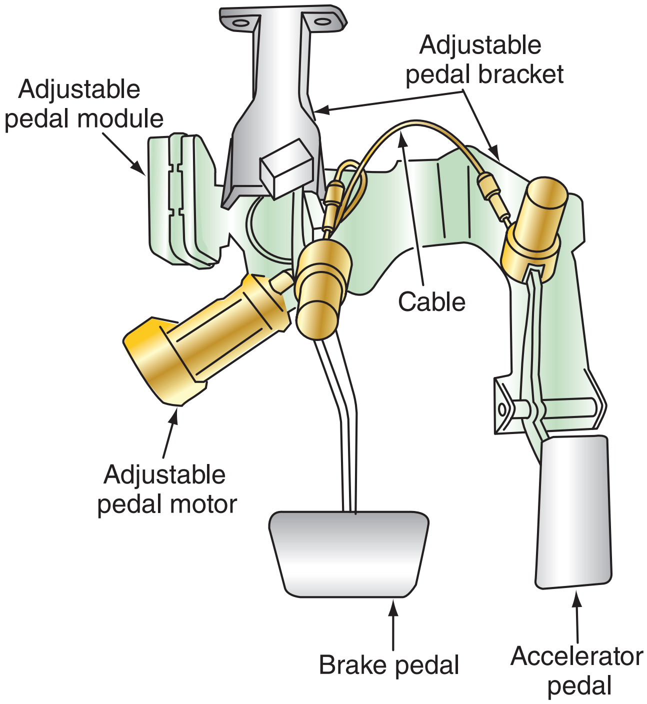


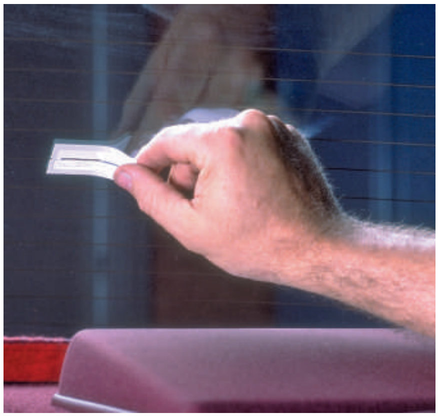
FIGURE 23–50 An electrically controlled pedal assembly.

PHOTO SEQUENCE 21

Typical Procedure for Grid Wire Repair

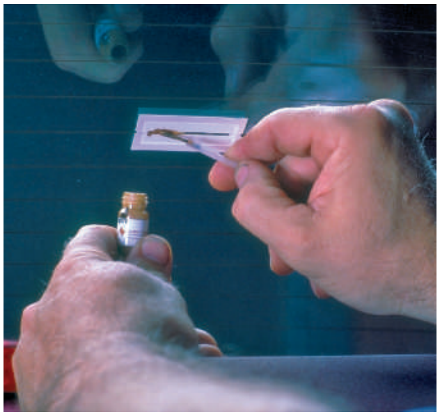
P21-1 The tools required to perform this task include masking tape, repair kit, 500°F heat gun, testlight, steel wool, alcohol, and a clean cloth.

P21-2 Clean the grid line area to be repaired. Buff with fine steel wool. Wipe clean with a cloth dampened with alcohol. Clean an area about ¼ inch (6 mm) on each side of the break.



P21-3 Position a piece of tape above and below the grid. The tape is used to control the width of the repair, so try to match the width with the original grid.

P21-4 Mix the hardener and silver plastic thoroughly. If the hardener has crystallized, immerse the packet in hot water.

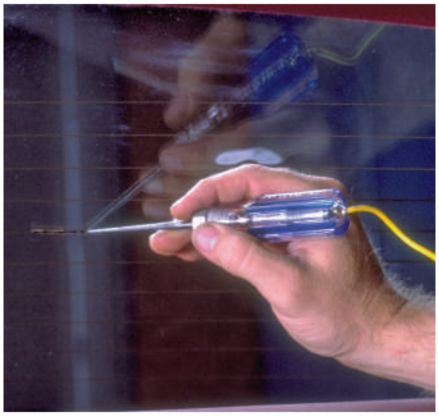


P21-5 Apply the grid repair material to the repair area using a small stick.

P21-6 Carefully remove the tape.

P21-7 Apply heat to the repair area for 2 minutes. Hold the heat gun 1 inch (25 mm) away from the repair.

P21-8 Inspect the repair. If it is discolored, apply a coat of tincture of iodine to the repair. Allow to dry for 30 seconds, then wipe off the excess with a cloth.



P21-9 Test the repair with a testlight. Note: It takes 24 hours for the repair to fully cure.

coating inside the windshield is used. This coating or laminate is sandwiched between layers of glass. Bus bars are connected to the inner laminate or coating to provide power and ground circuits.

Some systems use a silver and zinc laminate while others have a resistive coating located between the layers of glass. When a laminate is used, there is a sensor that can detect windshield damage and if there is damage, current stops. Windshield with a resistive coating will continue to work even if there is windshield damage.

Some systems require the use of a special AC generator. These generators are capable of providing the windshield with high AC voltage while also supplying a normal DC voltage for the other systems. Other systems, full-field a conventional AC generator to supply high AC voltage for the windshield. All systems run only long enough to clear the windshield.

When the windshield is turned on, the generator's output is increased and redirected to the windshield circuit. When the voltage regulator senses a drop in battery voltage, the system is turned off and the generator's output is directed to the battery. Check the service information for specific system details.

Power Roof Systems

A power roof (moonroof, sunroof, panoramic roof) can slide the roof panel open or closed. It can also tilt the panel up in the back to allow fresh air and natural light into the passenger compartment. The major components of any power roof panel system are a relay, control switch, sliding roof panel, and motor. This circuit is normally protected by the inline circuit breaker. The reversible motor powers a drive gear that pushes or pulls the roof panel.

When the two-position switch is moved to the open position, the roof panel moves into a storage area between the headliner and the roof. The panel stops moving any time the switch is released. Moving the switch to the closed position reverses the power flow through the motor.

If the system is not operating, check the fuse or circuit breaker. If these are okay, check for power at the switch with the ignition switch on. If the voltage is present, the relay is okay. Check for power to the motor with the switch held in the open position. Refer to the service information for additional diagnosis and testing information.

Retractable Hardtops

A few newer convertible models have retractable hardtops. The hard roof lowers and conceals itself in the vehicle's trunk. This system turns a regular coupe

Courtesy of the BMW of North America, Inc.

FIGURE 23–51 A retractable hardtop.

into a convertible. Most systems use electrohydraulic cylinders to move the hardtop **(Figure 23–51)**. In most cases, it takes about 30 seconds to stow or close the roof. Some of these hardtops have a power sliding glass sunroof. Diagnosis of these systems is conducted through the BCM.

Forward and Reverse Sensing Systems

Some vehicles are equipped with forward and/or a reverse sensing system that warns the driver when obstacles are within a designated range of the front and rear bumpers **(Figure 23–52)**. These systems have ultrasonic sensors located in the front and rear

FIGURE 23–52 Radar sensor and a rear view camera located at the rear of this car.

bumpers to detect any obstacles at the front and rear of the vehicle. The rear sensors are only active when the vehicle is in reverse. The reverse sensor detects obstacles up to 6 ft (2 m) from the rear bumper.

The front sensors are active when the vehicle is in any gear but Park or Neutral and its speed is below 6 mph (10 km/h). The front sensors can detect objects within an area of about 28 inches (70 cm) from the front of the vehicle and about 10 inches (25 cm) to the front side of the vehicle.

If the sensors detect something, the distance between the vehicle and the obstacle is broadcast through the vehicle's speakers by a series of chimes. As the vehicle moves closer, the tone's rate increases. If the system detects an object more than 10 inches (25 cm) from the side of the vehicle, the tone will be emitted for only 3 seconds. When the obstacle is less than 10 inches (25 cm) away, the tone is continuous. Once the system detects an object approaching, the tone will sound again. While emitting the warning, radio volume is reduced to a predetermined level. Once the warning is turned off, the radio will return to its previous volume.

Rear View Cameras

To assist the driver in safely backing the vehicle, some vehicles have a "television" camera that sends signals that display the behind-the-vehicle view on the instrument panel, rearview mirror, or the navigation screen. To meet NHTSA (National Highway Traffic Safety Administration) regulations, all 2017 and newer passenger cars, light trucks, and vans are required to have backup cameras. The display allows the driver to see what is behind the vehicle when moving in reverse. Normally these systems are comprised of a:

- Display and navigation module—this unit receives video signals that display an image of the area behind the vehicle.
- Camera assembly—a color video camera, with a wide-angle lens, mounted on the rear of the vehicle that transmits images of the area behind the vehicle to the display and navigation module display.
- Park/neutral position switch—that sends a signal to the ECU to display the views from the camera when reverse gear is selected, plus it triggers other views from the rear of the vehicle.

In most cases, the display shows a variety of paths, based on color and the current conditions **(Figure 23–53)**. These paths depend on what the system perceives is the driver's intended path. Two primary paths are displayed on the screen: active and fixed. These two displays will fade in and out on the display depending on the position of the steering wheel. Active guidelines show the intended path of the vehicle, based on the system's inputs. Fixed guidelines show the actual direction while the vehicle is moving.

The visual alerts are red, yellow, or green highlights which appear on top of the video image when an object is detected by the reverse sensing system. Basically, all objects that are the closest to the vehicle are shown in the red zone. Objects that are farther away are shown in the green zone. The yellow areas merely show the transition from the green to the red zone. The centerline shows where the vehicle is headed based on the position of the steering wheel.

Night Time and Dark Areas At night time or in dark areas, the camera system relies on the reverse lamp to provide the necessary light to produce an image.

FIGURE 23–53 The blue area shows what is directly behind the vehicle and the orange lines show where the vehicle is headed according to the steering wheel.

> **SHOP TALK**
> If either of the reverse lamps are not working properly, replace the lamps before allowing the customer to depend on the rearview cameras.

So, both reverse lamps must operate correctly to provide a clear image in the dark on the display.

Parking Assist

Using forward and rear sensing monitors and rear-view cameras, it allows drivers to park their vehicles easier. The parking assist control unit calculates the vehicle's location in regards to other vehicles and obstacles. The control unit receives signals from the front and rear sensing monitors, the ECM, steering angle sensor, power steering control unit, and ABS control unit. Tones from the monitoring system become more rapid as the vehicle nears an obstacle.

Normally the view from the camera is displayed on the navigation screen or an information display in the instrument panel or center stack. This view is displayed along with reference lines that mark off the area directly behind the vehicle and an additional area showing where the vehicle is headed.

Blind Spot Detection

Many vehicles now offer an option that allows drivers to view what is on the right and/or left side of their vehicle as they drive along the road **(Figure 23–54)**. Blind spot information system (BLIS) allows for safe lane changing. From personal experience, this feature has given me safe and confident lane changing, especially since my car has huge blind spots. Basically, a blind spot is an area that cannot be clearly seen while operating the vehicle. A blind spot can be at the front, sides, and rear of a vehicle.

FIGURE 23–54 The blind spot indicator will light up when the camera detects a vehicle entering the blind spot.

Radar sensors observe the rear blind spots on both sides of the vehicle and notify the driver of any oncoming or stationary vehicles on either side of the vehicle. When the vehicle enters the blind spot and there is a vehicle in one or both of them, a yellow light on the corresponding outside mirror lights up. In most cases, if the driver puts on the turn signal for a lane change, the yellow light starts flashing quickly to warn that a vehicle is in that lane.

Lane-Departure Warning Systems/ Lane-Keeping Support

Lane-departure warning systems are designed to warn a driver when the vehicle begins to move out of its lane, unless a turn signal is on in that direction, when traveling on open roads.

There are two basic lane-departure systems: those that emit a warning sound or vibration at the steering wheel or vibrate the driver's seat when the vehicle is leaving its lane and a system warns the driver and is capable of assuming control of the vehicle (lane-keeping support) if the driver does not respond to the warnings.

These systems rely on inputs from a number of sensors and a camera that identifies the lane markings as the vehicle moves forward. The camera monitors the lane markings and sends data to the system's control unit. Based on all of the inputs, the control unit is able to detect when a vehicle drifts out of the lane.

Pre-Collision Systems and Pedestrian Automatic Emergency Braking

A recent accident prevention system is called the pre-collision system and is offered on many vehicles and will be offered on more in the future. The pre-collision system detects other vehicles and obstacles at the front of a vehicle. In response it controls all systems within the basic pre-collision system to prevent an accident and if one occurs, the system will do what it can to prevent injuries to the driver and passengers. Basically the system relies on a front radar sensor, an object recognition camera sensor, and a driver monitor camera, which monitors the driver's facial direction.

When the system determines there is a risk of colliding with an obstacle at the front of the vehicle, the driver will be warned of the potential. In addition, if the system determines that a crash is unavoidable, all slack in the seat belts is instantly removed. In addition the system increases the amount of hydraulic pressure that is applied by the brake pedal and will control the suspension system to minimize the amount of nose dive while the brakes are strongly applied.

Pedestrian automatic emergency braking (PAEB) systems use forward-looking cameras and radar or ultrasonic receivers to detect, alert, and stop the vehicle if someone steps out into its path. PAEB systems check directly in front of and to the left and right of the vehicle to look for people even when turning corners.

Self-Parking

A few vehicles offer an option for self-parking, at times referred to as active park assist. This feature parallel parks a vehicle, without driver control, after the space is picked out by the driver. A variety of systems are used, but most calculate the size of the parking space and let the driver know if the vehicle will fit into the space. This technology is only possible with vehicles that have electric steering. The system can detect an available parallel parking space and automatically steer the vehicle into the space while the driver controls the accelerator, gearshift, and brakes.

The system uses ultrasonic sensors on either side of the front bumper, linked to a display in the instrument panel **(Figure 23–55)**. It also relies on wheel-speed and steering-angle sensors to monitor the vehicle's movement and alert the driver of the remaining available space. Some systems rely on global positioning systems, a steering wheel sensor, and a rearview camera.

When the system is activated, it knows what side of the street the driver wants to park the vehicle by the selection of the turn signal. Once it finds a suitable parking space, the space is displayed on the information screen along with instructions. To begin the process, the driver is told to drive forward until a message says to stop. At that point the transmission is placed into reverse and the driver takes his or her hands off the steering wheel. From this point on, the steering is controlled by the system and not the driver. By applying the brakes when the driver determines the vehicle has backed up enough, the vehicle can be placed into a forward gear. This process is repeated once the vehicle has moved forward enough. The instructions will tell the driver to make backward and forward maneuvers until the vehicle is safely parked. At that point, the system is shut down by the driver turning the steering wheel. If the vehicle is not properly placed within the parking spot, the driver should correct it.

Night Vision

A few vehicles have a feature that uses military-style thermal imaging to allow drivers to see things they normally may not see until it is too late **(Figure 23–56)**. The thermal-imaging system uses a camera with a fixed lens mounted behind the front grille and projects the image onto the bottom of the driver's side of the windshield by a HUD. The lens, which is an infrared sensor, is designed to operate at room temperature; therefore, the lens has its own heating and cooling system to keep it at the desired temperature.

FIGURE 23–55 The display for the self-park system shows where the vehicle is headed.

FIGURE 23–56 Night vision uses an infrared camera to project unseen objects on the screen.

The images seen on the HUD display are from the area in front of the light beams from the car's normal high-beam headlamps. The system allows the driver to see up to five times more of the road than with just headlights.

The system works by registering small differences in temperature and displaying them in sixteen different shades of gray on the HUD screen. It has the ability to display animals, or people, behind bushes or trees and can see through rain, fog, and smoke. Cold objects appear as dark images, whereas warm objects are white or a light color.

Semi-Autonomous and Autonomous Driving Systems

The increased use of driver aids, such as lane departure correction systems and adaptive cruise control, has led to vehicles being able to nearly drive themselves. Integrating advanced driver assistance systems (ADAS) into a functioning self-driving vehicle is a goal many manufacturers are working toward. This also include companies such as Google, Uber, and others. Technologies currently in use and applicable to autonomous driving include the following:

- Electronic stability control
- Blind spot detection
- Forward and rearward collision warning
- Lane departure warning and correction
- Rearview and 360 degrees video
- Automatic emergency braking and pedestrian emergency braking
- Lane centering assist
- Adaptive cruise control
- Self-parking systems

Combining these types of systems into a package that includes highly accurate GPS tracking, high-resolution maps, current traffic conditions, and even weather information, provides a method of allowing the vehicle to be guided and driven without human intervention. The level of autonomy is rated using the following scale:

Level 0—no autonomy at all, the driver does all of the driving.

Level 1—the vehicle has some driver assistance that can be performed by the vehicle. This includes some steering, braking, or acceleration control. Cars and trucks with stability control systems, park assist, and active cruise control may fall under Level 1 vehicles.

Level 2—incorporates some active control, such as adaptive cruise control and lane keeping assist, where the driver can allow the vehicle to take over but monitors operation and is ready to resume command. Examples include Tesla's Autopilot and Cadillac's Super Cruise features.

Level 3—increases the level of control where the ADAS can perform all driving functions in some situations depending on driving or environmental conditions. The driver must be ready to take control of vehicle if required.

Level 4—these are fully autonomous vehicles that can perform all driving functions expected under certain (normal) circumstances. Under the right conditions, the driver would let the vehicle do the driving.

Level 5—offers full autonomous operation with the expectation that the vehicle can perform functions equal to a human driver under any operating condition and the people are simply along for the ride.

There are several vehicles currently for sale, Tesla's Model S and Mercedes S class cars, that can operate at or near Level 2 and 3 status. However, several hurdles remain before self-driving cars are common on the roads. These include the following:

- Federal laws—As of this writing, there are no federal laws regarding the operation of autonomous vehicles on public roads. Congress is studying the issue and may pass legislation allowing manufacturers exemption from federal safety standards for a limited number of vehicles as the technology is being developed. Many of the current laws and regulations covering the operation of regular vehicles will require revision or elimination for self-driving cars. For example, there are federal laws and regulations regarding the size of steering wheels, something a fully autonomous vehicle does not need.
- State laws—States set their own traffic laws and speed limits without input or oversight from the federal government. As of 2017, twenty-one states and Washington D.C. have passed laws regarding the use of autonomous vehicles. These laws range from an intent to simply study the situation to allowing full autonomous vehicle operation if the vehicle can comply with federal safety standards and regulations.
- Public acceptance—There are many groups for which autonomous vehicles can and will be a huge benefit, such as those who cannot drive due to disabilities. For many people, the thought of sharing the road with a driverless car is not a

happy one. Worries about accidents, liability, and hacking are just a few of the concerns regarding the issue. And many people simply enjoy driving and do not want to give it up.

- Technological issues—Even though current technology can perform many automated driving functions, turning over all control to a driverless car will require advancements in several areas. These include the following:
  - V2V (vehicle to vehicle) communication systems that allow each autonomous vehicle to know where all the other vehicles in operation are.
  - V2I (vehicle to infrastructure) communication between traffic control systems and the cars. Both V2V and V2I will likely require the next level of cellular communication (5G) for the amount of high-speed data traffic among vehicles.
  - Redundant safety and power systems in the vehicles. For a truly driverless Level 5 vehicle, one with no operator controls, there will need to be backup and fail-safe functions to prevent accidents from hardware and software faults.

It is likely that within the lifetime of this text Level 4 autonomous vehicles will begin to operate in public, at least in larger urban areas. The rate at which the technology is improving and becoming ubiquitous virtually guarantees their inclusion into mainstream operation.

Garage Door Opener System

Most late-model vehicles have a programmable garage door opener built into the area around the inside rearview mirror. This system is programmed with the garage door's transmitter code and can also be used to control electric gates, entry gates, door locks, home lighting systems, security systems, or other transmitter code-based systems.

Security and Antitheft Devices

Three basic types of antitheft devices are available: locking devices, disabling devices, and alarm systems. Many of the devices are available as standard equipment or as options from the manufacturers; others are aftermarket installed.

Locks and Keys

Locks are designed to deny entry to the car as well as to prevent a thief from driving it away. Most locks move a mechanical block between the vehicle's body and the door. Keys simply move those blocks.

Manufacturers use specially cut keys that cannot be easily duplicated and lock mechanisms that are difficult to pick. The master key can lock and unlock the doors, trunk, fuel filler door, and glove compartment all at the same time. A special key, often called a valet key, only works in the doors and ignition, thereby preventing a valet from entering the trunk and glove compartment.

Many cars are equipped with special fuel filler doors that help to prevent the theft of gas. Voltage is present at the fuel filler door release switch at all times. When the switch is closed, the door release solenoid is energized and the fuel door opens.

Older vehicles may use a resistance key, which is a normally cut key with a small resistor bonded to it. When the key is inserted into the ignition switch, the circuit must recognize that resistance is the correct amount for the vehicle before the engine will start.

Passkeys

The passkey is a specially designed key, or transponder, that is programmed just for one vehicle. Although another key may fit into the ignition switch or door lock, the engine will not start because the system is not receiving the correct signal from the key.

Transponder key systems are based on a communication scheme between the vehicle's PCM and the transponder in the key **(Figure 23–57)**. Each time the key is inserted into the ignition switch, the PCM

FIGURE 23–57 An assortment of electronic keys and key fobs.

sends out a different radio signal. If the key's transponder is not capable of returning the same signal, the engine will not start.

Smart Keys

Newer vehicles are equipped with a specially designed key, or fob. They are commonly used with push button start systems **(Figure 23–58)**. To start the engine, the system must receive the correct signal from the key. These keys also control the door and trunk locks.

Transponder key systems set up communications between the vehicle's PCM and the transponder in the key. Each time the key is inserted into the ignition switch, the PCM sends out a different radio signal. If the key's transponder is not capable of returning the same signal, the engine will not start. The battery for the remote is charged each time the key is inserted into the ignition.

On some systems the transponder is inserted into a slot in the instrument panel. To start the engine, the transponder is pressed. On others, after the transponder is inserted into its slot, a start button is pressed. If there is a communication link between the transponder and the vehicle and the codes both match, the engine will start.

On many newer vehicles, the transponder does not need to be inserted. It merely needs to be close to the vehicle **(Figure 23–59)**. This system is normally called a smart access system. The system uses a radio frequency (RF) signal to communicate with your vehicle and authorize your vehicle to respond to commands. The system can perform many functions without inserting a key or pressing a button. It can lock and unlock the doors, allow the engine to start by pressing the engine switch while depressing the brake pedal, and open the trunk. Doors can be unlocked either by touching the inside of any exterior door handle, the luggage compartment handle, or pressing a button on the transmitter. To lock the doors, press or pass by the black spot (lock area) on either front exterior door handle **(Figure 23–60)**.

When the electronic key enters into zones around the vehicle, a certification control module certifies the ID code from the key. Once the signal is certified, the control module transmits an engine immobilizer deactivation signal to the ID code box and a steering

FIGURE 23–59 Examples of transponder (smart) keys.

FIGURE 23–58 A typical start/stop button in a late-model vehicle.

FIGURE 23–60 The black area next to the key lock serves as the sensor for unlocking and locking the doors.

unlock signal to the steering lock ECU. The BCM also receives a certification signal and actuates the door lock motor to unlock or lock the door.

The actuation zones are set up by several oscillators. Each oscillator transmits a signal every quarter of a second when the engine is off and the doors are locked. When a signal detects the electronic key, certification begins. The actuation zone is normally about 3 feet (1 meter).

The system can also trigger the BCM to restore the position of the driver's seat (driving position memory system), the shoulder belt anchor, the steering wheel, and the outside rearview mirror.

Keyless Entry Systems

A keyless entry system allows the driver to unlock the doors or trunk lid from outside the vehicle without using a key. It has two main components: an electronic control module and a coded-button keypad on the driver's door or a key fob.

The electronic control module typically can unlock all doors, unlock the trunk, lock all doors, lock the trunk, turn on courtesy lamps, and illuminate the keypad or keyhole after any button on the keypad is pushed or either front door handle is pulled.

Remote keyless entry systems rely on a handheld transmitter, frequently part of the key fob. With a press of the unlock button on the transmitter from 25 to 50 feet away (depending on the type of transmitter) in any direction range, the interior lights turn on, the driver's door unlocks, and the theft security system is disarmed. The trunk can also be unlocked. Pressing the lock button locks all doors and arms the security system. For maximum security, some remote units and their receiver change access codes each time the remote is used.

Some remote units can also open and close all of the vehicle's windows, including the sunroof. They may also be capable of setting off the alarm system in the case of panic.

Automatic Liftgate Openers Some late model Ford SUVs and Crossovers have a feature that allows the liftgate to open automatically with the swipe of a foot under the rear bumper. Opening is activated by a sensor that triggers the locking mechanism and opening motors at the liftgate.

Alarm Systems

Antitheft systems are either installed by the OEM or are installed by aftermarket companies. The basic idea of these systems is to scare away a thief and/or prevent the vehicle from starting. **Figure 23–61** shows most of the components of common antitheft systems.

The two methods for activating alarm systems are passive and active. Passive systems switch on automatically when the ignition key is removed or the doors are locked. Active systems are activated with a key fob transmitter, keypad, key, or toggle switch. Switches similar to those used to turn on the courtesy lights when the doors are opened are often used. When a door, hood, or trunk is opened, the switch closes and the alarm sounds. It turns itself

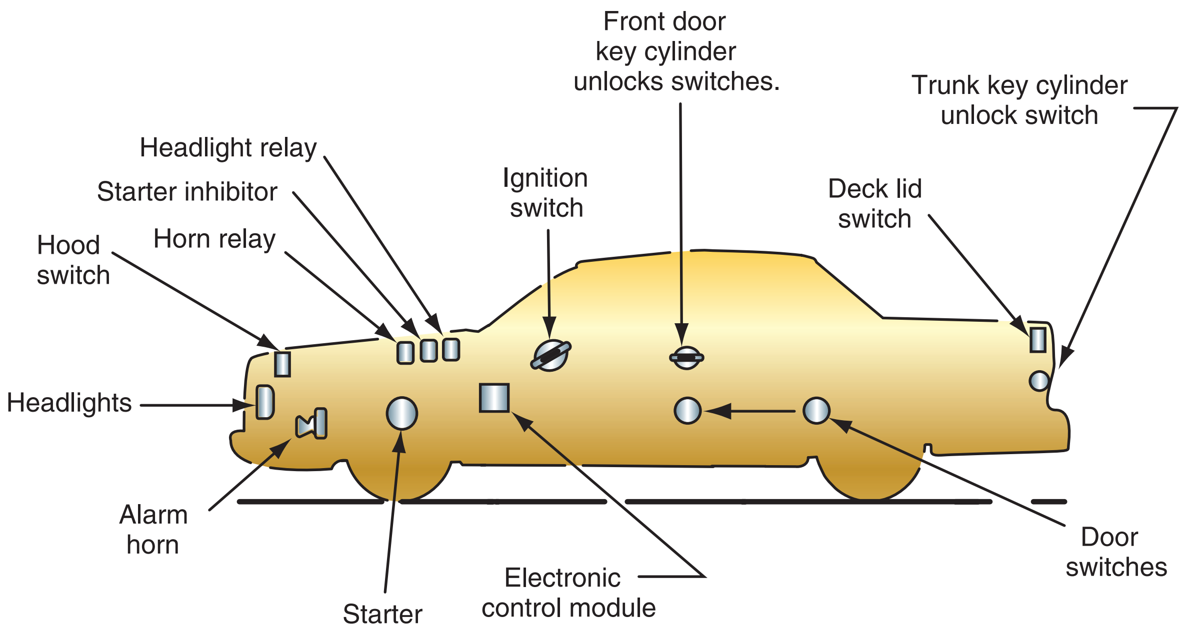


FIGURE 23–61 The basic layout of an antitheft system.

off automatically (provided the intruder has stopped trying to enter the car) to prevent the battery from being drained. It then automatically rearms itself.

Ultrasonic sensors are used to detect motion and will trigger the alarm if there is movement inside the vehicle. Current-sensitive sensors activate the alarm if there is a change in current within the electrical system, such as when a courtesy light goes on or the ignition starts. Motion detectors monitor changes in the vehicle's tilt, such as when someone is attempting to steal the tires.

Many alarm systems are designed to sound an alarm, turn on the hazard lights, and cause the high beams to flash along with the hazard lamps. Indicator lamps on the inside of the vehicle alert others that the alarm is set and also remind the driver to turn the alarm off before entering. To avoid false alarms, some systems allow for the disabling of particular sensors, such as the motion detector inside the vehicle that could be set off by a pet inside the vehicle.

Some late-model vehicles have an immobilizer system that will prevent the engine from starting if a wrong coded key is used. When the driver (or passenger) is in the vehicle while carrying the correct key and depresses the brake pedal and pushes down on the start/stop switch, the engine will start. Starting is permitted because the key code is recognized by the control unit. In a fraction of a second, the ECU turns on all engine systems required to start the engine and to unlock the steering wheel.

SHOP TALK

A common service for antitheft systems is the replacement or addition of keys. Each manufacturer has a specific procedure for setting up communication with the vehicle and the key, transponder, and key fob. Without this communication link, the new key will not work.

Diagnosis There are many different types of antitheft systems used by the manufacturers; there also are many different aftermarket systems available. When diagnosing a problem, it is very important to have as much information as possible about the system. Most often a manufacturer specific scan tool is needed to diagnose an OEM antitheft system. In some cases, only dealership personnel have access to the necessary data for diagnosis. Before proceeding with a detailed diagnosis, inspect all fuses and relays in the system. Also check for loose wires, connectors, and components. This is especially important if the system works intermittently.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2017	**Make:** Kia	**Model:** Soul	**Mileage:** 446	**RO:** 18214
Concern:	Customer states the Apple CarPlay doesn't work.			
To confirm the complaint the technician plugs her iPhone into the vehicle and finds CarPlay working correctly. She then talks to the customer and finds he is trying to use CarPlay over Bluetooth.				
Cause:	Customer was trying to use Bluetooth for CarPlay instead of phone cable connection.			
Correction:	Showed customer how to correctly connect his phone to the car.			

KEY TERMS

Peltier element
Telematics
Telemetry
Transducer
Tweeter
Woofers

SUMMARY

- Many accessories may be controlled and operated by a body computer and, therefore, diagnosis may involve retrieving trouble codes from the computer.
- The basic designs of windshield wiper systems used on today's vehicles include a standard two or

three-speed system with or without an intermittent or rain-sensing feature.

- The motors can have electromagnetic fields or permanent magnetic fields. With permanent magnetic fields, motor speed is regulated by the placement of the brushes on the commutator. The speed of electromagnetic motors is controlled by the strength of the magnetic fields.
- Diagnosis of a wiper/washer system should begin by determining if the problem is mechanical or electrical.
- Most current vehicles have electronically regulated cruise control systems that are controlled with a separate control module or by the vehicle's PCM.
- Diagnosis of PCM-controlled cruise control systems is aided by a scan tool.
- Complex sound systems may include an AM/FM radio receiver, stereo amplifier, CD player, cassette player, MP3 player, equalizer, several speakers, and a power antenna system.
- Poor speaker or sound quality is usually caused by a bad antenna, damaged speakers, loose speaker mountings or surrounding areas, poor wiring, or damaged speaker housings.
- Diagnosis of power door locks, windows, and seats is best done by dividing the circuit into individual circuits and the total circuit and basing your testing on the symptoms.
- One of the most common problems with rear-window defrosters is damage to the grids on the window, which can usually be repaired.
- Navigation systems use global positioning satellites to help drivers make travel decisions while they are on the road.
- Three basic types of antitheft devices are available: locking devices, disabling devices, and alarm systems.
- Most ignition keys for late-model vehicles are either resistance or transponder passkeys that only work on the vehicle for which they were intended.
- Passive alarm systems switch on automatically when the ignition key is removed or the doors are locked. Active systems are activated manually.

REVIEW QUESTIONS

Short Answer

1. Explain the principles of adaptive cruise control.
2. Describe telematics.
3. What could be the problem when the vehicle's dome light dims significantly when a power seat is moved?
4. What should be checked if none of the grids in a rear-window defogger work?
5. What component in a wiper system makes it possible for the wipers to shut off and rest in a certain location? How does it work?
6. Name the two most common problems that occur with power seats.

True or False

1. *True or False?* Rain-sensitive wiper systems respond to the weight of the water on the windshield to regulate the speed of the wipers.
2. *True or False?* On some passkey systems, when the PCM or BCM is replaced, the key must be reprogrammed with a new password.

Multiple Choice

1. Technician A says vehicles with electronic throttle control do not need a separate cruise control module, stepper motor, or cable to control engine speed. Technician B says a faulty brake light switch may cause the cruise control to not operate. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. Rear defrosters generally have a relay with a timer. This allows ___.
   a. the defogger to shut down after a predetermined length of time
   b. the defogger to function just until the rear window is clear
   c. the defogger to be independent of the ignition switch
   d. none of the above
3. Which of the following can be sources of radio interference?
   a. Ignition system wiring
   b. Electrical power lines
   c. Neon signs
   d. All of the above

4. The front passenger power window motor goes down but not back up. Technician A says a faulty power window relay is the cause. Technician B says the passenger window switch may be the cause. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Which of the following parts or circuits could cause one power window to not operate from either the master or the door switch?
   a. Power window fuse
   b. Power window motor
   c. Faulty wiring
   d. All of the above
6. When diagnosing a vacuum/mechanical cruise control system that cannot maintain a constant speed, all of the following should be checked, except ___.
   a. the brake switch
   b. the vacuum lines
   c. the vacuum servo
   d. the vehicle speed sensor
7. Which of the following is not a true statement?
   a. When all power windows do not operate, check the fuse and the wiring to the master switch, including the ground.
   b. When one power window does not operate, check the wiring to the individual switch, the switch, and the motor. Also check the window for binding in its tracks.
   c. When both rear power windows cannot be operated by their individual switches, check the lockout and master switch.
   d. When one power window moves in one direction only, check the fuse and the wiring to the master switch, including the ground.

ASE-STYLE REVIEW QUESTIONS

1. While discussing power door locks: Technician A says that if none of the locks work, the actuators at each door should be checked first. Technician B says that a scan tool is required to test the operation of the keyless entry remote. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. A vehicle's horns do not work. When the horn button is pressed, the relay can be heard clicking. Technician A says that the horn button is likely not completing the relay circuit to ground. Technician B says that the horn fuse may be blown. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. The right front power door lock does not work: Technician A says that the motor might have a bad ground. Technician B says that the master door switch could be the problem. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. The reasons for slower than normal wiper operation are being discussed: Technician A says that the problem may be in the mechanical linkage. Technician B says that there may be excessive resistance in the electrical circuit. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. A six-way power seat does not work in any switch position: Technician A says to check the circuit breaker. Technician B says to use a continuity chart to test the switch. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. Technician A says that some antitheft systems sound an alarm if someone enters the vehicle without a key. Technician B says that some antitheft devices prevent the engine from starting. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

7. The circuit breaker at a power seat motor continuously trips: Technician A says that this could be caused by a seat track problem that is causing mechanical resistance. Technician B says that this could be caused by corrosion at the motor, which is causing electrical resistance. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. Technician A says that a resistance key has a small thermistor bonded to it. Technician B says that a transponder key sends a radio signal to the PCM. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. Technician A says that navigational systems rely on global positioning satellites. Technician B says that navigational systems rely on information programmed in its memory and information stored on a CD or DVD. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While diagnosing an adaptive cruise control system that does not hold the set speed: Technician A checks for dirt or obstructions around the radar unit. Technician B says the radar sensor may need to be realigned. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

SECTION 4

ENGINE PERFORMANCE

CHAPTER 24

ENGINE PERFORMANCE SYSTEMS

How well an engine runs depends on the combustion process. To ensure combustion takes place efficiently, various engine performance systems are used. Today's systems are designed to achieve as close to complete combustion as possible. Basically, if all of the fuel that enters an engine's cylinder is burned, combustion is complete.

The requirements for complete combustion are simple. However, achieving these is not. Complete combustion will occur when the correct amount of air is mixed, in a sealed container, with the correct amount of fuel. The mixture is compressed and shocked by the correct amount of heat at the correct time. Air entering the cylinder via the intake valve is mixed with fuel. This mixture is compressed, which greatly increases the amount of energy released during combustion. Once

OBJECTIVES

- State the purpose of the major engine performance systems/components.
- Explain what is meant by open loop and closed loop.
- Explain the requirements to illuminate the malfunction indicator light in an OBD II system.
- Briefly describe the monitored systems in an OBD II system.
- Describe an OBD II warm-up cycle.
- Explain trip and drive cycle in an OBD II system.
- Describe the purpose of having two oxygen sensors in an exhaust system.
- Diagnose the causes of emissions or driveability concerns resulting from malfunctions in the computerized engine control system with stored diagnostic trouble codes.
- Obtain and interpret scan tool data.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2014	**Make:** Jeep	**Model:** Grand Cherokee	**Mileage:** 38,146	**RO:** 18370
Concern:	Customer states check engine light is on.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

compressed, the mixture is ignited and burns. The spent exhaust gases then flow out from the cylinder through the exhaust valve. The amount of air and fuel must be precisely controlled, as should the spark for ignition. Because the engine runs at different speeds, loads, and temperatures, these requirements are very difficult to meet.

Emission control devices are added to the vehicle because complete combustion at all times has not been achieved. These devices reduce the amount of unwanted vehicle emissions. They also affect the operation of the engine and are, therefore, an engine performance system.

Ignition Systems

For complete combustion, the ignition system must supply properly timed, high-voltage surges across the spark plug electrodes **(Figure 24–1)** at the proper time under all engine operating conditions. This is quite a task: Consider a six-cylinder engine running at 4,000 rpm; the ignition system must supply 12,000 sparks per minute because it must fire three spark plugs per revolution. These plug firings must also occur at the correct time and generate the correct amount of heat. If the ignition system fails to do these things, fuel economy, engine performance, and emission levels will be adversely affected. There are basically two types of ignition systems: distributor ignition (DI) and **electronic ignition (EI) (Figure 24–2)** or distributorless ignition systems (DIS).

Courtesy of Honeywell International Inc.

FIGURE 24–1 An ignition system has the sole purpose of providing the spark to start combustion.

FIGURE 24–2 An ignition coil for an electronic (distributorless) ignition system.

Purpose of the Ignition System

For each cylinder, the ignition system has three primary jobs:

- It must generate an electrical spark with enough heat to ignite the air-fuel mixture in the combustion chamber.
- It must maintain that spark long enough to allow total combustion of the fuel in the chamber.
- It must deliver the spark to each cylinder to allow combustion to begin at the right time during the compression stroke.

Ignition Timing

Ignition timing refers to the precise time spark occurs and is specified by referring to the position of the number 1 piston in relation to crankshaft rotation. Engines with distributor ignition systems have ignition timing reference marks located on a pulley or flywheel to indicate the position of the number 1 piston at TDC on the compression stroke. This reference is used to set initial ignition timing. For those engines, the manufacturers typically list an initial or **base ignition timing** specification. The specification, such as 10 BTDC, indicates that the spark occurs at 10 degrees before top dead center of the compression stroke.

Timing may be advanced, meaning that the process to generate the spark occurs sooner as engine speed increases **(Figure 24–3)**. This is so there is sufficient time for the spark to be produced in the coil and delivered to the combustion chamber. Timing also may be retarded, meaning the spark is delivered later.

Firing Order

Each cylinder must produce power once every 720 degrees of crankshaft rotation. Therefore, the ignition system must provide a spark at the right time so that each cylinder can have a power stroke at its own appropriate time. To do this, the ignition system must monitor the rotation of the crankshaft and the relative position of each piston to determine which piston should be delivered the spark. The spark for all cylinders must be delivered at the right time. How the ignition system does this depends on the design of the system.

The firing order is the sequence in which each spark plug ignites the air-fuel mixture in the cylinders. This order cannot be altered without adversely affecting engine performance. Each engine has a mechanical sequence of valves opening and closing as the pistons move up and down. The sequence defines when each cylinder produces power. The firing order corresponds to each cylinder as it moves through the compression stroke. If the spark occurs at any time other than during the end of the compression stroke, performance will be affected.

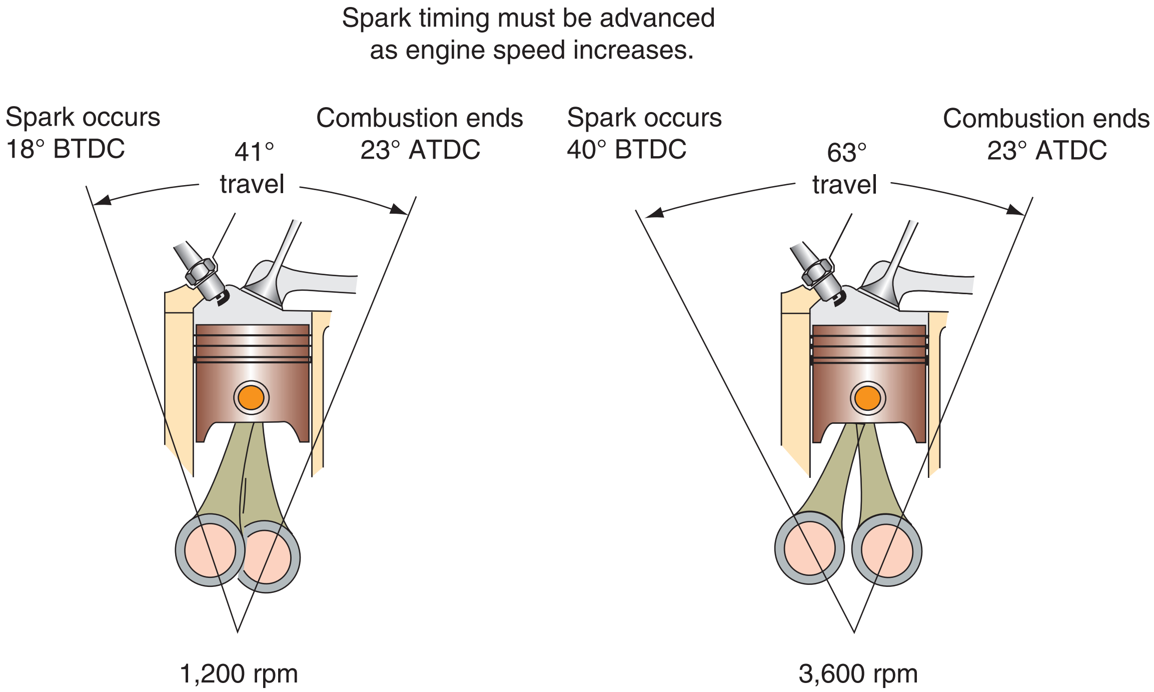


FIGURE 24–3 With an increase in speed, ignition must begin earlier to end by 23 degrees ATDC.

With a distributor system, the firing order follows the placement of the ignition wires along the distributor cap. EI systems trigger the ignition coils to fire in order.

Computer-Controlled Systems

With computerized ignition systems, inputs sensor data is used by the PCM to advance or retard spark timing as required. This causes changes in engine operation, which sends new messages to the computer. The computer can constantly adjust timing for maximum efficiency **(Figure 24–4)**.

The advantage of the electronic spark control system is threefold. It compensates for changes in engine (and sometimes outside air) temperature. It makes changes at a rate many times faster than older systems. And, finally, it has a feedback mechanism in which sensor readings allow it to constantly compensate for changing conditions.

Fuel System

The fuel delivery system has the important role of delivering fuel to the fuel injection system. The fuel must also be delivered in the right quantities and at the right pressure. The fuel must also be clean when it is delivered.

A typical fuel delivery system includes a fuel tank, fuel lines, fuel filters, and a pump **(Figure 24–5)**. The system works by using a pump to draw fuel from the fuel tank and passing it under pressure through fuel

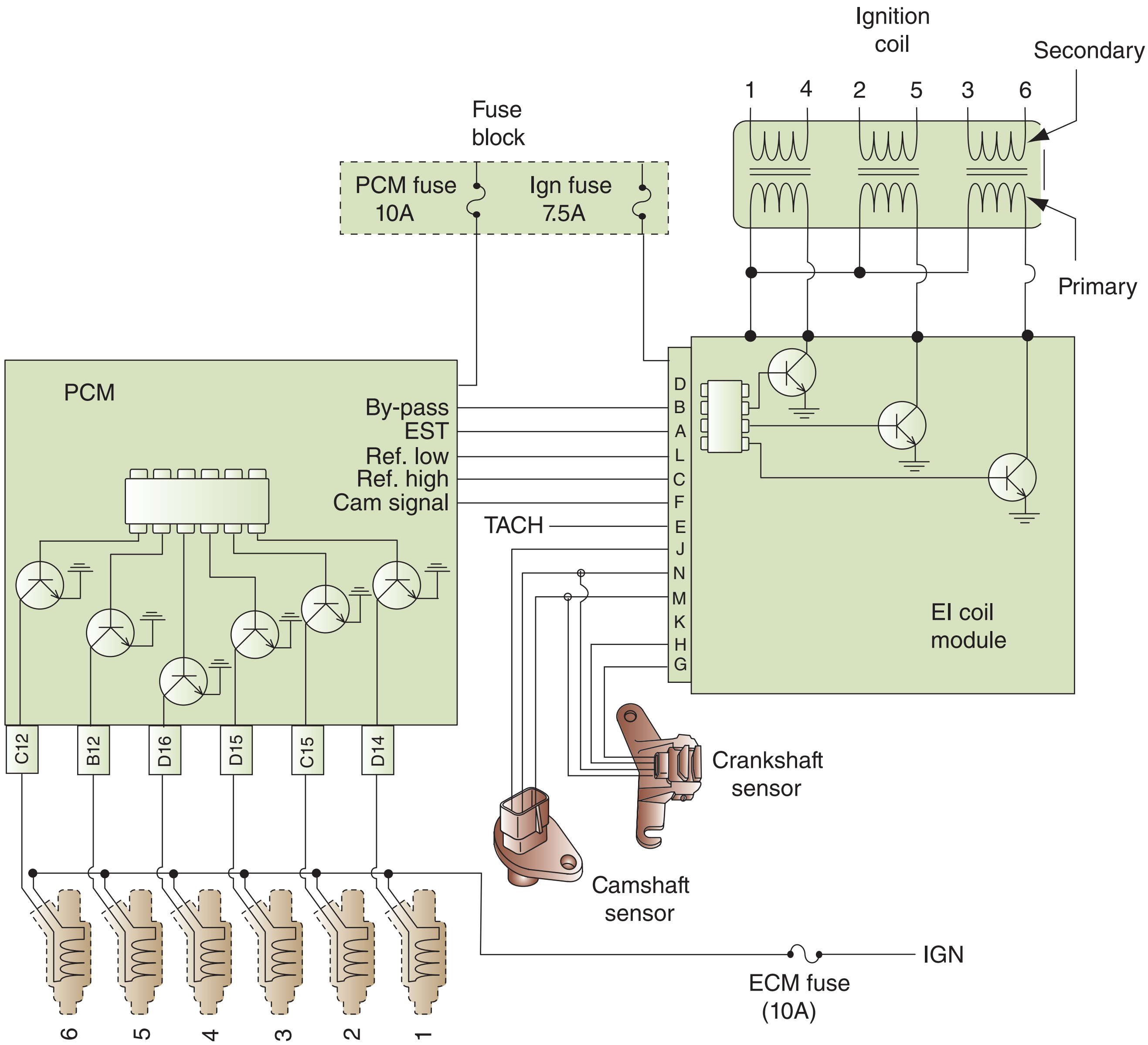


FIGURE 24–4 Basic layout for a computer-controlled ignition system.

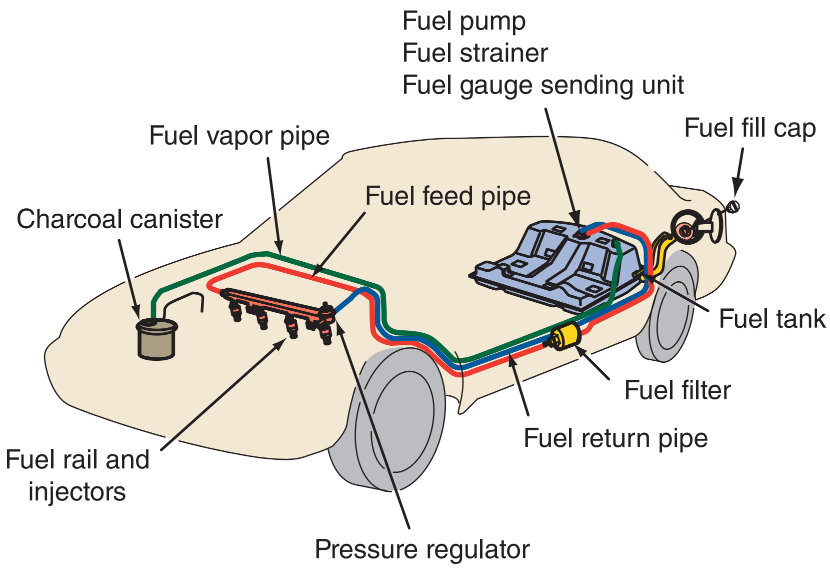


FIGURE 24–5 The fuel delivery system for a late-model car.

lines and filters to the fuel injection system. The filter removes dirt and other harmful impurities from the fuel. A fuel line pressure regulator maintains a constant high fuel pressure. This pressure generates the spraying force needed to inject the fuel. Excess fuel not required by the engine returns to the fuel tank through a fuel return line.

Fuel Injection

Electronic fuel injection (EFI) has proven to be the most precise, reliable, and cost-effective method of delivering fuel to the combustion chambers of today's engines. EFI systems are computer controlled and designed to provide the correct air-fuel ratio for all engine loads, speeds, and temperature conditions.

Although fuel injection technology has been around since the 1920s, it was not until the 1980s that manufacturers began to replace carburetors with **electronic fuel injection (EFI)** systems. Many of the early EFI systems were throttle body injection (TBI) systems in which the fuel was injected above the throttle plates. A similar system, central port injection (CPI), has the injector assembly located in the lower half of the intake manifold. TBI systems have been replaced by **port fuel injection (PFI)**, which has injectors located in the intake ports of the cylinders. All new cars have been equipped with an EFI system since the 1995 model year to fulfill OBD II requirements. Many engines are now equipped with **gasoline direct-injection (GDI)**. In these systems, the fuel is injected directly into the cylinders **(Figure 24–6)**. Direct injection has been used for years with diesel fuels but has not been successfully used on gasoline engines until lately.

Most EFI systems only inject fuel during the engine's intake cycle. The engine's fuel needs are measured by intake airflow past a sensor or by intake manifold pressure (vacuum). The airflow or manifold pressure sensor converts its reading to an electrical signal and sends it to the engine control computer. The computer processes this signal (and others) and calculates the fuel needs of the engine. The computer then sends an electrical signal to the fuel injector or injectors. This signal determines the amount of time the injector opens and sprays fuel. This interval is known as the injector pulse width.

When determining the amount of fuel required at any given time, the PCM also looks at throttle position, engine speed, crankshaft position, engine temperature, inlet air temperature, and oxygen in the exhaust inputs.

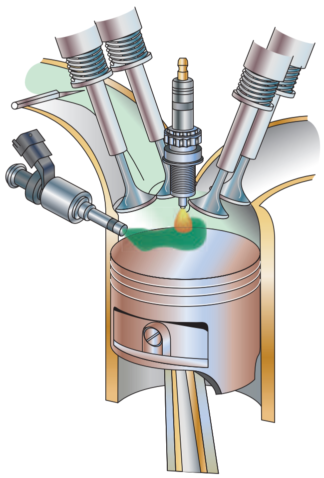


FIGURE 24–6 A gasoline direct injection (GDI) system.

Air Induction System

An internal combustion engine needs air to run. This air supply is drawn into the engine by the vacuum created during the pistons' intake stroke. Controlling the flow of air is the job of the **air induction system**.

Prior to the introduction of emission control devices, the induction system was quite simple. It consisted of an air cleaner housing mounted on top of the engine with a filter inside the housing. Its function was to filter dust and grit from the air being drawn into the engine.

Modern air induction systems filter the air and do much more. The introduction of emission standards and fuel economy standards encouraged the development of intake air temperature controls. The air intake system on a modern fuel-injected engine is complicated **(Figure 24–7)**. Ducts channel cool air from outside the engine compartment to the throttle plate assembly. The air filter has been moved to a position below the top of the engine to allow for aerodynamic body designs. Electronic meters measure airflow, temperature, and density.

To improve fuel economy, manufacturers are using smaller engines equipped with turbo- or superchargers **(Figure 24–8)**. These increase engine efficiency by forcing more air into the cylinders.

GO TO Chapter 32 for more information about turbo and superchargers.

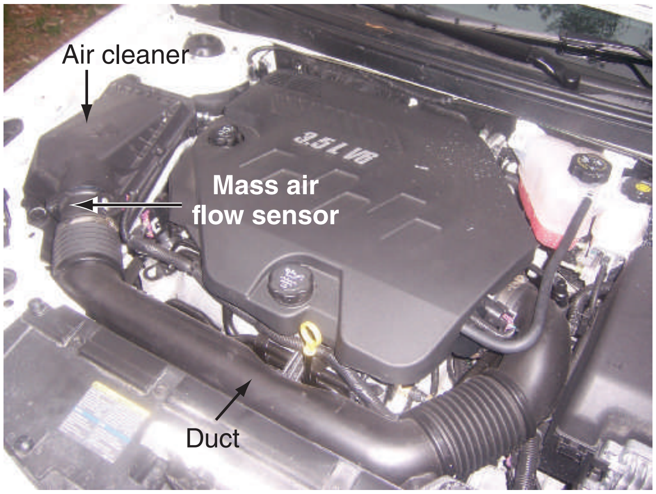


FIGURE 24–7 An air induction system for a late-model vehicle.

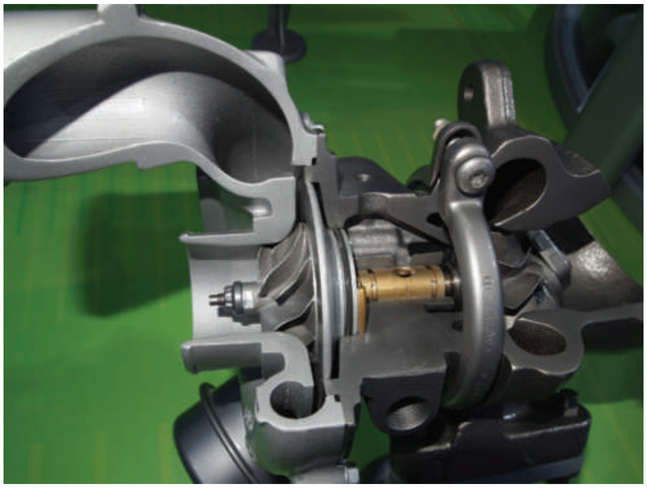


FIGURE 24–8 A cutaway of a turbocharger.

Air-Fuel Mixtures

The amount of air mixed with the fuel is called the air-fuel ratio. The ideal air-fuel ratio for most operating conditions of a gasoline engine is approximately 14.7 pounds of air mixed with 1 pound of gasoline. This provides an ideal ratio of 14.7:1. Because air is so much lighter than gasoline, it takes nearly 10,000 gallons of air mixed with 1 gallon of gasoline to achieve an air-fuel ratio of 14.7:1. This is why proper air delivery is as important as fuel delivery.

When the mixture has more air than the ideal ratio calls for, the mixture is said to be lean. Ratios of 15 to 16:1 provide the best fuel economy from gasoline engines. Mixtures that have a ratio below 14.7:1 are considered rich mixtures. Rich mixtures (12 to 13.1) provide more power production from the engine but increase fuel consumption. An advantage of GDI systems is the ability to have very lean mixtures under certain operating conditions, which results in increased fuel economy and reduced exhaust emissions.

Emission Control Systems

Emission controls have one purpose and that is to reduce the amount of pollutants and environmentally damaging substances released by vehicles. The consequences of the pollutants are grievous **(Figure 24–9)**. The air we breathe and water we drink have become contaminated with chemicals that adversely affect our health. It took many years for the public and industry to address the problem of these pollutants. Not until smog became an issue

FIGURE 24-9 Dirty exhaust is bad for everyone.

did anyone in power really care and do something about these pollutants.

Smog not only appears as dirty air, it is also an irritant to the eyes, nose, and throat. The things necessary to form photochemical smog are hydrocarbons (HC) and oxides of nitrogen (NO_x) exposed to sunlight in stagnant air. HC in the air that reacts with the NO_x causes these two chemicals to react and form photochemical smog.

There are three main automotive pollutants: HC, carbon monoxide (CO), and NO_x. Particulate (soot) emissions are also present in diesel engine exhaust. HC emissions are caused largely by unburned fuel from the combustion chambers. HC emissions can also originate from evaporative sources such as the gasoline tank. CO emissions are a by-product of the combustion process, resulting from incorrect air-fuel mixtures. NO_x emissions are caused by nitrogen and oxygen uniting at cylinder temperatures above 2,300 °F (1,261 °C). Current concerns also include carbon dioxide emissions. CO_2 is a byproduct of complete combustion but is said to contribute to global warming.

Computer-Controlled Systems

The EGR valve, air pump, and evaporative emissions canister are controlled by the PCM. The computer keeps the level of the three major pollutants (CO, HC, and NO_x) at acceptably low levels. Other emission control devices may also be wholly or partly controlled by the computer. The control of the air, fuel, and ignition systems also contributes significantly to the control of emissions.

Engine Control Systems

As manufacturers come closer to achieving complete combustion, engines are able to produce more power, use less fuel, and emit fewer pollutants. This has been made possible by technological advances, primarily in electronics.

GO TO Chapter 22 for a detailed discussion of computers and control systems.

The computer is an engine control system that functions like other computers. It receives inputs, processes information, and commands an output. The primary computer in an engine control system is the **engine control module (ECM)** or the powertrain control module (PCM).

The engine control system relies on sensors that convert engine operating conditions such as temperature, engine and vehicle speeds, throttle position, and other conditions into electrical signals that are constantly monitored by the PCM **(Figure 24–10)**. The PCM also senses some conditions through electrical connections. These include voltage changes at various components.

The PCM sorts the input signals and compares them to parameters programmed in it. This is the processing role of the computer. Based on the comparison, the computer may command a change in the operation of a component or system. The PCM also monitors the activity of the system and can detect any problems that occur. At that point, it will set a DTC and store other diagnostic information. The PCM may also store vehicle information, such as the VIN, calibration identification (CAL ID), and calibration verification. These are used to ensure all calibration settings match the vehicle.

Based on the input information and the programs, the PCM decides the best operating parameters and sends out commands to various outputs

SHOP TALK A PCM controls more than the engine and it often performs the functions of the ECM as well. In this text, the term "PCM" is used unless something is specifically part of an ECM.

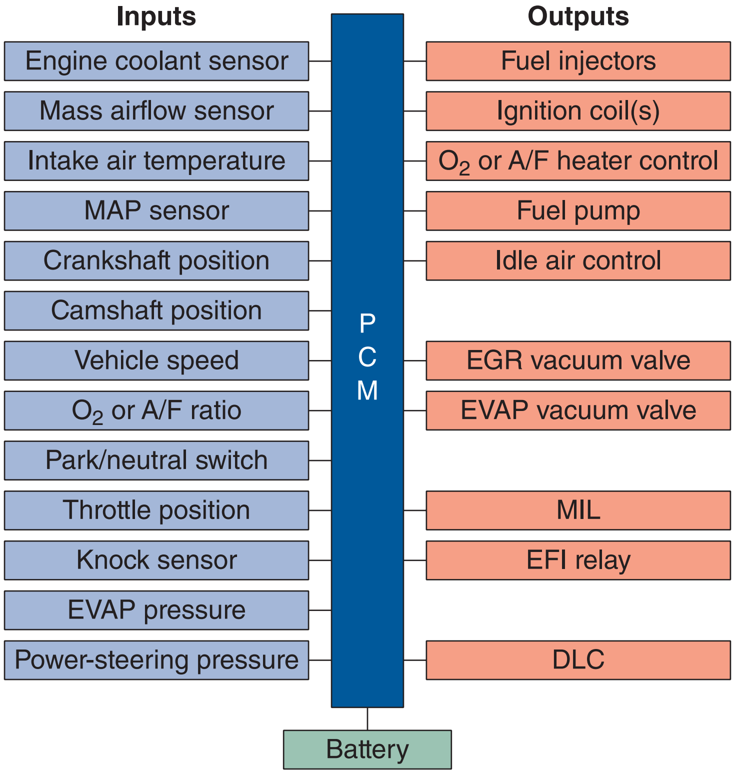


FIGURE 24–10 A basic look at an engine control system.

or actuators. These commands are first sent to output drivers that cause an output device to turn on or off. These outputs include solenoids, relays, lights, motors, clutches, and heaters.

The PCM is linked with several other control modules. They share information and, in some cases, one control module controls another. The shared information is present on the CAN data bus in most vehicles **(Figure 24–11)**.

GO TO Chapter 22 for a detailed discussion of CAN and other multiplexing systems.

System Components

The sensors, actuators, and computer communicate through the use of electronic and multiplexed circuits. For example, when the incoming voltage signal from the coolant sensor tells the PCM that the engine is getting hot, the PCM sends out a command to turn on the electric cooling fan. The PCM does this by grounding the relay circuit that controls the electric cooling fan. When the relay clicks on, the electric cooling fan starts to spin and cools the engine. The information may also be used to alter the air-fuel ratio and ignition timing.

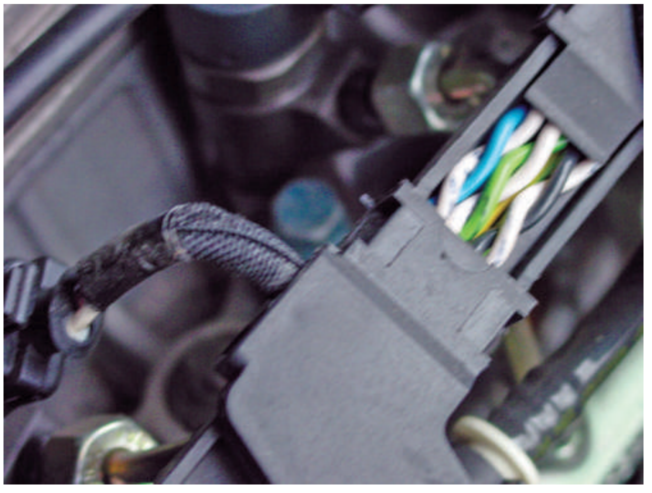


FIGURE 24–11 The twisted pairs of wires that serve as data buses in a multiplexed system.

In a PCM **(Figure 24–12)**, RAM is used to store data collected by the sensors, the results of calculations, and other information that is constantly changing during engine operation. Information in volatile RAM is erased when the ignition is turned off or when the power is disconnected. Nonvolatile RAM does not lose its data if its power source is disconnected.

The computer's permanent memory is stored in ROM or PROM and is not erased when the power

FIGURE 24–12 A cutaway of a current "advanced" powertrain control module.

source is disconnected. ROM and PROM are used to store computer-controled system strategy and look-up tables. PROM normally contains the specific information about the vehicle.

The look-up tables (sometimes called maps) contain calibrations and specifications. Look-up tables indicate how an engine should perform. For example, information indicating a vacuum reading of 20 in. Hg is received from the manifold absolute pressure (MAP) sensor. This information and the information from the engine speed sensor are compared to a table for spark advance. This table tells the computer what the spark advance should be for that throttle position and engine speed **(Figure 24–13)**. The computer then modifies the spark advance.

When making decisions, the PCM is constantly referring to three sources of information: the look-up tables, system strategy, and the input from sensors. The computer makes informed decisions by comparing information from these sources.

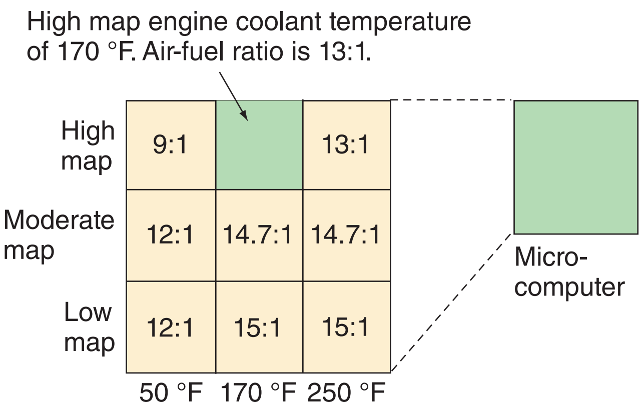


FIGURE 24–13 Example of a base look-up table.

Computer Logic

In order to control an engine system, the computer makes a series of decisions. Decisions are made in a step-by-step fashion until a conclusion is reached. Generally, the first decision is to determine the engine mode. For example, to control air-fuel mixture the computer first determines whether the engine is cranking, idling, cruising, accelerating, or decelerating. Then the computer can choose the best system strategy for the present engine mode. In a typical example, sensor input indicates that the engine is warm, rpm is high, manifold absolute pressure is high, and the throttle plate is wide open. The computer determines that the vehicle is under heavy acceleration or has a wide-open throttle. Next, the computer determines the goal to be reached. For example, with heavy acceleration, the goal is to create a rich air-fuel mixture. At wide-open throttle, with high manifold absolute pressure and coolant temperature of 170 °F, the table indicates that the air-fuel ratio should be 13:1, that is, 13 pounds of air for every 1 pound of fuel. An air-fuel ratio of 13:1 creates the rich air-fuel mixture needed for heavy acceleration.

In a final series of decisions, the computer determines how the goal can be achieved. In our example, a rich air-fuel mixture is achieved by increasing fuel injector pulse width. The injector nozzle remains open longer and more fuel is injected into the cylinder, providing the additional power needed.

Control of Non-Engine Functions

Some devices that are not directly connected to the engine are also controlled by the PCM to ensure maximum efficiency. For example, air conditioner compressor clutches can be turned on or off, depending on various conditions. One common control procedure turns off the compressor when the throttle is fully opened. This allows maximum engine acceleration by eliminating the load of the compressor.

On some vehicles, the torque converter lock-up clutch is applied and released by a signal from the computer. The clutch is applied by transmission hydraulic pressure, which is controlled by electrical solenoids that are in turn controlled by the computer.

In most cases, the PCM works with other control modules to control a system. Examples of these are antilock brake systems, traction and stability control systems, and other accessories.

On-Board Diagnostic Systems

Because all manufacturers have continually updated, expanded, and improved their computerized control systems, there are hundreds of different domestic and import systems on the road. Fortunately for technicians, OBD II called for all vehicles to use the same terms, acronyms, and definitions to describe their components. They also have the same type of diagnostic connector, the same basic test sequences, and display the same trouble codes. OBD II began in 1996 and has been on all vehicles sold in North America since 1997.

The primary goal of OBD systems is to reduce vehicle emissions and reduce the possibility of future emission increases by detecting and reporting system malfunctions.

Vehicle Emission Control Information (VECI) Decal

In the mid-1990s, OBI I systems were being phased out and OBD II was being phased in. This meant that, depending on model year, make and model, a vehicle could be OBD I and have an OBD II diagnostic connector or have OBD I and OBD II diagnostic connectors. To determine which system is actually used, refer to the VECI decal **(Figure 24–14)** located under the hood. This decal provides information about which OBD system is used as well as listing the installed emission control devices and what emission year the vehicle conforms with. Other information commonly found on the VECI includes a vacuum diagram for the emission control system, engine size, spark plug gap, and valve lash specifications.

FIGURE 24–14 The VECI from a late-model car.

OBD I (On-Board Diagnostic System, Generation 1)

OBD I systems were first used in 1988. The ECM was capable of monitoring critical emission-related parts and systems and illuminate a malfunction indicator if a defect was found. The **malfunction indicator lamp (MIL)** was in the instrument panel. Most OBD I systems used flash codes to display DTCs. The codes were displayed with the MIL. Often, the codes were displayed by jumping across terminals at a diagnostic data link connector (DLC). Manufacturers provided lists of what the codes represented, along with step-by-step diagnostic procedures for identifying the exact fault.

Typically, the DTCs represented problems with the sensors, fuel metering system, and the operation of the EGR valve. If any of these were open, shorted, had high resistance, or were operating outside a normal range, a code was set. The MIL not only helped with diagnostics, but also alerted the driver that there was a problem. The MIL would turn off when the condition returned to normal; however, the DTC remained in memory until it was erased by a technician.

OBD I was a step in the right direction, but it had several faults. It monitored few systems, had a limited number of DTCs (these were not standardized, so each manufacturer had its own), and allowed a limited use of serial data; most manufacturers required a specific scan tool and procedure, and the names used to describe a component varied across the manufacturers and their model vehicles.

OBD II (On-Board Diagnostic System, Generation 2)

OBD II was established to overcome some of the weaknesses of OBD I. This was possible because of the advances made in computer technology and was necessary because of stricter emissions standards. OBD I systems monitored only a few emission-related parts and were not set to maintain a specific level of emissions. OBD II was developed to be a more comprehensive monitoring system and to allow more accurate diagnosis by technicians.

Studies estimate that approximately 50 percent of the total emissions from late-model vehicles are the result of emission-related problems. OBD II systems are designed to ensure that vehicles remain as clean as possible over their entire life. During an emissions or “smog” check, an inspection computer can be plugged into the DLC of the vehicle and read

the data from the vehicle's computer. If emission-related DTCs are present, the vehicle will fail the test.

OBD II added monitor functions for such things as catalyst efficiency, engine misfire detection, evaporative system, secondary air system, and EGR system flow rate. These monitors detect problems that would affect emissions levels. Also, a serial data stream of twenty basic data parameters and common DTCs was adopted.

OBD II systems monitor the effectiveness of the major emission control systems and anything else that may affect emissions and will illuminate the MIL when a problem is detected. During the monitoring functions, every part that can affect emission performance is checked by a diagnostic routine to verify that it is functioning properly. OBD II systems must illuminate the MIL **(Figure 24–15)** if the vehicle's conditions allow emissions to exceed 1.5 times the allowable standard for that model year based on a federal test procedure (FTP). When a component or strategy failure would allow emissions to exceed this level and the fault was detected during two consecutive trips, the MIL would illuminate to inform the driver of a problem and a DTC would be stored in the PCM.

Besides increasing the capability of the PCM, additional hardware is required to monitor and maintain emissions performance. Examples of these are the addition of a heated oxygen sensor down the exhaust stream from the catalytic converter, upgrade of specific connectors, components designed to last the mandated 80,000 miles or 8 years, more precise crankshaft or camshaft position sensors, and a new standardized 16-pin DLC.

Rather than use a fixed, unalterable PROM, OBD II PCMs have an EEPROM to store a large amount of

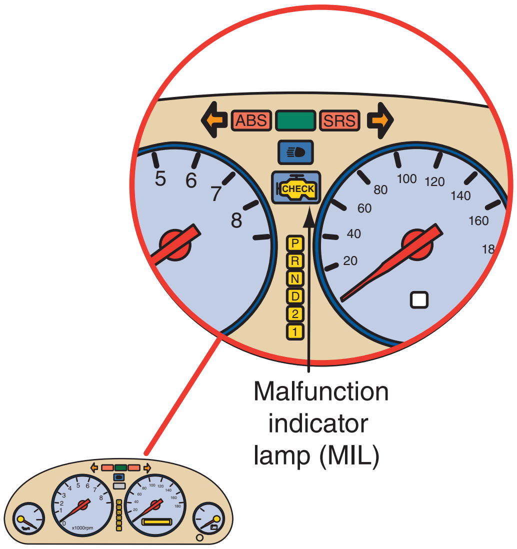


FIGURE 24–15 A typical MIL.

information. The EEPROM stores data without the need for a continuing source of electrical power. It is an integrated circuit that contains the program used by the PCM to provide powertrain control. It is possible to erase and reprogram the EEPROM without removing it from the computer. When a modification to the PCM operating strategy is required, the EEPROM may be reprogrammed through the DLC using a scan tool or pass-through device and a computer.

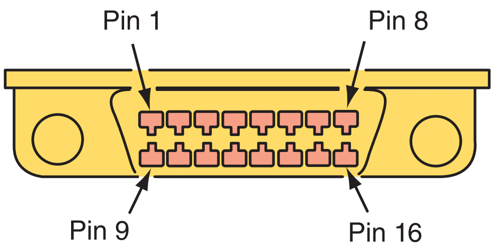
GO TO Chapter 22 for more information on computer memory and for instructions on flashing a computer.

For example, if the vehicle calibrations are updated for a specific car model sold in California, a computer may be used to erase the EEPROM. After the erasing procedure, the EEPROM is reprogrammed with the updated information. The new program may be accessed via the vehicle manufacturer's service information website or from a disc. Manufacturers periodically send authorized service facilities the disks required for current updating of the EEPROMs. PCM recalibrations must be directed by a service bulletin or recall letter.

Data Link Connector OBD II standards require the DLC to be easily accessible while sitting in the driver's seat **(Figure 24–16)**. The DLC cannot be hidden behind panels and must be accessible without tools. The connector pins are arranged in two rows and are numbered consecutively. Seven of the sixteen pins have been assigned by the OBD II standard. They are used for the same information, regardless of the vehicle's make, model, and year. The remaining nine pins can be used by the individual manufacturers to meet their needs and desires.

The connector is "D"-shaped and has guide keys that allow the scan tool to only be installed one way. Using a standard connector and designated pins allows data retrieval with any scan tool designed for OBD II. Some vehicles meet OBD II standards by providing the designated DLC along with their own connector for their own scan tool. Often a vehicle will have more than one DLC, each with its own purpose. Due to OBD standards, the OBD DLC will

SHOP TALK When a vehicle has a 16-pin DLC, this does not necessarily mean that the vehicle is equipped with OBD II.



Pin 1: Manufacturer discretionary
Pin 2: J1850 bus positive
Pin 3: Manufacturer discretionary
Pin 4: Chassis ground
Pin 5: Signal ground
Pin 6: Manufacturer discretionary
Pin 7: ISO 1941-2 "K" line
Pin 8: Manufacturer discretionary

Pin 9: Manufacturer discretionary
Pin 10: J1850 bus negative
Pin 11: Manufacturer discretionary
Pin 12: Manufacturer discretionary
Pin 13: Manufacturer discretionary
Pin 14: Manufacturer discretionary
Pin 15: ISO 9141-2 "L" line
Pin 16: Battery power

FIGURE 24-16 A standard OBD II DLC with pin designations.

always be located within a foot, to the right or left, of the steering column.

OBD II Terms All vehicle manufacturers must use the same names and acronyms for all electric and electronic systems related to the engine and emission control systems. Previously, there were many names for the same component. Now all similar components will be referred to with the same name. Beginning with the 1993 model year, all service information has been required to use the new terms. This new terminology is commonly called J1930 terminology because it conforms to the SAE standard J1930.

OBD II for Light-Duty Diesels The OBD II systems are also mandated for all diesel engine vehicles that weigh 14,000 pounds or less. These systems are very similar to those found in gasoline engines. The exceptions to this are the exclusion of the systems that are unique to gasoline engines and the inclusion of those systems unique to a diesel engine.

OBD III (On-Board Diagnostic System, Generation 3)

Although not implemented at the printing of this book, the basic functions and operation of OBD III will likely remain very similar to OBD II. The exception will be for the reporting of data collected from emission related faults. How the data collection and reporting will be performed has not been determined. One likely possibility is using a built-in communication system, such as OnStar.

The main goal of OBD III is to minimize the delay between the detection of an emissions failure by the OBD II system and the actual repair of the vehicle. It has been said that the check engine light is a poor motivator for prompt repair and many repairs to the emissions-related parts of vehicles are being delayed until the mandatory emissions inspection is approaching. In other words, vehicles are running around with problems that increase emissions and some owners are doing nothing about it.

If OBD III is adopted with remote monitoring and reporting as a function, there will probably be one centralized data collection agency for each state. Once the vehicle's emission data is collected, the vehicle's owner will be notified about the results. If a fault is present that increases emission, the owner will be given a certain amount of time to have the problem corrected and the vehicle retested.

This type of vehicle monitoring has raised some fear in car owners. They feel that the government will be able to know too much about their driving habits and driving routes, and they want their privacy protected. For this reason, the final design and method for OBD III have not been decided.

System Operation

The PCM will operate in different modes based on the conditions. These modes are often referred to as control loops. The PCM does not always process all information it receives. It is programmed to ignore or modify some inputs according to the current operating conditions.

Open-Loop Mode

When the engine, oxygen sensors, and catalytic converter are cold, most electronic engine controls go into **open-loop** mode. In this mode, the control loop is not a complete cycle and the computer does not react to feedback information from the oxygen sensors. Instead, the computer makes decisions based on preprogrammed information that allows it to make basic ignition or air-fuel settings based on coolant temperature, throttle position, and other inputs. The open-loop mode is activated when a signal from the temperature sensor indicates that the engine temperature is too low for the fuel to properly vaporize and burn in the cylinders. Systems with unheated oxygen sensors may also go into the open-loop mode while idling, or at any time that the oxygen sensor cools off enough to stop sending a good signal, and at wide-open throttle. Modern systems warm the catalytic converter(s) very quickly to put the vehicle into closed-loop as soon as possible.

Closed-Loop Mode

During the **closed-loop** mode, the PCM receives and processes all information available. Sensor inputs are sent to the PCM; the PCM compares those values to its programs, and then sends commands to the output devices. The output devices adjust ignition timing, air-fuel ratio, and emission control operation. The resulting engine operation will result from the new inputs from the sensors. This continuous cycle of information is called a closed loop.

Closed control loops are often referred to as feedback systems. This means that the sensors provide constant information, or feedback, on what is taking place in the engine. This allows the PCM to constantly monitor, process, and send out new output commands.

Fail-Safe or Limp-In Mode

Most computer systems also have what is known as the fail-safe or limp-in mode. The limp-in mode is nothing more than the computer's attempt to take control of vehicle operation when input from one of its critical sensors has been lost or is well out of its normal range. To be more specific, if the computer sees a problem with the signal from a sensor, it either works with fixed values in place of the failed sensor input, or, depending on which input was lost, it can also generate a modified value by combining two or more related sensor inputs.

To illustrate this, if a fault occurs in the electronic throttle control system, such as a reading from the accelerator position sensors that is out of range, the PCM will disable throttle control and run the engine at a predetermined rpm. This limited function limits engine speed, often to only 1,200 rpm but does allow the engine to run until the driver can reach a service location.

SHOP TALK

Most late-model engines have a heated oxygen sensor that reduces the time a PCM will be in open loop. If the system can go to closed loop just 1 minute sooner, the amount of pollutants released will be cut nearly in half.

Adaptive Strategy

A system's adaptive strategy is based on a plan for the timing and control of systems during different operating conditions. If a computer has adaptive strategy capabilities, it can actually learn from past experiences. For example, the normal voltage signals from the TP sensor to the PCM range from 0.6 to 4.5 volts. If a 0.2-volt signal is received, the PCM may regard this signal as the result of a worn TP sensor and assign this lower voltage to the normal low-voltage signal. The PCM will add 0.4 volt to the 0.2 volt it received. All future signals from the various throttle positions will also have 0.4 volt added to the signal. Doing this calculation adjusts for the worn TP sensor and ensures that the engine will operate normally. If the input from a sensor is erratic or considerably out of range, the PCM may totally ignore the input.

Most adaptive strategies have two parts: short term and long term. Short-term strategies are those immediately enacted by the computer to overcome a change in operation. These changes are temporary. Long-term strategies are based on the feedback about the short-term strategies. These changes are more permanent.

OBD II Monitoring Capabilities

OBD II monitors the performance of emission and other related systems. The purpose of these monitors **(Figure 24–17)** is to detect failing systems and not wait until they fail before illuminating the MIL. OBD II systems will perform certain tests on various

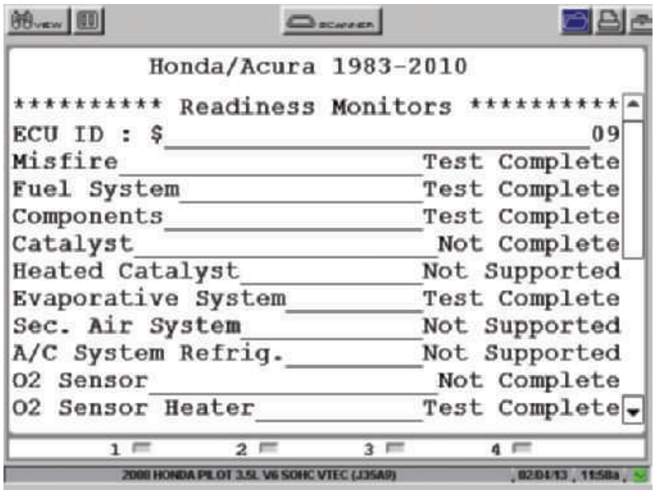


FIGURE 24–17 A report from a scan tool noting which monitor has been completed.

subsystems of the engine management system. If one or more monitored systems are found to have a malfunction, the MIL will illuminate to alert the driver of a problem. Some monitors run continuously, whereas others will run only when certain operating conditions are present during the drive cycle.

These conditions are called the **enable criteria**. An example of enable criteria for a particular monitor may be:

- Time since engine start greater than 300 seconds.
- Engine coolant temperature between 170 °F and 220 °F.
- Throttle position between 1.5 volts and 3 volts.
- Vehicle speed between 10 mph and 60 mph.
- Fuel level between 20 percent and 80 percent.

If the enable criteria for a specific monitor are not met during routine driving, the monitor will not run. In addition, a fault in one system can prevent the monitor for another system to run. For example, a thermostat that is stuck open can cause engine coolant temperature to remain below the value needed for a monitor to begin. This could keep many of the monitors from running and completing.

Drive Cycle The OBD II **drive cycle** is a defined set of operating conditions that must take place for all monitors to run and complete. If the monitor does not complete, some aspects of self-diagnosis cannot take place. A drive cycle **(Figure 24–18)** includes an engine start and operation that brings the vehicle into closed loop and includes whatever specific operating conditions are necessary either to initiate and complete a specific monitoring sequence or to verify a symptom or repair. Each manufacturer has guidelines that define how the vehicle is to be driven to complete a drive cycle.

OBD II Trip A **trip** is a partial drive cycle that includes all of the conditions (enable criteria) required for a particular monitor to run. To run a monitor, the vehicle must be driven at different speeds and conditions, similar to when performing a drive cycle.

During diagnosis, it may be necessary to complete a trip for a monitor to verify the problem or the

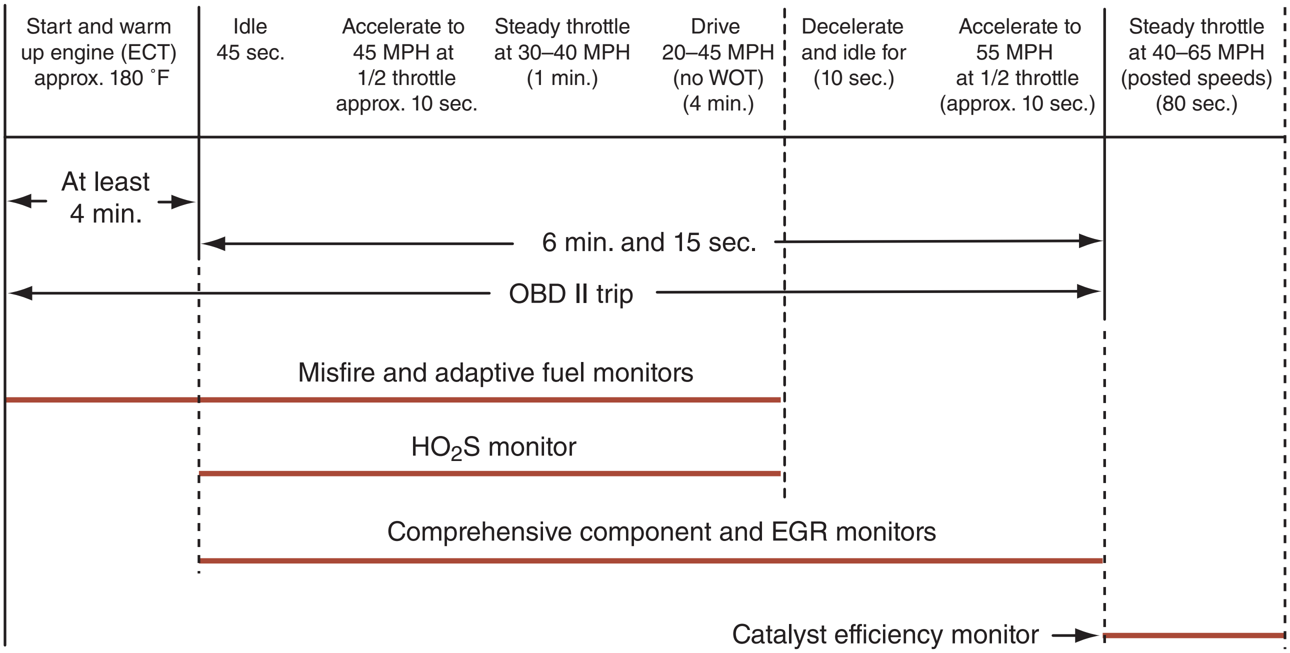


FIGURE 24–18 OBD trip cycle.

repair. Depending on the monitor, the system tests the component or system once per trip. It is important to note that once a repair has been made, the vehicle will need to complete a trip or the drive cycle so that affected monitors can run and pass. If a monitor will not pass, ensure that the enable criteria are met and the drive cycle is correct. Failure of a monitor to complete can also be caused by a fault in another circuit or system that prevents the monitor from running to completion.

Warm-Up Cycle OBD II standards define a warm-up cycle as the period from when the engine is started until the engine temperature has increased by at least 60 °F (16 °C) and has reached at least 160 °F (88 °C).

Catalyst Efficiency Monitor

OBD II vehicles use a minimum of two oxygen sensors. One of these is used for feedback to the PCM for fuel control, and the other, located at the rear of the catalytic converter, gives an indication of the efficiency of the converter and may also be used for fuel control. The downstream O_2 sensor is sometimes called the "catalyst monitor sensor" (CMS). The catalyst efficiency monitor compares the signals between the two O_2 sensors to determine how well the catalyst is working.

One heated O_2 sensor (HO_2S) is mounted near the exhaust manifold and the additional HO_2S is mounted downstream from the catalytic converter **(Figure 24–19)**. The HO_2S are identified by their position and location relative to the converters. S1 means the O_2 sensor is upstream or before the catalytic converter, and S2 is downstream or after the catalytic converter. On V-type engines, the additional designation B1 means the sensor is installed in the bank for cylinder No. 1. B2 indicates it is for the other bank of cylinders.

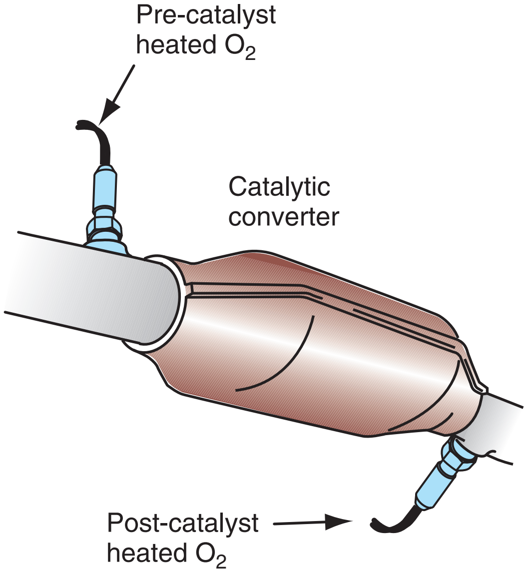


FIGURE 24–19 Pre-catalyst and post-catalyst heated O_2 sensors (HO_2S).

The downstream HO_2S are designed to prevent the collection of condensation on their ceramic material. The internal heater is not turned on until the ECT sensor indicates a warmed-up engine. This action prevents cracking of the ceramic. Gold-plated pins and sockets are used in the HO_2S, and the downstream and upstream sensors have different wiring harness connectors.

A catalytic converter stores oxygen during lean engine operation and gives up this stored oxygen during rich operation to burn up excessive HCs. Catalytic converter efficiency is measured by monitoring the O_2 storage capacity of the converter during closed-loop operation.

When the catalytic converter is storing oxygen properly, the downstream HO_2S provide fewer cross counts (low-frequency) voltage signals. If the catalytic converter is not storing O_2 properly, the cross counts of the voltage signal increase on the downstream HO_2S. When the signals from the downstream HO_2S approach the cross counts of the upstream sensors **(Figure 24–20)**, a DTC is set in the PCM memory. If the fault occurs on three drive cycles, the MIL light is illuminated.

Misfire Monitor

If a cylinder misfires, HC is exhausted from the cylinder and enters the catalytic converter. A misfire means a lack of combustion in at least one cylinder for at least one combustion event. This often allows unburned fuel to pass through the cylinder and into the exhaust. Although the converter can handle an occasional sample of raw fuel, too much fuel to the converter can overheat and destroy it. The honeycomb material in the converter may melt into a solid mass. If this happens, the converter is no longer efficient in reducing emissions.

Cylinder misfire monitoring requires measuring the contribution of each cylinder to total engine power. The misfire monitoring system uses a highly accurate crankshaft angle measurement to measure the crankshaft acceleration each time a cylinder fires **(Figure 24–21)**. If a cylinder is contributing normal power, a specific crankshaft acceleration time occurs. When a cylinder misfires, the cylinder does not contribute to engine power, and crankshaft

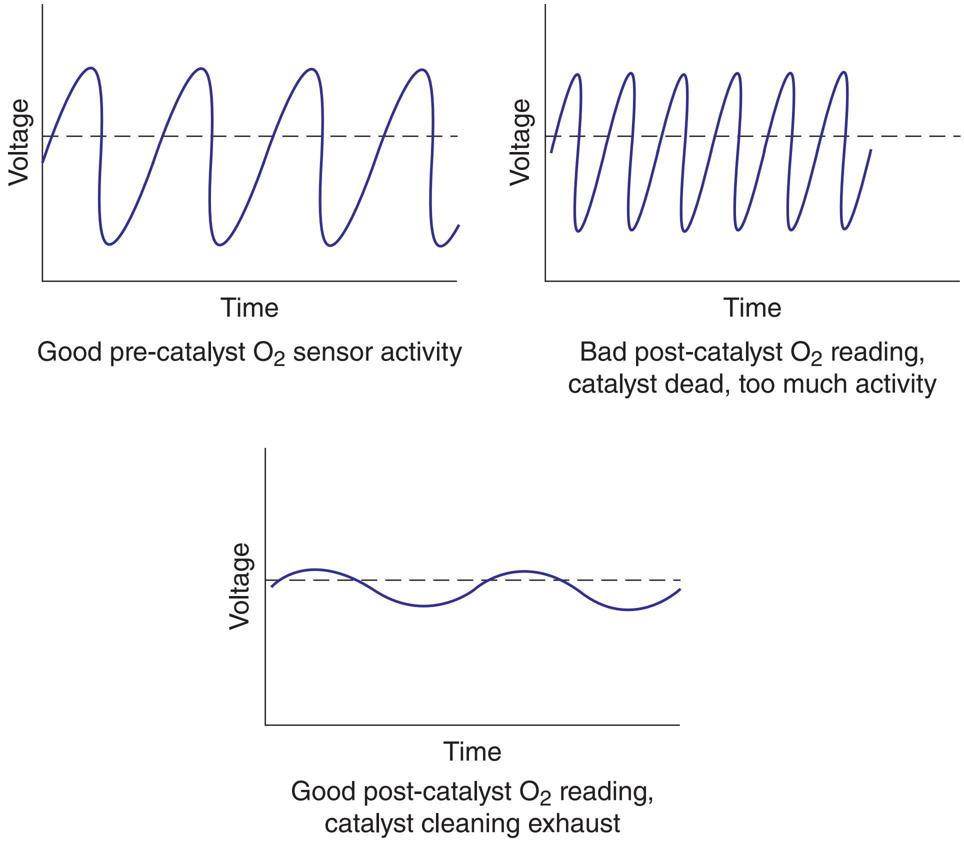


FIGURE 24-20 Oxygen sensor signal for a good and bad catalytic converter.

acceleration for that cylinder is slowed. With a few exceptions, this monitor runs continuously while the engine is running. An example of an exception is during closed-throttle deceleration.

Most OBD II systems allow a random misfire rate of about 2 percent before a misfire is flagged as a fault. It is important to note that this monitor only looks at the crankshaft's speed during a cylinder's firing stroke. It cannot determine if the problem is fuel-, ignition-, or mechanically-related. Misfires are categorized as type A, B, or C. Type A could cause immediate catalyst damage. Type B could cause emissions of 1.5 times the design standard, and type C could cause an I/M failure. When there is a type A misfire, the MIL will flash. If there is a type B misfire, the MIL will turn on but will not flash. Type C misfires will typically not cause the MIL to light or flash.

The misfire monitoring sequence includes an adaptive feature that compensates for variations in engine operation caused by manufacturing tolerances and component wear. It also has the capability to allow vibration at different engine speeds and loads. When an individual cylinder's contribution to engine speed falls below a certain threshold, the misfire monitoring sequence calculates the vibration, tolerance, and load factors before setting a misfire code.

Type A Misfires The monitor checks for type A misfires in 200 revolution increments. If a cylinder misfires between 2 percent and 20 percent of the time, the monitor considers the misfiring to be excessive. This condition may cause the PCM to shut off the fuel injectors at the misfiring cylinder or cylinders to limit catalytic converter heat. When the engine is operating under heavy load, the PCM will not turn off the injectors. If a type A misfire is not corrected, the catalytic converter can be damaged.

If the misfire monitor detects a type A cylinder misfire and the PCM does not shut off the injector or injectors, the MIL light begins flashing. When the misfire monitor detects a type A cylinder misfire, and the PCM shuts off an injector or injectors, the MIL light is illuminated continually.

Type B Misfires To detect a type B cylinder misfire, the misfire monitor checks cylinder misfiring over a 1,000 revolution period. If cylinder misfiring exceeds 2 percent to 3 percent during this period, the monitor considers the misfiring to be excessive. This

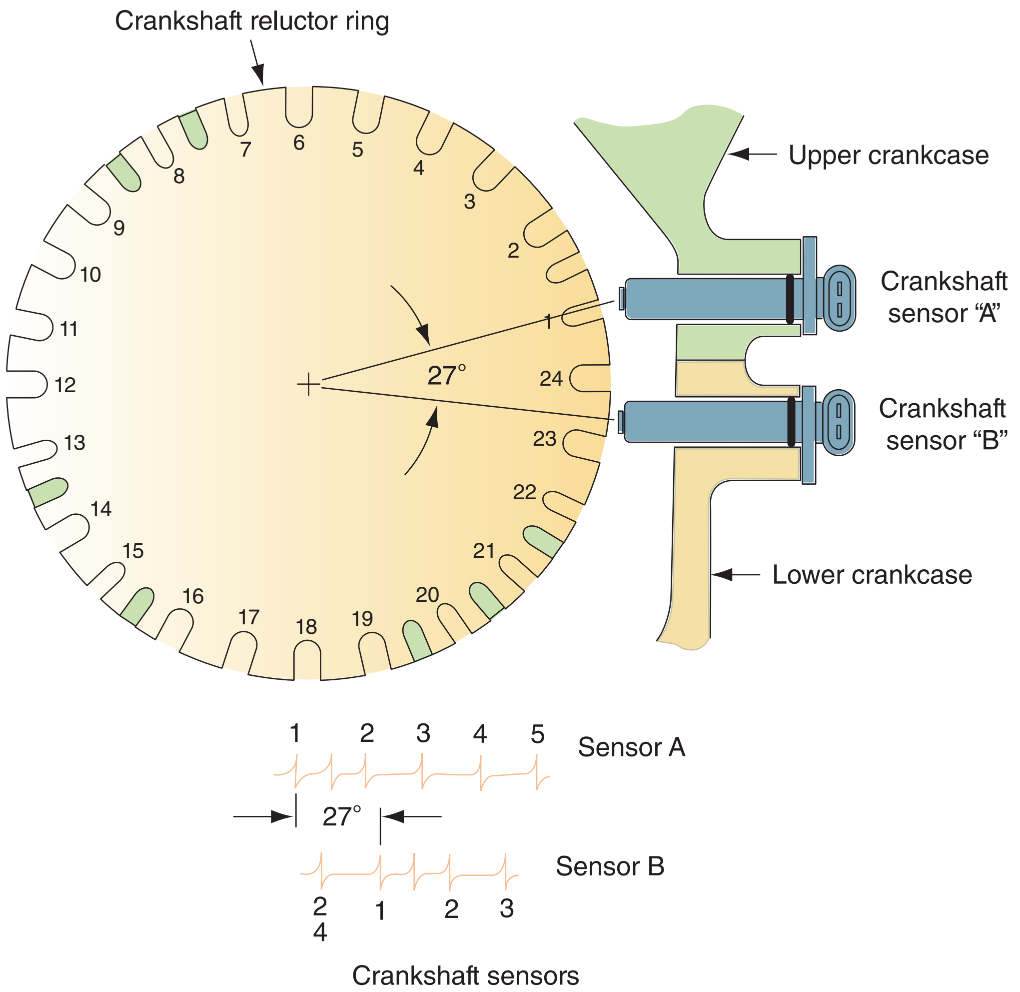


FIGURE 24-21 An example of using two crankshaft sensors to monitor the engine and detect misfire.

amount of cylinder misfiring may not overheat the catalytic converter, but it may cause excessive emission levels. When a type B misfire is detected, a pending DTC is set in the PCM memory. If this fault is detected on a second consecutive drive cycle, the MIL light is illuminated.

Type C Misfires This type of misfire can cause a vehicle to fail an emissions test but will normally not damage the catalytic converter or raise the emissions levels beyond 1.5 times the FTP.

Fuel System Monitoring

The PCM continuously monitors conditions and adjusts the amount of fuel delivered by the injectors. Most of these changes are within a particular range around a base setting. The PCM checks the effectiveness of these changes through feedback from the oxygen sensor. The PCM then makes corrections as necessary. When the PCM needs to make a change outside that range, it will make a fuel trim adjustment. Fuel trim is the required new setting compared to the basic injector pulse width. Remember, the amount of fuel injected into the engine is controlled by the amount of time the injector is turned on.

The system allows for short-term and long-term fuel trim. Short-term fuel trim makes minor adjustments to the pulse width. These adjustments are temporary and not held in memory when the ignition is switched off. Long-term fuel trim is set by the effectiveness of the short-term trim. If the short-term trim meets the requirements of the engine during different operating conditions, the PCM may use those adjustments as the new base for injection timing. Fuel requirements will change as a vehicle ages. As short-term fuel trim averages increase or decrease, a new long-term fuel trim value will be learned and remain in memory. This new long-term value will be such to allow the short-term fuel trim to return to 0 percent correction. The PCM stores fuel trim data in

blocks based on engine load and speed or by air mass entering the engine.

The fuel trim monitor is a continuous monitor and reports the amount of correction made with short term and long term. By monitoring the total amount of fuel trim (short term plus long term), the PCM is checking its ability to control the air-fuel ratio. If the PCM must move the short-term and long-term fuel trims to the lean or rich limits, a DTC is set on the next trip if the condition is still necessary.

Heated Oxygen Sensor Monitor

The system also monitors lean-to-rich and rich-to-lean time responses of the oxygen sensor. This test can pick up a lazy O_2 sensor that cannot switch fast enough to keep proper control of the air-fuel mixture. The time it takes the heated O_2 sensors to send a clean signal to the PCM is also monitored. This gives an indication of how the heater circuit is working.

All of the system's HO_2S are monitored once per drive cycle, but the heated oxygen sensor monitor provides separate tests for the upstream and downstream sensors. The heated oxygen sensor monitor checks the voltage signal frequency of the upstream HO_2S. At certain times, the heated oxygen sensor monitor varies the fuel delivery and checks for HO_2S response. A slow response in the sensor voltage signal frequency indicates a faulty sensor. The sensor signal is also monitored for excessive voltage.

The heated oxygen sensor monitor also checks the frequency of the rear HO_2S signals and checks these signals for excessively high voltage. If the monitor does not detect signal voltage frequency within a specific range, the rear HO_2S are considered faulty. The heated oxygen sensor monitor will command the PCM to vary the air-fuel ratio to check the response of the rear HO_2S.

EGR System Monitoring

The EGR monitors use different strategies to determine if the system is operating properly. Some monitor the temperature within the EGR passages. A high temperature indicates that the valve is open and exhaust gases are moving through the passages. Other systems look at the MAP signal, energize the EGR valve, and look for corresponding change in vacuum levels. As the valve is opening, there should be a drop in vacuum. Some systems open the EGR during coast down and monitor the change in STFT.

The EGR monitor looks at the operation of the EGR valve and the flow rates of the system. It also looks for shorts or opens in the circuit. If a fault is detected in any of the EGR monitor tests, a DTC is set in the PCM memory. If the fault occurs during two drive cycles, the MIL light is illuminated. The EGR monitor operates once per OBD II trip.

There are many different EGR systems used today. The pressure feedback EGR, linear EGR, and delta pressure feedback EGR systems are the most common. If the system uses a delta pressure feedback EGR (DPFE), there is an orifice located under the EGR valve. Small exhaust pressure hoses are connected from each side of this orifice to the DPFE sensor. During the EGR monitor, the PCM first checks the DPFE signal. If this sensor signal is within the normal range, the monitor proceeds with the tests.

The PCM checks EGR flow by checking the DPFE signal against an expected DPFE value for the operating conditions at steady throttle within a specific rpm range.

With the EGR valve closed, the PCM checks for pressure difference at the two pressure hoses connected to the DPFE sensor. When the EGR valve is closed and there is no EGR flow, the pressure should be the same at both pipes. If the pressure is different at these two hoses, the EGR valve is stuck open.

The PCM commands the EGR valve to open and then checks the pressure at the two exhaust hoses connected to the DPFE sensor. With the EGR valve open and EGR flow through the orifice, there should be higher pressure at the upstream hose than at the downstream hose **(Figure 24–22)**.

Evaporative (EVAP) Emission System Monitor

In addition to the various components and failures that could affect the tailpipe emissions on a vehicle, OBD II monitors the fuel evaporative systems. The system tests the ability of the fuel tank to hold pressure and the purge system's ability to vent the gas fumes from the charcoal canister when commanded to do so by the PCM.

Chrysler and others often use a leak detection pump (LDP) to detect leaks in the EVAP system. When specific operating conditions are met, the PCM powers the pump to test the EVAP system. The pump pressurizes the system. As pressure builds, the cycling rate of the pump decreases. If the system does not leak, pressure will continue to build until the pump shuts off. If there is a leak, pressure will not build up and the pump will continue to run.

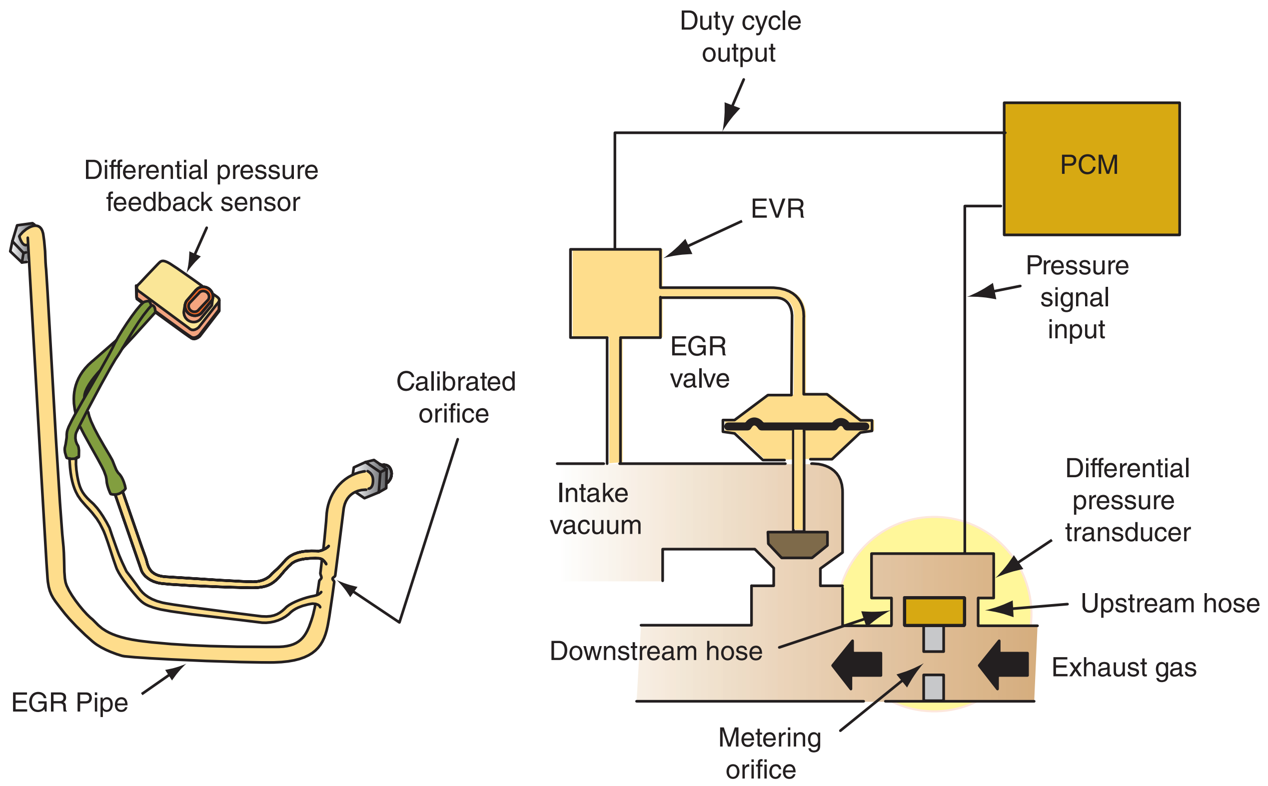


FIGURE 24–22 An EGR system with a delta pressure feedback sensor.

The pump continues to run until the PCM determines it has run a complete test cycle and then sets a DTC. If there are no leaks, the PCM will run the purge monitor. Because of the pressure in the system from the pump, the cycle rate should be high. If no leaks are present and the purge cycle is high, the system passed the test.

In most systems, the EVAP monitor has two parts: the system integrity test that checks for leaks in the tank, gas cap, fuel lines and hoses, canister, and vapor lines, and the purge flow test that checks for blockage in the vapor lines and purge solenoid. During the integrity test, the PCM closes the canister vent solenoid and pulses the purge solenoid until the tank sensor reads a negative pressure of 20 inches of water. The PCM then closes the purge solenoid and measures the time it takes for the vacuum in the tank to decay. The EVAP purge volume test opens the canister vent solenoid and then varies the duty cycle of the purge solenoid until a measured change in STFT occurs. The EVAP monitor will be suspended whenever the fuel tank is less than one-quarter full or more than three-quarters full.

A few EVAP systems have a purge flow sensor (PFS) connected to the vacuum hose between the canister purge solenoid and the intake manifold **(Figure 24–23)**. The PCM monitors the PFS signal once per drive cycle to determine if there is vapor flow or no vapor flow through the solenoid to the intake manifold.

Enhanced EVAP Systems All new vehicles have an enhanced evaporative system monitor since 2003. This system detects leaks and restrictions in the EVAP system **(Figure 24–24)**. This monitor first checks the integrity of the EVAP system. This test is only run when certain enable criteria are met. Once the integrity test is run, the monitor will conduct a vacuum pull-down test. During this test, the PCM commands the EVAP canister vent to close. It then opens the vapor management valve, which allows intake vacuum to draw a small amount of vacuum on the system. If the system has a leak, vacuum will not be held in the system and the monitor will set a DTC. If there are no leaks, the monitor will close the vapor management valve and monitor the system's ability to hold a vacuum. The final check is the vapor generation test. The PCM releases the vacuum in the system and then closes the EVAP system. The monitor looks for pressure changes in the system. An increase in pressure indicates excessive vapor generation.

A specially designed fuel tank filler cap is used on these systems. In these systems, an evaporative system leak or a missing fuel tank cap will cause the

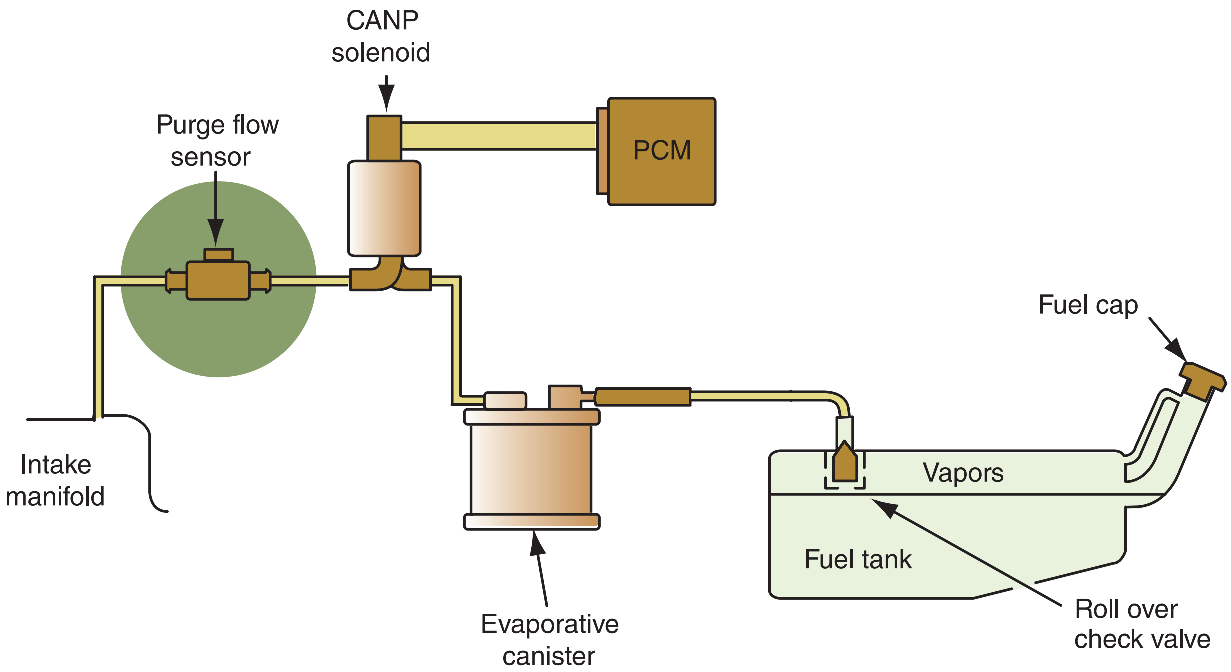


FIGURE 24–23 An EVAP system with a purge flow sensor.

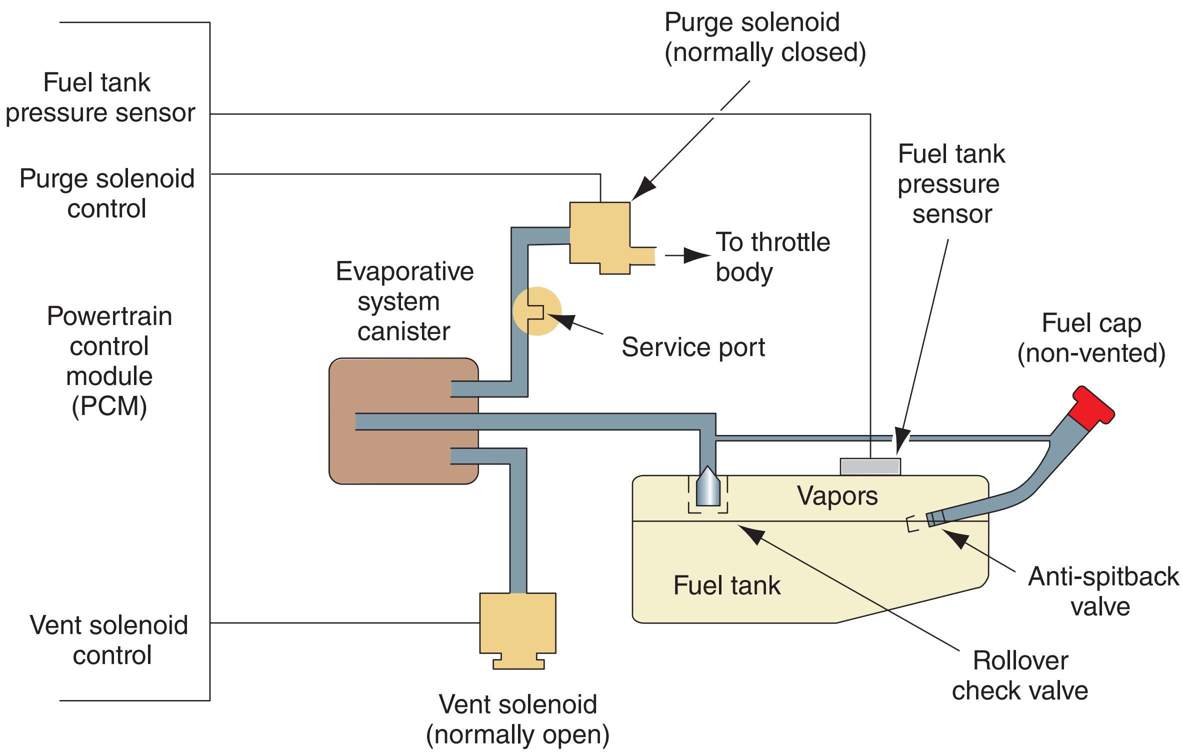


FIGURE 24–24 An enhanced EVAP system.

MIL is turn on. Also, if the fuel filler cap is not on tight enough, the OBD system can detect leaking vapor and the MIL will light up. If the filler cap is then tightened, the indicator will generally go out after a short period. Some vehicles illuminate a "check gas cap" light instead of the MIL.

Secondary Air Injection (AIR) System Monitor

The AIR system operation can be verified by turning the system on to inject air upstream of the O_2 sensor while monitoring its signal. Many older designs inject

SHOP TALK

Many engines do not need to have a secondary air injection system; therefore this monitor does not run.

air into the exhaust manifold when the engine is in open loop and switch the air to the converter when it is in closed loop. If the air is diverted to the exhaust manifold during closed loop, the O_2 sensor thinks the mixture is lean and the signal should drop.

On some vehicles, the AIR system is monitored with passive and active tests. During the passive test, the voltage of the precatalyst HO_2S is monitored from startup to closed-loop operation. The AIR pump is normally on during this time. Once the HO_2S is warm enough to produce a voltage signal, the voltage should be low if the AIR pump is delivering air to the exhaust manifold. The secondary AIR monitor will indicate a pass if the HO_2S voltage is low at this time. The passive test also looks for a higher HO_2S voltage when the AIR flow to the exhaust manifold is turned off by the PCM. When the AIR system passes the passive test, no further testing is done. If the AIR system fails the passive test or if the test is inconclusive, the AIR monitor in the PCM proceeds with the active test.

During the active test, the PCM cycles the AIR flow to the exhaust manifold on and off during closed-loop operation and monitors the precatalyst HO_2S voltage and the short-term fuel trim value. When the AIR flow to the exhaust manifold is turned on, the sensor's voltage should decrease and the short-term fuel trim should indicate a richer condition. The secondary AIR system monitor illuminates the MIL and stores a DTC in the PCM's memory if the AIR system fails the active test on two consecutive trips.

Some vehicles have an electric air pump system. In this system, the air pump is controlled by a solid-state relay. The relay is operated by a signal from the PCM. An air-injection by-pass solenoid is also operated by the PCM. This solenoid supplies vacuum to dual air diverter valves **(Figure 24–25)**.

The PCM monitors the relay and air pump to determine if secondary air is present. This monitor functions once per drive cycle. When a malfunction occurs in the air pump system on two consecutive drive cycles, a DTC is stored and the MIL is turned on. If the malfunction corrects itself, the MIL is turned off after three consecutive drive cycles in which the fault is not present.

Thermostat Monitor

Present on all 2002 and newer vehicles, the thermostat monitor checks the engine and its cooling system for defects that would affect engine temperature and prevent the engine from reaching normal operating temperature. The goal of this monitor is to identify anything that may stop the PCM from going into closed loop. The monitor checks the time it

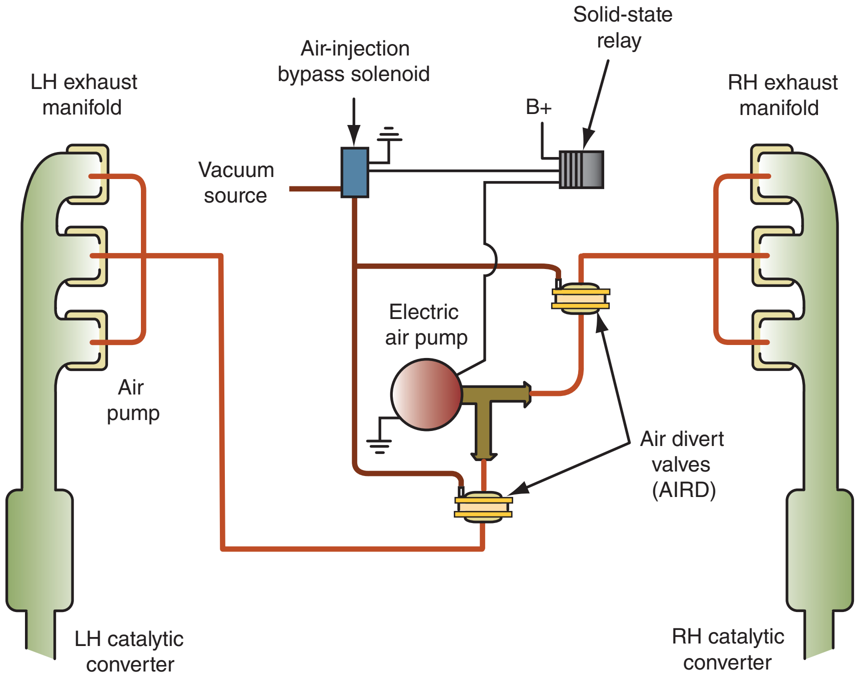


FIGURE 24–25 An electric air pump system.

takes for the cylinder head to reach a specific temperature. If the required temperature is not reached within the desired time, a malfunction is indicated and the monitor will set a pending code. The pending code becomes a real DTC if the malfunction is detected on two consecutive drive cycles. The MIL will be illuminated at that time.

PCV Monitor

The PCV valve removes unwanted vapors from the crankcase. Most of these vapors are HC. The system uses engine vacuum to draw the vapors out and into the intake. If there is a vacuum leak, the system will not work and HC can enter the atmosphere. Also, if there is a leak the engine may stall or not start. The leak causes the engine to run lean, especially at idle. The PCV monitor looks at HO_2S signals for consistent lean readings and the lack of switching from rich to lean. Abnormal signals will cause the monitor to illuminate the MIL after two consecutive driving cycles and will store one or more of the DTCs.

Variable Cam Timing System Monitor

Late-model vehicles equipped with variable valve timing (VVT) use a monitor that checks system operation. Because VVT systems are often used for EGR purposes, the operation of the VVT can directly affect exhaust emissions. The monitor examines the response time for the camshaft position to change based on VVT command and camshaft position measured by the CMP sensor **(Figure 24–26)**. If the response rate is slow, a DTC will set for VVT performance.

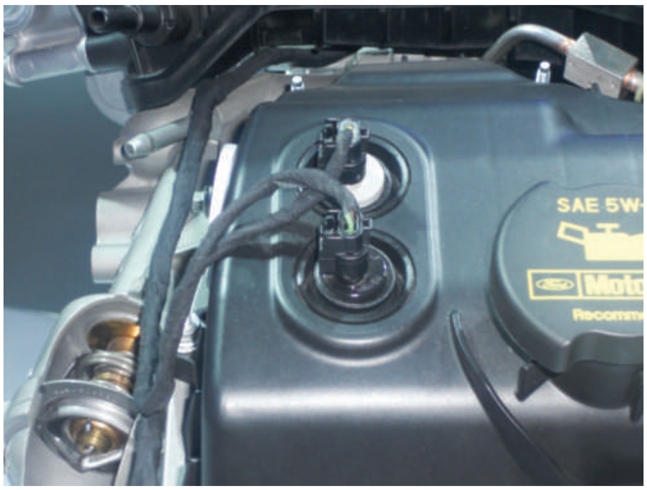


FIGURE 24–26 Location of camshaft sensors.

Electronic Throttle Control System Monitor

Engines equipped with ETC use a separate monitor to evaluate system operation. This is because of the safety concerns related to ETC operation. Instead of using one computer processor for ETC operation, two separate processors and monitoring systems are used. This provides redundant control and monitoring of the system.

If a fault is detected, the monitor may limit rpm, force rpm to remain at idle speed or even force engine shutdown by turning off the fuel injectors.

Comprehensive Component Monitor

The comprehensive component monitor (CCM) is a continuous monitor. It looks at the inputs and outputs that would affect emission levels. The system looks at any electronic input that could affect emissions. The strategy is to look for opens and shorts or input signal values that are out of the normal range. It also looks to see if the actuators have their intended effect on the system and to monitor other abnormalities.

The CCM uses several strategies to monitor inputs and outputs. One strategy for monitoring inputs involves checking inputs or electrical defects and out-of-range values by checking the input signals at the analog digital converter. This monitor also checks the circuits for the various outputs. These circuit checks look for continuity and out-of-range values. If an open circuit is detected, a DTC will be set.

The CCM also checks frequency signal inputs by performing rationality checks. During a rationality check, the monitor uses other sensor readings and calculations to determine if a sensor reading is proper for the present conditions. The following get rationality checks:

- Crankshaft position sensor (CKP)
- Output shaft speed sensor (OSS)
- Camshaft position sensor (CMP)
- Vehicle speed sensor (VSS)

The functional test of the CCM checks most of the outputs by monitoring the voltage of each output solenoid, relay, or actuator at the output driver in the PCM. If the output device is off, this voltage should be high. This voltage is pulled low when the output is turned on.

OBD II Self-Diagnostics

It is important to remember that although the diagnostic capabilities of OBD II are great, the system does not check everything and is not capable of finding the cause of all driveability problems. Not all problems will activate the MIL or store a DTC. A DTC only indicates that a problem exists somewhere in a system, in the circuit of the sensor, or in an output. A technician's job is to find the problem. Often DTCs are set that indicate an out-of-range reading by a sensor. This does not mean the sensor is bad. The abnormal signals can be caused by engine mechanical problems or faults in the air, fuel, ignition, emission control, and other systems. Retrieving the information stored in the PCM is a starting point for diagnosis.

When no DTCs are present but there is a driveability problem, or when determining the true cause of the DTC, the basic engine should be checked before moving to the support systems. Many engine control systems offer a running compression test. This test runs much like the misfire monitor. The speed of the crankshaft between cylinder firings is measured and compared. If one or more cylinders accelerate slower on the power stroke, there may be a compression problem. This test should be followed up with the other standard engine mechanical tests.

GO TO Chapter 9 for the procedures for conducting the various engine mechanical tests.

MIL

According to OBD II regulations, the PCM must illuminate the MIL when it detects a problem that affects emissions. Also, when a malfunction is detected, a DTC must be set. Depending on the problem, the MIL will either light and stay on or it will blink. The action of the MIL depends on the monitor and the problem. For example, a misfire that would allow emissions to exceed regulations but not damage the catalyst will light the MIL. If the misfire will raise the catalytic converter's temperature enough to destroy it, the MIL will blink.

The MIL will be turned off if the misfire did not occur during three consecutive drive cycles. This requirement is true for most monitors. But an appropriate DTC will be recorded, as will freeze frame data. If the same fault is not detected during forty warm-up cycles, the DTC and freeze frame data are erased from active memory. However, the DTC and freeze frame data will be stored as a history code with freeze frame data until it is cleared.

Diagnostic Trouble Codes

OBD II codes are standardized, which means that most DTCs mean the same thing regardless of the vehicle. However, vehicle and scan tool manufacturers can have additional DTCs and add more data streams, report modes, and diagnostic tests. DTCs are designed to indicate the circuit and the system where a fault has been detected.

An OBD II DTC is a five-character code with both letters and numbers **(Figure 24–27)**. This is called the alphanumeric system.

The first character of the code is a letter. This defines the system where the code was set. Currently there are four possible first character codes: "B" for body, "C" for chassis, "P" for powertrain, and "U" for undefined. The U-codes are designated for future use.

The second character is a number. This defines the code as being a mandated code or a special manufacturer code. A "0" code means that the fault is defined or mandated by OBD II. A "1" code means the code is manufacturer specific. As an example, all OBD II vehicles can set a P0300 random cylinder

First digit—Letter indicates component group area
- P = Powertrain
- B = Body
- C = Chassis
- U = Network communications

Second digit
- 0 = SAE or OBD mandated
- 1 = Manufacturer specific

Third digit—Subgroup, powertrain subgroups:
- 0 = Total system
- 1 = Fuel and air metering
- 2 = Fuel and air metering
- 3 = Ignition system or misfire
- 4 = Auxiliary emission controls
- 5 = Idle speed control
- 6 = PCM and auxiliary inputs
- 7 = Transmission
- 8 = Transmission

Fourth and fifth digits—Defines the area or component and basic problem

FIGURE 24–27 Interpreting OBD II DTCs.

misfire code. The "P0" indicates this is an OBD II code common to all makes, models, and engines. A manufacturer code, such as P1259, is specific to a particular system or component that is not common across all engines. In this case, a P1259 refers to a problem with the V-TEC system used by Honda and Acura vehicles. Codes of "2" or "3" are designated for future use.

The third through fifth characters can be letters or numbers. These describe the fault. The third character tells indicates where the fault occurred. The remaining two characters describe the exact condition that set the code. The digits are organized so that the various codes related to a particular sensor or system are grouped together.

Not all DTCs will cause the MIL to light; this depends on the monitor and the problem. DTCs that will not affect emissions will never illuminate the MIL. Basically there are three types of DTCs. An active or current DTC represents a fault that was detected and occurred during two trips. When a two-trip fault is detected for the first time, a DTC is stored as a pending code. A pending DTC is a code representing a fault that has occurred but that has not occurred enough times to illuminate the MIL. There are some DTCs that will set in one trip; again this depends on the monitor.

Freeze Frame Data

One of the mandated capabilities of OBD II is the "**freeze frame**" or snapshot feature. Although the regulations mandate just emission-related DTCs, manufacturers can choose to include this feature for other systems. With this feature, the PCM takes a snapshot of the activity of the various inputs and outputs at the time the PCM illuminated the MIL. The PCM uses this data for identification and comparison of similar operating conditions if the same problem occurs in the future. This feature is also valuable to technicians, especially when trying to identify the cause of an intermittent problem. The action of sensors and actuators when the code was set can be reviewed. This can be a great help in identifying the cause of a problem. The information held in freeze frame are actual values; they have not been altered by the adaptive strategy of the PCM **(Figure 24–28)**.

Once a DTC and the related freeze frame data are stored in memory, they will stay there even if other emission-related DTCs are set. However, if a fault occurs that has a greater effect on emission, the freeze frame of a lower priority fault may be overwritten by the data of the more serious fault. For example, if a freeze frame is stored for a small EVAP leak, this data may be overwritten if a catalyst damaging misfire occurs. The data is stored by priority; information related to misfire and fuel control have priority over other DTCs. This data is lost if the vehicle's battery is disconnected or it can be erased with a scan tool. When a scan tool is used to erase a DTC, it automatically erases all associated freeze frame data.

Generic and Enhanced Data

Within the OBD II computer, there are two different types of access: generic, also called Global OBD II, and enhanced. Enhanced is sometimes called OE or the manufacturer side of the system. These two inter-connected systems both provide access to codes and data, but do so differently.

Generic OBD II provides access to the test modes discussed in the next section. This access can be used by tools such as code readers and aftermarket scan tools, such as those made by Snap-on, Bosch, OTC, and others. The data available is often limited compared to that which is available when using the OE scan tool or one that can access enhanced data. To obtain data using the generic mode, the tool does not need to be programmed to the vehicle. This means that entering VIN information is not necessary to access the serial data stream. It is important to remember that generic access is for emission control system purposes only. You will not be able to see other systems, such as ABS or body systems, when using generic mode.

Enhanced data often provides access to a greater number of PIDs and to more systems for bidirectional control. To utilize enhanced functions, the scan tool must be programmed to the vehicle, requiring entering VIN information into the scan tool. Late-model systems often have automatic VIN identification by

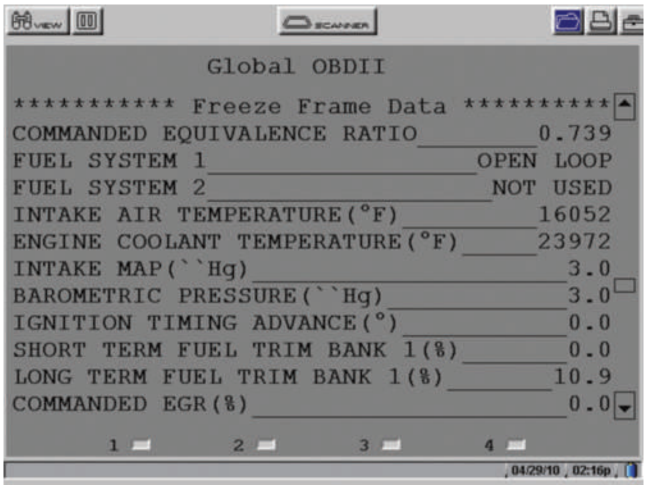


FIGURE 24–28 An example of the data captured in a freeze frame for a DTC.

the scan tool so manual VIN entry is not necessary. When using enhanced data, especially with the OE scan tool, you will find you have access to systems other than powertrain and emissions.

Many technicians begin their diagnosis by using generic mode to check for DTCs and freeze frame data. In many cases, the generic data is sufficient to diagnose and repair a fault.

Generic Test Modes

All OBD II systems have the same basic test modes and all are accessible with a generic OBD II scan tool. Always refer to the manufacturer's information when using these test modes for diagnosis. Photo Sequence 22 shows the procedure for preparing a Snap-on scan tool to read OBD II data.

Mode 1 is the **parameter identification (PID)** mode. This mode allows access to current emission-related data values of inputs and outputs, calculated values, and system status information. Some PID values are manufacturer specific; others are common to all vehicles. This information is referred to as **serial data (Figure 24–29)**.

Mode 2 is the freeze frame data access mode. This mode permits access to emission-related data values from specific generic PIDs. The number of freeze frames that can be stored is limited. The freeze frame information updates if the condition recurs.

Mode 3 permits scan tools to obtain stored DTCs. The information is transmitted from the PCM to the scan tool following a Mode 3 request. The DTC or its descriptive text, or both, can be displayed on the scan tool.

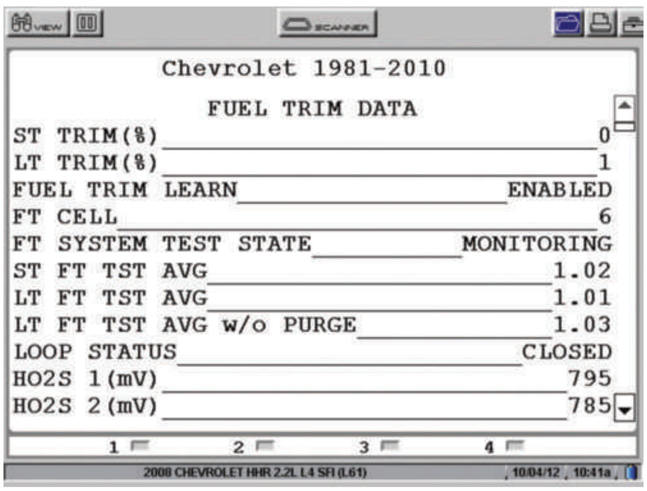


FIGURE 24–29 An example of what is available when a technician looks at the serial data on a scan tool.

Mode 4 is the PCM reset mode. It allows the scan tool to clear all emission-related diagnostic information from its memory. When this mode is activated, all DTCs, freeze frame data, DTC history, monitoring test results, status of monitoring test results, and on-board test results are cleared and reset.

Mode 5 is the oxygen sensor monitoring test for pre-CAN vehicles. This mode gives the actual oxygen sensor outputs during the test cycle. These are stored values, not current values that are retrieved in Mode 1. This information is used to determine the effectiveness of the catalytic converter.

Mode 6 is the output state mode (OTM) and can be used to identify potential problems in the non-continuous monitored systems.

Mode 7 reports the test results for the continuous monitoring systems **(Figure 24–30)**.

Mode 8 is the request for control of an on-board system test or component mode. It allows the technician to control the PCM, through the scan tool, to test a system. In some cases, the scan tool will only set the conditions for conducting a test and not actually conduct the test. An example of this is the EVAP leak test, which is done with other test equipment.

Mode 9 is the request for vehicle information mode. This mode reports the vehicle's identification number, calibration identification, and calibration verification. This information can be used to see if the most recent calibrations have been programmed into the PCM.

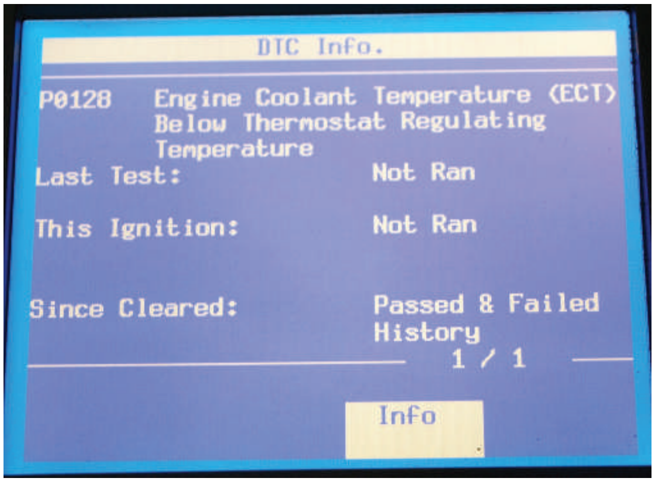
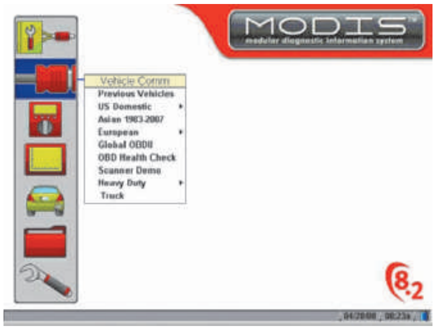


FIGURE 24–30 In test Mode 7, the DTCs reported in Continuous Tests and Pending Codes are pending DTCs. If the conditions are detected again, the DTCs will be stored as active DTCs.

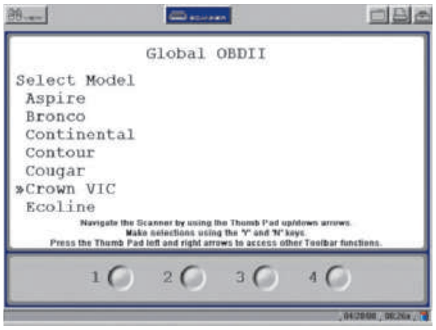
PHOTO SEQUENCE 22

Preparing a Snap-on scan tool to Read OBD II Data



P22-1 Once the Modis is connected to the vehicle, select the category you wish to check. Global OBD II is for all non-manufacturer specific data.

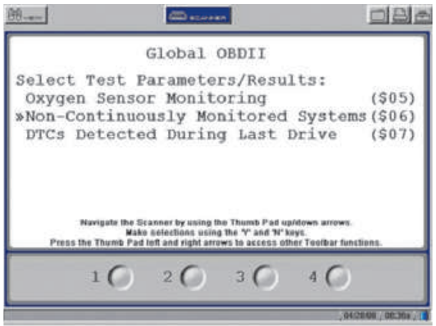
P22-2 After the tool enters into the generic OBD II mode, select Diagnose to check the system.



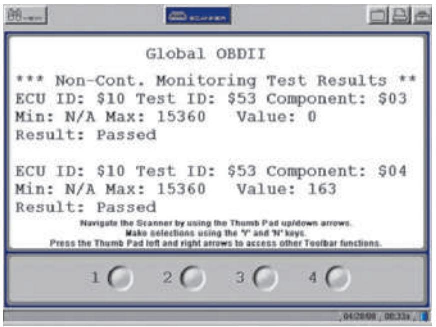
P22-3 Select the make of the vehicle and then the model.

P22-4 The tool will display basic information about the control system.

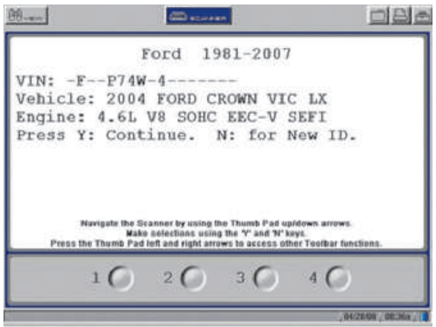
P22-5 The display will ask what you want to do.



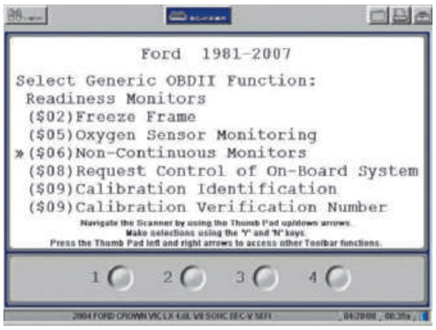
P22-6 Mode 6 and other test parameters can be selected.



P22-7 Test results for the selected tests will appear on the tool.



P22-8 Mode 6 data can be retrieved by entering specific vehicle information, such as the VIN.



P22-9 Data from the non-continuous monitors (Mode 6) will be displayed.

Mode 10 or 0A displays DTCs that may have been cleared but have not yet been removed from memory. Called permanent trouble codes, these DTCs are kept in memory until the associated monitor successfully runs and completes to clear the code. For example, a failed catalytic converter sets a P0420 in memory. A shop replaced the converter and clears the code but the P0420 is retained by Mode 10 until the catalyst monitor successfully runs and passes. Once the monitor is complete, the DTC is released.

Basic Diagnosis of Electronic Engine Control Systems

Diagnosing a computer-controlled system is much more than accessing DTCs. You need to know what to test, when to test it, and how to test it. Because the capabilities of the engine control computer have evolved from simple to complex, it is important to know the capabilities of the system you are working with before attempting to diagnose a problem. Refer to the service information for this information. After you understand the system and its capabilities, begin your diagnosis using your knowledge and logic.

The importance of logical troubleshooting cannot be overemphasized. The ability to diagnose a problem (to find its cause and its solution) is what separates an automotive technician from a parts changer.

Logical Diagnosis

When faced with an abnormal engine condition, the best automotive technicians compare clues (such as scan tool data, meter readings, oscilloscope readings, visible problems) with their knowledge of proper conditions and discover a logical reason for the way the engine is performing. Logical diagnosis means following a simple basic procedure. Start with the most likely cause and work to the most unlikely. In other words, check out the easiest, most obvious solutions first before proceeding to the less likely, and more difficult, solutions. Do not guess at the problem or jump to a conclusion before considering all of the factors.

The logical approach has a special application to troubleshooting electronic engine controls. Always check all traditional nonelectronic engine control possibilities before attempting to diagnose the electronic engine control system. For example, low battery voltage might result in faulty sensor readings. Remember, even the most advanced on-board computer system is not capable of correcting for mechanical engine problems. Incorrect valve timing, sticking valves, low compression, and vacuum leaks may present problems that appear to be computer or sensor faults.

Repair Information

All late-model engine controls have self-diagnosis capabilities. A malfunction in any sensor, output device, or in the computer itself is stored as a DTC. DTCs are retrieved and the indicated problem areas checked further. Correct diagnosis depends on correctly interpreting all data collected and performing all subsequent tests properly. The following service information will help:

- Instructions for retrieving DTCs and obtaining freeze frames
- Instructions for diagnosing a no communication problem between the system and the scan tool
- Current technical bulletins for the vehicle
- A fail-safe chart that shows what strategy is taken when certain DTCs are set
- The operating manual for the scan tool
- A DTC chart with the codes and possible problem areas
- A parts locator for the system
- An electrical wiring diagram for the system
- Identification of the various terminals of the PCM
- A DTC troubleshooting guide
- Component testing sequences

Diagnosing OBD II Systems

At least one drive cycle is required for the monitors to run. All OBD II scan tools include a readiness function that shows all of the monitoring sequences and the status of each: complete or incomplete. Some systems may show the monitors as ready or not-ready. Incomplete can mean the monitor did not complete, judgment is withheld pending further testing, the monitor did not operate, or the monitor operated and recorded a failure. The “Readiness Test” and “Monitor Status” screens on most scan tools contain identical information **(Figure 24–31)**.

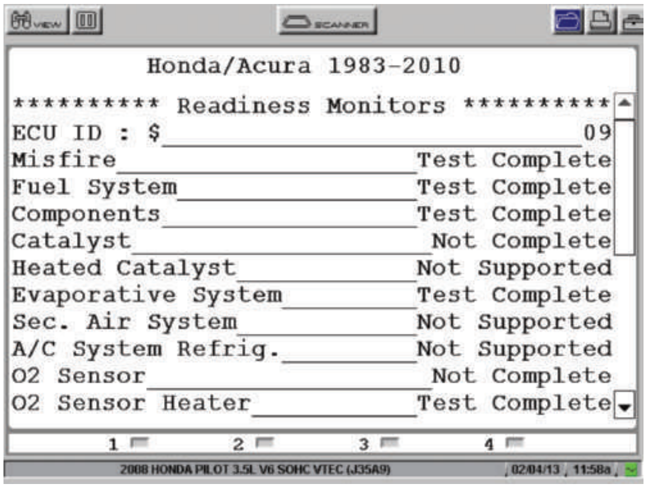


FIGURE 24–31 These scan tool displays show which monitors have been completed, are available, are not available, and have been completed.

Readiness monitor tools are available. These plug into the DLC and alert the technician when a drive cycle is completed. These can save much time while trying to gather data before and after a repair. They are especially handy after a repair has been made. The vehicle is taken for a test drive and when the readiness monitor flashes and/or beeps, the vehicle can be brought back into the shop and checked for DTCs.

Troubleshooting OBD II Systems

The following steps provide a general outline for troubleshooting OBD II systems. There are slight variations in different years and with different models. Always refer to the manufacturer's information before beginning your diagnosis. Troubleshooting OBD II systems involves a series of steps as listed in **(Figure 24–32)**. Here is a brief discussion of each step:

1. *Interview the Customer.* Gather as much information as possible from the customer. Ask the customer to describe the driving conditions present when the problem appears. This should include weather, traffic, and speed.
2. *Check the MIL.* The MIL should turn on when the ignition is turned on and the engine is not running. When the engine is started, the MIL should go off. If either of these does not occur, troubleshoot the lamp system before continuing.
3. *Connect the Scan Tool.* Make sure the tool is OBD II compliant.
4. *Check DTC(s) and Freeze Frame Data.* When using a scan tool, an asterisk (*) next to the DTC often indicates there is stored freeze frame data associated with that DTC. During diagnostics, it is helpful to know the conditions present when the DTC was set, such as: Was the vehicle running or stopped, what was the engine's temperature, and was the air-fuel ratio rich or lean? Print or record all DTC and related information. If there was a no or poor communication DTC, solve that problem before continuing.
5. *Check Service History and Service Publications.* There may be a TSB or other service alert that may have the necessary repair information. Check these and follow the procedures outlined in them before continuing. This is especially important to note whether an updated calibration or flash is available. Hours of lost diagnostic time can wasted trying to diagnose and solve a problem addressed by a new software release. Service history can give clues about the cause of the problem because the problem may be related to a recent repair.
6. *Visual Inspection.* Take a quick look at the very basics. Check all wires to make sure they are firmly connected and not damaged. Try not to wiggle the wires while doing this; a wiggle may correct an intermittent problem and it may be hard to find later. Conduct a visual inspection on the battery and fuel level. Correct any problems if necessary. If the engine does not start, move down to step 8.
7. *Check DTCs.* Repeat step 4. If there are no DTCs, check the status of the monitors' readiness and the pending codes on the scan tool. Do what is necessary to complete the necessary drive cycles before continuing. For many DTCs, the PCM will enter into the fail-safe mode. This means the PCM has substituted a value to allow the engine to run. Refer to the service information to determine if any DTCs indicate the fail-safe mode; if so, follow the appropriate diagnostic steps. If there is a DTC, proceed to step 9. If no DTCs are present, go to step 10.
8. *Basic Inspection.* When the DTC is not confirmed in the previous check, diagnosis of the engine's support system should be done. Use the problem symptoms chart in the service information to diagnose when a no code is displayed but the problem is still occurring.
9. *DTC Chart.* Use the DTC chart to determine what was detected, the probable problem areas, and how to diagnose that DTC **(Figure 24–33)**.

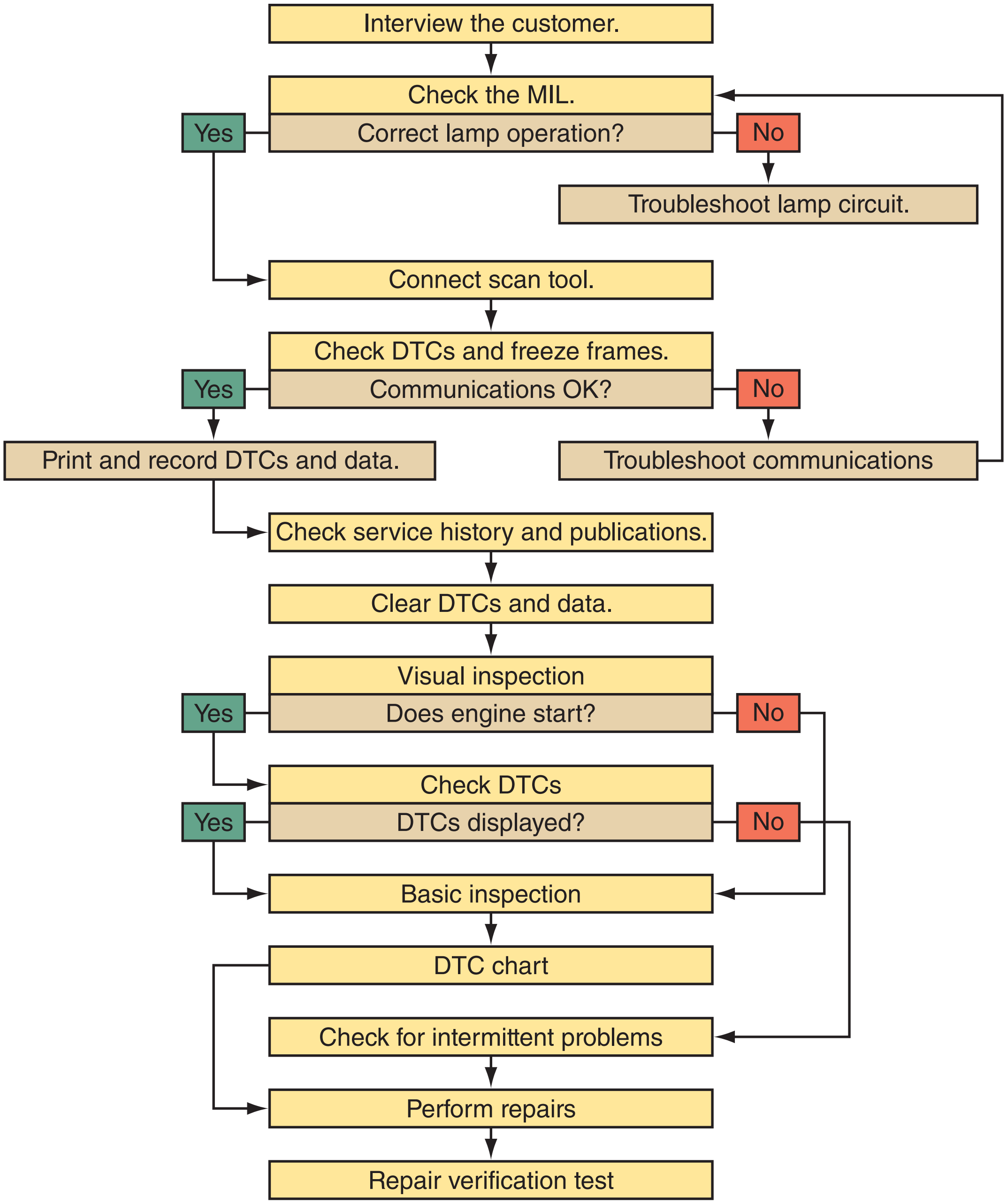


FIGURE 24-32 The steps that should be followed when troubleshooting OBD II systems.

10. *Check for Intermittent Problems.* If the cause of the problem has not yet been determined, proceed to check for an intermittent problem.
11. *Perform Repairs.* Once the cause of the concern has been identified, perform all required services.
12. *Repair Verification Test.* After making a repair, check your work by repeating steps 2, 3, and 4.

Intermittent Faults

An intermittent fault is a fault that is not always present. It may not activate the MIL or cause a DTC to be set. Therefore, intermittent problems can be difficult to diagnose. By studying the system and the relationship of each component to another, you should be able to create a list of possible causes for the intermittent problem. To help identify the cause, follow these steps:

1. Observe the history DTCs, DTC modes, and freeze frame data.
2. Call technical assistance for possible solutions. Combine your knowledge of the system with the service information that is available.
3. Evaluate the symptoms and conditions described by the customer.

DTC #	Detection Item = the system that has the problem	Trouble Area = the suspected problem area of the system	The MIL is lit (Y/N)	Information is held in Memory (Y/N)
P0100	Mass Air flow circuit malfunction	■ Open or short in MAF circuit ■ Faulty MAF sensor ■ Faulty PCM	N	Y
P0101	MAF circuit–range/ performance problem	Faulty MAF sensor	Y	Y
P0110	Faulty IAT circuit	■ Open or short in IAT circuit ■ Faulty IAT ■ Faulty PCM	Y	Y
P0115	Faulty ECT circuit	■ Open or short in ECT circuit ■ Faulty ECT ■ Faulty PCM	Y	Y

FIGURE 24–33 An explanation of a typical DTC chart.

4. Use a check sheet to identify the circuit or electrical system component that may have the problem.
5. Follow the suggestions for intermittent diagnosis found in service material.
6. Visually inspect the suspected circuit or system.
7. Use the data capturing capabilities of the scan tool.
8. Test the circuit's wiring for shorts, opens, and high resistance. This should be done with a DMM and in the typical manner, unless instructed differently in the service information.

Most intermittent problems are caused by faulty electrical connections or wiring. Refer to a wiring diagram for each of the suspected circuits or components. This will help identify all of the connections and components in that circuit. The entire electrical system of the suspected circuit should be carefully and thoroughly inspected. Check for burnt or damaged wire insulation, damaged terminals at the connectors, corrosion at the connectors, loose connectors, wire terminals loose in the connector, and disconnected or loose ground wire or straps. The absence of a visual problem with a connector or terminal does not mean that a problem does not exist. Perform a pin drag test to check the connection between the male and female terminals in a suspect connector. This requires inserting the correct male terminal into the female terminal and noting the amount of drag or tension between the two. If the male terminal easily slides or falls out of the female terminal, examine the cavity of the female terminal for damage.

To locate the source of the problem, a voltmeter using the MIN/MAX function can be connected to the suspected circuit and the wiring harness wiggled **(Figure 24–34)**. As a guideline for what voltage should be expected in the circuit, refer to the reference value table in the service information. If the voltage reading changes with the wiggles, the problem is in that circuit. The vehicle can also be taken for a test drive with the voltmeter connected. If the voltmeter readings become abnormal with changing operating conditions, the circuit being observed probably has the problem.

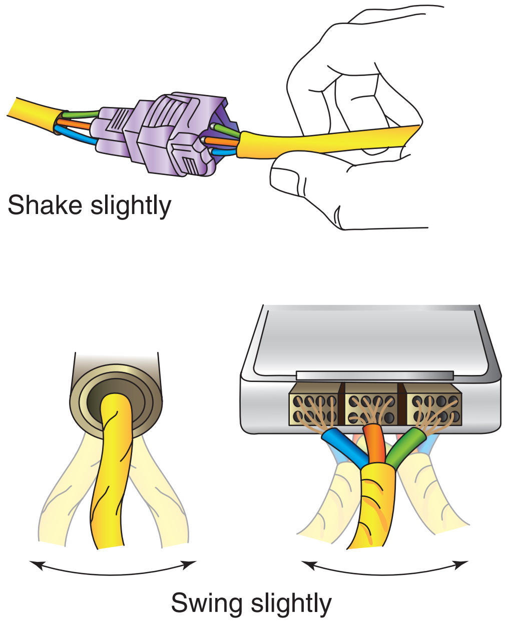


FIGURE 24–34 The wiggle test can be used to locate intermittent problems.

The vehicle can also be taken for a test drive with the scan tool connected. The scan tool can be used to monitor or record the activity of a circuit while the vehicle is being driven. This allows you to look at a circuit's response to changing conditions. The snapshot or freeze frame feature stores engine conditions and operating parameters at command or when the PCM set a DTC. If the snapshot can be taken when the intermittent problem is occurring, the problem will be easier to diagnose.

With an OBD II scan tool, actuators can be activated and their functionality tested. The results of the change in operation can be monitored. Also, the outputs can be monitored as they respond to input changes. When an actuator is activated, watch the response on the scan tool. Also listen for the clicking of the relay that controls that output. If no clicking is heard, measure the voltage at the relay's control circuit; there should be a change of more than 4 volts when it is activated.

To monitor how the PCM and an output respond to a change in sensor signals, use the scan tool. Select the mode that relates to the suspected circuit and view, then record, the scan data for that circuit. Compare the reading to specifications. Then create a condition that would cause the related inputs to change. Observe the data to see if the change was appropriate.

Parameter Identifications

Parameter identification codes, usually called PIDs, identify which pieces of data the scan tool is requesting. When a scan tool is connected to the DLC and serial data is displayed, the scan tool is asking the computer to see sensor data that is categorized by the parameter ID. For example, when you use the scan tool to observe engine coolant temperature sensor data, the scan tool requests data from Mode $01 PID 5. Regardless of what scan tool is used on an OBD II equipped vehicle, requesting generic data from Mode $01 PID 5 will show ECT data. The list of PIDs is standardized and has been updated since the introduction of OBD II.

Generic PIDs can be accessed by any type of scan tool or code reader with generic functions. To access enhanced or manufacturer PIDs requires using either an enhanced or manufacturer's scan tool. Because of these two separate sets of PIDs, not all data is available on a generic scan tool using Mode $01. The standardized data enables the use of generic scan tools and code readers to access OBD II data under the SAE J1979 standards.

Often the scan tool has the ability to show or hide PIDs based on user preferences. Reducing the number of PIDs shown can speed up the transfer of data between the vehicle and the scan tool, which allows the data displayed to update more quickly. The scan tool and or service information may also have details about typical values, min/max values, and complete descriptions for each PID.

Serial Data

PIDs are codes used to request data from a PCM. A scan tool is used for the request and receipt of the serial data. To do this, the desired PID **(Figure 24–35)** is entered into the scan tool. The device connected to the CAN bus that is responsible for this PID reports the value for that PID back to the bus and is read on the scan tool. Many PIDs are standard for all OBD II systems; however, not all vehicles will support all PIDs and there are manufacturer-defined PIDs that are not part of the OBD II standard.

Manufacturers list and define the various applicable PIDs in their service information. This information should be compared to the observed data. If an item is not within the normal values, record the difference and diagnose that particular item.

Connecting a scan tool and reviewing serial data is shown in Photo Sequence 23.

Using Mode 6

Mode 6 allows access to the results of various monitor diagnostic tests. The test values are stored at the time each monitor is completed. The information available in Mode 6 can be extremely helpful, but it also can be very difficult to decipher. Mode 6 data is given with $ signs, test IDs (TIDs), and content IDs (CIDs) and a mixture of letters and numbers. Most of this has no face value because it is given in "hexadecimals," which is foreign language. For example, the hex code for the number 10 is $0A. This is why it is recommended that only scan tools capable of interpreting this data be used. The way to observe Mode 6 data on a scan tool varies with the make and model of the tool. **(Figure 24–36)** Always refer to the tool's instruction manual.

If the scan tool you are using reads Mode 6 data but does not translate it into usable data, you can still use the date supplied by the tool. You will need to access the Mode 6 data supplied on the websites of many auto manufacturers. Using the information from the scan tool and the information from the manufacturer, you should be able to determine what each TID means and what the reported values represent.

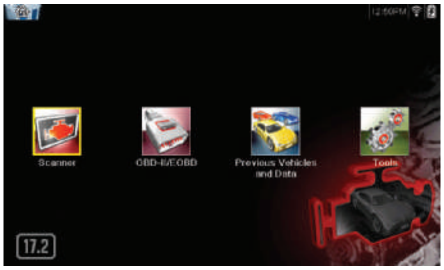
Freeze Frame	Acronym	Description	Measurement Units
X	AAT	Ambient Air Temperature	Degrees
X	AIR	Secondary Air Status	On/Off
X	APP_D	Accelerator Pedal Position D	%
X	APP_E	Accelerator Pedal Position E	%
X	APP_F	Accelerator Pedal Position F	%
X	CATEMP11	Catalyst Temperature Bank 1, Sensor 1	Degrees
X	CATEMP12	Catalyst Temperature Bank 1, Sensor 2	Degrees
X	CATEMP21	Catalyst Temperature Bank 2, Sensor 1	Degrees
X	CATEMP22	Catalyst Temperature Bank 2, Sensor 2	Degrees
	IAT	Intake Air Temperature	Degrees
X	LOAD	Calculated Engine Load	%
X	LOAD_ABS	Absolute Load Value	%
X	LONGFT1	Current Bank 1 Fuel Trim Adjustment (kamref1) from Stoichiometry, Which Is Considered Long Term	%
X	LONGGFT2	Current Bank 2 Fuel Trim Adjustment (kamref2) from Stoichiometry, Which Is Considered Long Term	%
X	MAF	Mass Air Flow Rate	gm/s-lb/min
	MIL_DIST	Distance Traveled with MIL on	Kilometer
X	O2S11	Bank 1 Upstream Oxygen Sensor (11)	Volts
X	O2S12	Bank 1 Downstream Oxygen Sensor (12)	Volts
X	O2S13	Bank 1 Downstream Oxygen Sensor (13)	Volts
X	O2S21	Bank 2 Upstream Oxygen Sensor (21)	Volts
X	O2S22	Bank 2 Downstream Oxygen Sensor (22)	Volts
X	O2S23	Bank 2 Downstream Oxygen Sensor (23)	Volts
X	SHRTFT1	Current Bank Fuel Trim Adjustment (lambse1) from Stoichiometry, Which Is Considered Short Term	%
X	SHRTFT2	Current Bank 2 Fuel Trim Adjustment (lambse1) from Stoichiometry, Which Is Considered Short Term	%
X	SPARKADV	Spark Advance Requested	Degrees
X	SPARK_ACT	Spark Advance Actual	Degrees
	TAC_PCT	Commanded Throttle Actuator	%
X	TP	Throttle Position	%
X	VSS	Vehicle Speed Sensor	km/h-mph

FIGURE 24–35 A sample list of generic PIDs.

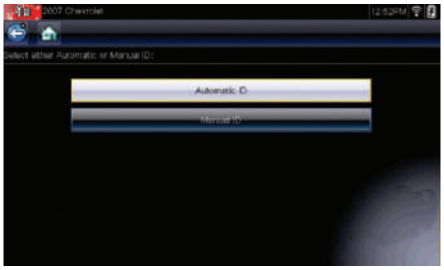
PHOTO SEQUENCE 23

Diagnosis with a Scan Tool

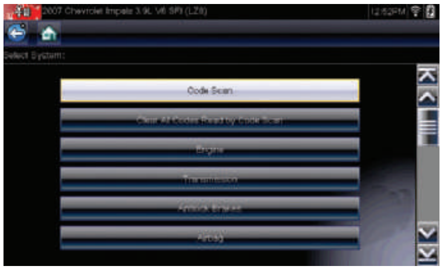
P23-1 Connect the scan tool to the DLC. The tool should power up once connected.



P23-2 To use vehicle-specific functions, select Scanner from the main menu.



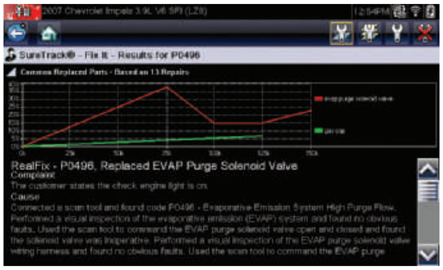
P23-3 Select either Automatic ID (if supported) or enter the vehicle's model year and VIN code into the scan tool.



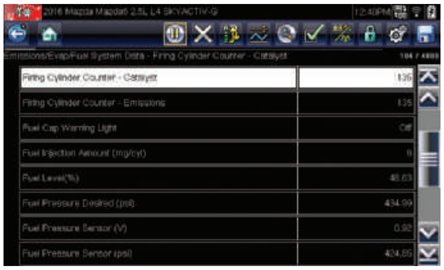
P23-4 Code Scan shows the results of which modules have stored DTCs.

P23-5 Select Engine to view powertrain codes.

P23-6 Retrieve the DTCs with the scan tool.



P23-7 Interpret the codes by using the service information or the information available on the scan tool.



P23-8 Start the engine and obtain the input sensor and output actuator data on the scan tool. If a printer for the tool is available, print out the data report.

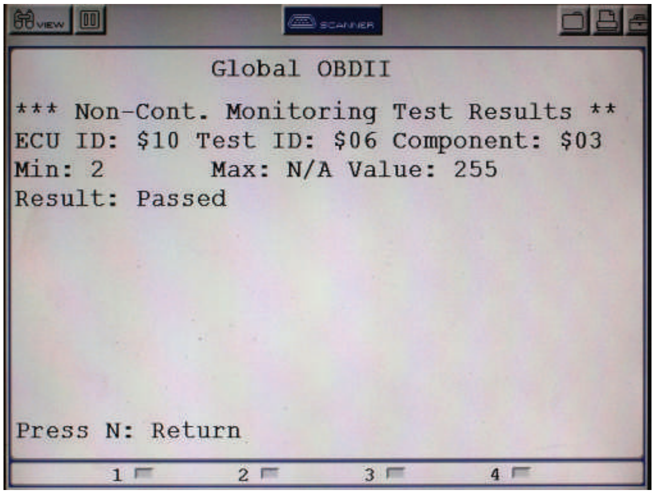


FIGURE 24-36 An example of how Mode 6 data may be displayed.

Mode 6 data can help identify the cause of problems when a DTC has not been retrieved. Manufacturers normally list the various normal Mode 6 values. To effectively use Mode 6 data, compare the captured reading with the normal values. Then use logic and your knowledge of the system, part, and electricity to determine what is abnormal and what could be causing that. Some manufacturers recommend using Mode 6 to diagnose specific systems. Using this data is also very handy in diagnosing any system of the control circuit.

Repairing the System

After identifying the cause of the problem, repairs should be made. When servicing or repairing OBD II circuits, the following guidelines are important:

- Do not connect aftermarket accessories into an OBD II circuit or network.
- Do not move or alter grounds from their original locations.
- Always replace a relay with an exact replacement. Damaged relays should be thrown away, not repaired.
- Make sure all connector locks are in good condition and are in place.
- After repairing connectors or connector terminals, make sure the terminals are properly retained and the connector is sealed.
- When installing a fastener for an electrical ground, be sure to tighten it to the specified torque.

After repairs, the system should be rechecked to verify that the repair took care of the problem. This may involve road testing the vehicle in order to verify that the complaint has been resolved.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2014	**Make:** Jeep	**Model:** Grand Cherokee	**Mileage:** 38,146	**RO:** 18370
Concern:	Customer states check engine light is on.			
The technician confirms the MIL is on and finds a P0128 stored. After running the engine for 30 minutes, coolant temperature remained below 160 °F .				
Cause:	Found P0128 stored and engine coolant temp below normal. Found thermostat stuck open.			
Correction:	Replaced thermostat and refilled cooling system. Engine reaches operating temp and DTC cleared.			

KEY TERMS

Air induction system
Base ignition timing
Closed loop
Drive cycle
Electronic fuel injection (EFI)
Electronic ignition (EI)
Enable criteria
Engine control module (ECM)
Freeze frame
Gasoline direct-injection (GDI)
Ignition timing
Malfunction indicator lamp (MIL)
Open loop
Parameter identification (PID)
Port fuel injection (PFI)
Serial data
Trip

SUMMARY

- To have complete combustion, there must be the correct amount of fuel mixed, in a sealed container, with the correct amount of air and this must be shocked by the correct amount of heat at the right time.
- The ignition system is responsible for delivering the spark that causes combustion.
- The fuel system must deliver the fuel from the fuel tank to the fuel injectors, which spray fuel into the cylinders.
- The air induction system delivers the air to the cylinders.
- Emission control devices are added to engines because an engine does not experience complete combustion during all operating conditions.
- Engine control systems operate in a loop—input, process, and control.
- An engine control module will operate in open or closed loop. In closed loop, the computer processes all inputs.
- Most engine control systems have self-diagnostic capabilities. By entering this mode, the computer is able to evaluate the entire control system, including itself.
- According to OBD II standards, all vehicles have a universal DLC with a standard location, a standard list of DTCs, a standard communication protocol, common use of scan tools on all vehicle makes and models, common diagnostic test modes, the ability to record and store a snapshot of the operating conditions that existed when a fault occurred, and a standard glossary of terms, acronyms, and definitions that must be used for all components in electronic control systems.
- An OBD II system has many monitors to check system operation, and the MIL light is illuminated if vehicle emissions exceed 1.5 times the allowable standard for that model year.
- Monitors included in OBD II are: catalyst efficiency, engine misfire, fuel system, heated exhaust gas oxygen sensor, EGR, EVAP, secondary air injection, thermostat, and comprehensive component monitors.
- OBD II vehicles use a minimum of two oxygen sensors. One of these is used for feedback to the PCM for fuel control and the other gives an indication of the efficiency of the converter.
- An OBD II drive cycle includes whatever specific operating conditions are necessary either to initiate and complete a specific monitoring sequence or to verify a symptom or a repair.
- OBD II's short-term fuel trim and long-term fuel trim strategies monitor the oxygen sensor signals and use this information to make adjustments to the fuel control calculations. The adaptive fuel control strategy allows for changes in the amount of fuel delivered to the cylinders according to operating conditions.
- An OBD II system monitors the entire emissions system, switches on a MIL if something goes wrong, and stores a fault code in the PCM when it detects a problem.
- OBD II regulations require that the PCM monitor and perform some continuous tests on the engine control system and components. Some OBD II tests are completed at random, at specific intervals, or in response to a detected fault.
- OBD II systems note the deterioration of certain components before they fail, which allows owners to bring in their vehicles at their convenience and before it is too late.
- The MIL informs the driver that a fault that affects the vehicle's emission levels has occurred. After making the repair, technicians may need to take the vehicle for three trips to ensure that the MIL does not illuminate again.
- Most intermittent problems are caused by faulty electrical connections or wiring.

REVIEW QUESTIONS

Short Answer

1. Describe the difference between an open- and a closed-loop operation.
2. Explain the use and importance of system strategy and look-up tables in the computerized control system.
3. Describe an OBD II warm-up cycle.
4. Explain the trip and drive cycle in an OBD II system.
5. Describe how engine misfire is detected in an OBD II system.
6. Describe the purpose of having both upstream and downstream oxygen sensors in an exhaust system.
7. Briefly describe the monitors in an OBD II system.

8. Type B engine misfires are excessive if the misfiring exceeds ___ to ___ percent in a ___ rpm period.
9. The ___ monitor system checks the action of the canister purge system.
10. The ___ monitor system has a(n) ___ and ___ test to check the efficiency of the air injection system.
11. The fuel monitor checks ___ ___ fuel trim and ___ fuel trim.

Multiple Choice

1. Which sensor is used for misfire monitoring on OBD II systems?
   a. Oxygen sensor
   b. Camshaft position sensor
   c. Crankshaft position sensor
   d. DPFE sensor
2. Which of the following statements is *not* true?
   a. DTCs that will not affect emissions will never illuminate the MIL.
   b. An active or current DTC represents a fault that was detected and occurred during two trips.
   c. When a two-trip fault is detected for the second time, a DTC is stored as a pending code.
   d. There are some DTCs that will set in one trip.
3. A computer is capable of doing all of the following except___.
   a. receive input data
   b. process input data according to a program and monitor output action
   c. control the vehicle's operating conditions
   d. store data and information
4. Which of the following memory circuits is used to store trouble codes and other temporary information?
   a. Read-only memory
   b. Programmed read-only memory
   c. Random access memory
   d. All of the above

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that the oxygen sensor provides the major input during the open-loop mode. Technician B says that the coolant temperature sensor input is not used during open-loop mode operation. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. While discussing OBD II systems: Technician A says that the PCM illuminates the MIL if a defect causes emission levels to exceed 2.5 times the emission standards for that model year vehicle. Technician B says that if a misfire condition threatens engine or catalyst damage, the PCM flashes the MIL. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. While discussing the catalyst efficiency monitor: Technician A says that if the catalytic converter is not reducing emissions properly, the voltage frequency increases on the downstream HO_2S. Technician B says that if a fault occurs in the catalyst monitor system on three drive cycles, the MIL will be illuminated. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. While discussing monitoring systems: Technician A says that the fuel system monitor checks the short-term and long-term fuel trims. Technician B says that the heated oxygen sensor monitoring system checks lean-to-rich and rich-to-lean response times. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. While discussing the comprehensive monitoring system: Technician A says that it tests various input circuits. Technician B says that it tests various output circuits. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. While discussing the MIL on OBD II systems: Technician A says that the MIL will flash if the PCM detects a fault that would damage the catalytic converter. Technician B says that whenever

the PCM has detected a fault, it will turn on the MIL. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

7. While discussing diagnostic procedures: Technician A says that after the visual inspection has been performed, the DTCs should be cleared from the memory of the PCM. Technician B says that serial data can be helpful when there are no DTCs but there is a fault in the system. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

8. Technician A says that the enable criteria are the criteria that must be met before the PCM completes a monitor test. Technician B says that a drive cycle includes operating the vehicle under specific conditions so that a monitor test can be completed. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

9. While discussing PCM monitor tests: Technician A says that some monitors only run after another monitor completes. Technician B says that the monitor tests are run when the scan tool activates them. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

10. While discussing the misfire monitor: Technician A says that while detecting type A misfires, the monitor checks cylinder misfiring over a 500-revolution period. Technician B says that while detecting type B misfires, the monitor checks cylinder misfires over a 1,000-revolution period. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

DETAILED DIAGNOSIS AND SENSORS

CHAPTER 25

OBJECTIVES

- Perform a scan tester diagnosis on various vehicles.
- Conduct preliminary checks on an OBD II system.
- Monitor the activity of OBD II system components.
- Diagnose computer voltage supply and ground wires.
- Test and diagnose switch-type input sensors.
- Test and diagnose variable resistance-type input sensors.
- Test and diagnose generating-type input sensors.
- Test and diagnose output devices (actuators).
- Perform active tests of actuators using a scan tool.

On-board diagnostic systems will lead a technician to the area of a driveability or emissions problem. Many different input sensors are involved in the overall driveability of a vehicle. This includes diesel- and gasoline-powered engines. Because of the use of computer networks, the inputs from the various sensors play an important part in the operation of all engine performance systems. Because the signals from these sensors are shared by many control modules, one sensor cannot be designated as affecting only one system. Often, a DTC will be set that reflects a problem affecting more than one system. These problems are typically caused by a faulty sensor or sensor circuit. This chapter looks at the most common sensors and how to test each.

Using Scan Tool Data

The engine control module (ECM) or PCM constantly monitors information from various switches, sensors, and other control modules. It controls the operation

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2008	**Make:** Dodge	**Model:** Ram 1500	**Mileage:** 108,540	**RO:** 18510
Concern:	Customer states check engine light is on; engine idles rough sometimes and stalls occasionally.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

of systems that affect vehicle performance and emission levels and monitors emission-related systems for deterioration. OBD II monitors set a DTC when the performance of a system can cause elevated emissions. The PCM also alerts the driver of emission-related concerns by illuminating the MIL. At the same time, a DTC is set defining the area that caused the MIL to be lit **(Figure 25–1)**.

Diagnostic System Checks

Before starting to diagnose a concern, make sure you have covered the basics. At the beginning of most diagnostic routines, you are asked if you have performed a diagnostic system check. This usually means making basic checks of items such as:

- Battery voltage and charging system operation
- Checking for any open fuses
- Visually inspecting obvious components of the system in question
- Checking for the installation of any aftermarket devices
- Noting if any other malfunction or warning lights are on

Connecting the Scan Tool

1. Be sure the ignition switch is OFF.
2. If required, install the proper module for the vehicle and the system into the scan tool.
3. Connect the scan tool to the DLC.

Establish communication with the computer system. If the scan tool does not power up, check the fuses and wiring for the data link connector (DLC). If the scan tool powers up but does not communicate, you will need to diagnose this problem before continuing.

SHOP TALK

On older versions of the Solus and Modis, Snap-On uses personality keys **(Figure 25–2)**. These keys tell the scan tool all it needs to know. But, a GM vehicle may require a Key 20 to talk to powertrain and a Key 17 to talk to body. Different cars and different communication protocols use different keys to program the tool to the car. As scan tool software has been updated, some cars, particularly GMs, don't need a key to talk to powertrain but may need a key to talk to ABS or chassis.

GO TO Chapter 24 for diagnosing computer communication system faults.

Quick Tests

Used primarily on Ford vehicles, quick tests provide three methods of obtaining diagnostic information from the on-board computer system. The three quick tests are:

- Key on engine off (KOEO) self-test
- Key on engine running (KOER) self-test
- Continuous memory self-test

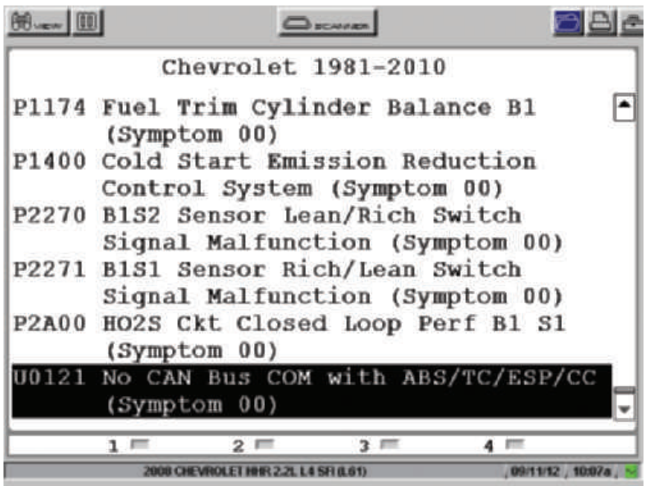


FIGURE 25–1 The DTCs that caused the MIL to light will be listed on the scan tool.

FIGURE 25–2 A personality key in position between the scan tool's connector and the interface for the DLC.

The KOEO self-test performs a functional test of certain input sensors and output actuators. If the concern is present during the KOEO self-test, a DTC will be generated and stored in memory. However, if the problem is intermittent or not occurring during the test, this test will not detect the problem and no codes will be set.

The KOER self-test is similar to the KOEO test except the engine is running during the test. For the test to complete correctly, the engine should be at normal operating temperature. In addition, action is often need by the technician during this test to press the brake pedal, turn the steering wheel, and cycle overdrive switches. Like the KOEO test, the fault must be present during the KOER test to be detected and for a code to set.

The continuous memory self-test allows you to retrieve both emission and non-emission related DTCs. All stored DTCs are read during this test.

Once you have confirmed the customer complaint and determined a problem does exist, you will need to use the scan tool to access other information. The information provided by the scan tool varies depending on the scan tool and the vehicle tested. Because of the standardization provided by OBD II, scan tools are able to display the same basic type of information regardless of the vehicle.

DTCs and Service Information

To access stored diagnostic trouble codes (DTCs), the scan tool requests data using Mode $03. Depending on the scan tool, a description of the DTC may be provided on the scan tool. If the scan tool does not provide this information, you will need to find the details using the service information. Check for current, pending, and history DTCs stored in memory.

After retrieving the DTCs, find their descriptions in the service information. Normally the descriptions are followed by additional information to help diagnosis. As can be seen in **Figure 25–3**, there is more than one possible cause of the problem. One is the sensor itself and the other two concern the sensor's circuit. Detailed testing will identify the exact cause. It is important to understand what conditions cause a DTC to set for a particular vehicle as the conditions are often slightly different for different vehicle manufacturers or even different engines from the same manufacturer.

Notice that the description also leads to pinpoint tests. These are designed to guide the technician through a step-by-step procedure. To be effective, each step should be performed, in the order given, until the problem has been identified.

Make sure to check all available service information related to the DTCs. There may be a TSB related to the code and following those procedures may fix the problem. Also, make sure the ECM/PCM is programmed with the most current software.

Monitor Failures

When checking for DTCs, check the status of the OBD II monitors. All OBD II scan tools have a readiness function showing all of the monitoring sequences and the status of each: complete or incomplete. If vehicle travel time, operating conditions, or other parameters were insufficient for a monitoring sequence to complete a test, the scanner will indicate which monitoring sequence is not yet complete.

The specific set of driving conditions that will set the requirements for OBD II monitoring sequences is described in Chapter 24.

GO TO Chapter 24 for more information about monitors and drive cycles.

When most monitor tests are run and a system or component fails a test, a pending code is set. When the fault is detected a second time, a DTC is set and the MIL is lit **(Figure 25–4)**. It is possible that a DTC for a monitored circuit may not be entered into memory even though a malfunction has occurred. This may happen when the monitoring criteria have not been met.

P0117–Engine Coolant Temperature (ECT) Sensor 1 Circuit Low	
Description:	Indicates the sensor signal is less than the self-test minimum. The ECT sensor minimum is 0.2 volt or 121 °C (250 °F).
Possible Causes:	■ Grounded circuit in the harness ■ Damaged sensor ■ Incorrect harness connection
Diagnostic Aids:	A concern is present if an ECT PID reading less than 0.2 volt with the key ON engine OFF or during any engine operating mode.

FIGURE 25–3 A description of a DTC, as given in typical service information, with additional information to help diagnosis.

Monitor	Failure can be caused by:
Catalyst Monitor	Fuel Contaminants Leaking Exhaust Engine Mechanical Problems Defective Upstream or Downstream Oxygen Sensor Circuits Defective PCM
Fuel System Monitor	A Defective Fuel Pump Abnormal Signal from the Upstream HO_2S Engine Temperature Sensor Faults Malfunctioning Catalytic Converter MAP or MAF Related Faults Cooling System Faults EGR System Faults Fuel Injection System Faults Ignition System Faults Vacuum Leaks Worn Engine Parts
EGR Monitor	Faulty EGR Valve Faulty EGR Passages or Tubes Loose or Damaged EGR Solenoid Wiring and/or Connectors Damaged DPFE or EGR VP Sensor Disconnected or Loose Electrical Connectors to the DPFE or EGR VP Sensors Disconnected, Damaged, or Misrouted EGR Vacuum Hoses
EVAP Monitor	Disconnected, Damaged, or Loose Purge Solenoid Connectors and/or Wiring Leaking Hoses, Tubes, or Connectors in the EVAP System Vacuum and/or Vent Hoses to the Solenoid and Charcoal Canister Are Misrouted Plugged Hoses from the Purge Solenoid to the Charcoal Canister Loose or Damaged Connectors at the Purge Solenoid Fuel Tank Cap Not Tightened Properly or It Is Missing
Misfire Monitor	Fuel Level Too Low During Drive Cycle Dirty or Defective Fuel Injectors Contaminated Fuel Defective Fuel Pump Restricted Fuel Filter EGR System Faults EVAP System Faults Restricted Exhaust System Faulty Secondary Ignition Circuit Damaged, Loose, or Resistant PCM Power and/or Ground Circuits.
Oxygen Sensor Monitor	Malfunctioning Upstream and/or Downstream Oxygen Sensor Malfunctioning Heater for the Upstream or Downstream Oxygen Sensor A Faulty PCM Defective Wiring to and/or from the Sensors

FIGURE 25–4 Possible causes of OBD II monitor failures. *(continued)*

AIR System Monitor	Faulty Secondary AIR Solenoid and/or Relay
	Damaged, Loose, or Disconnected Wiring to the Secondary Air Solenoid and/or Relay Circuit
	Defective Aspirator Valve
	Disconnected or Damaged AIR Hoses And/or Tubes
	A Defective Electric or Mechanical Air Pump
	Air Pump Drive Belt Missing
	Faulty AIR Check Valve

FIGURE 25–4 *(continued)*

Freeze Frame Data

Freeze frame data associated with a DTC should also be retrieved. This data contains values from specific generic PIDs that provide information about the operating conditions present when the code was set. It can also be used to identify components that should be tested.

Misfire freeze frame (MFF) data contains some unique PIDs. MFF data is not part of freeze frame data that is stored with a DTC. It is used only for identifying the cause of a misfire. Generic freeze frame data is also captured when a misfire occurs. However, that data will not represent what happened at the time of the misfire; rather, it will show what happened after the misfire. MFF data is captured at the time of the highest rate of misfire and not when the DTC is set.

Recording the freeze frame (FF) information is helpful so that once the vehicle is repaired it can be driven under conditions similar to those in the FF.

SHOP TALK

Many electronic control systems have adaptive strategies that allow the engine to run when one or more inputs fail. The ECM/PCM relies on a predetermined value when it senses an out-of-limit value from a sensor. When looking at enhanced-mode data, the input signal may not change with changes in conditions, and this can be misleading. The serial data may show a substitute value when using enhanced data. When using generic or global OBD II data, the PIDs will show actual data as substitute values cannot be displayed as part of generic data.

Some technicians call this “driving the freeze frame.” This allows you to recreate the operating conditions that were present with the DTC set.

Serial Data

Once you have identified the DTC and the related system or component, perform a check of the data for the apparent issues. For example, if a P0118 Engine Coolant Temperature Sensor Circuit High DTC is set in memory, examine the sensor voltage and temperature data on the scan tool. If the readings are outside the normal range, such as 4.9 volts and minus 40 degrees, it would be a good idea to check the sensor and its wiring.

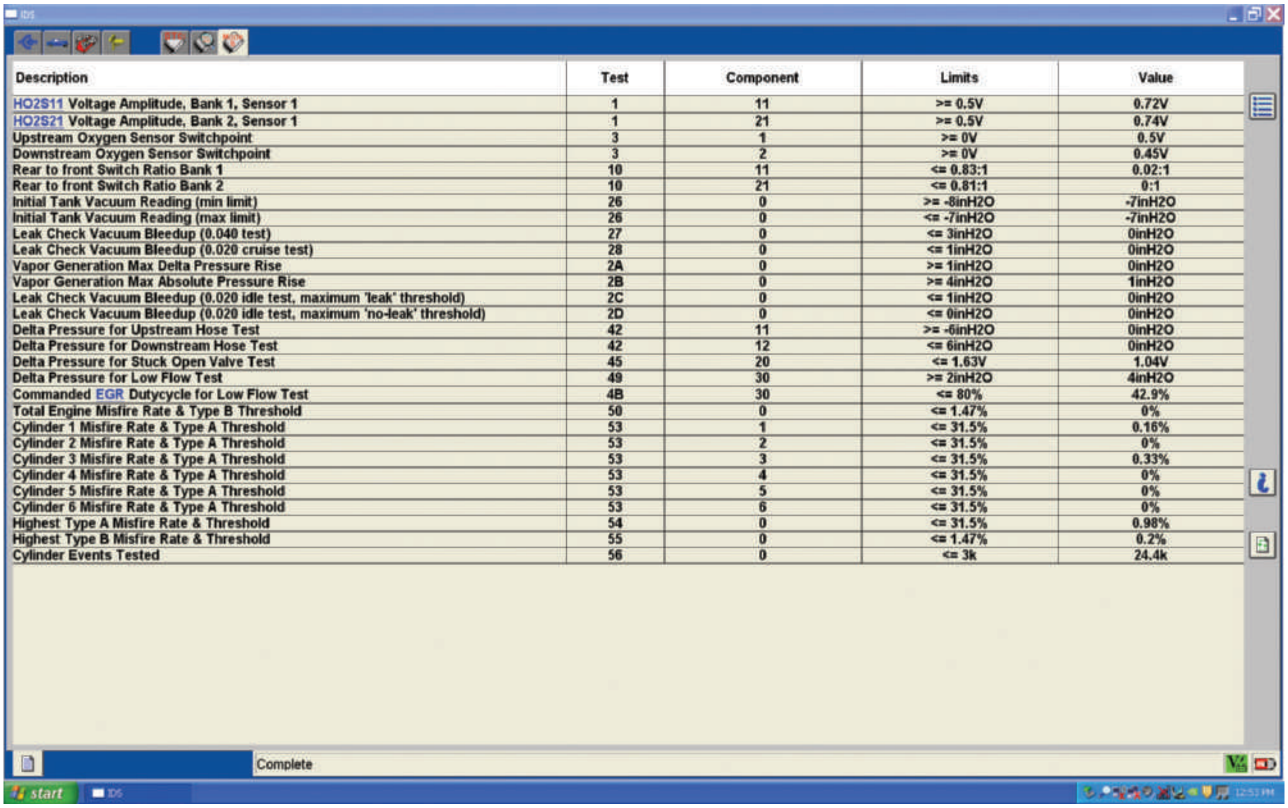
Mode $06 Data

The data available in Mode $06 can also be used to identify the cause of a concern. Mode $06 allows access to the results of the various monitor diagnostic tests **(Figure 25–5)**. These values are stored when a specific monitor has completed a test. In addition to providing specific test results, Mode $06 data can be used to determine component condition and misfire rates. In some cases, Mode $06 data can also help determine that a component is near failure. For example, as catalyst efficiency decreases, the rear O_2 sensor switch rate will increase. By examining the Mode $06 data for rear O_2 sensor switch rate, catalyst degradation can be monitored. Once the test values reach the programmed limits, a DTC will set.

Visual Inspection

Once you have checked for DTCs and examined the data, perform a visual inspection. Pay close attention to wiring and components that are related to the DTCs. Often the cause of a driveability problem can be discovered by doing the following:

- Check all vacuum hoses. Make sure they are connected and are not pinched, cut, or cracked.



Description	Test	Component	Limits	Value
HO2S11 Voltage Amplitude, Bank 1, Sensor 1	1	11	>= 0.5V	0.72V
HO2S21 Voltage Amplitude, Bank 2, Sensor 1	1	21	>= 0.5V	0.74V
Upstream Oxygen Sensor Switchpoint	3	1	>= 0V	0.5V
Downstream Oxygen Sensor Switchpoint	3	2	>= 0V	0.45V
Rear to front Switch Ratio Bank 1	10	11	<= 0.83:1	0.02:1
Rear to front Switch Ratio Bank 2	10	21	<= 0.81:1	0:1
Initial Tank Vacuum Reading (min limit)	26	0	>= -8inH2O	-7inH2O
Initial Tank Vacuum Reading (max limit)	26	0	<= -7inH2O	-7inH2O
Leak Check Vacuum Bleedup (0.040 test)	27	0	<= 3inH2O	0inH2O
Leak Check Vacuum Bleedup (0.020 cruise test)	28	0	<= 1inH2O	0inH2O
Vapor Generation Max Delta Pressure Rise	2A	0	>= 1inH2O	0inH2O
Vapor Generation Max Absolute Pressure Rise	2B	0	>= 4inH2O	1inH2O
Leak Check Vacuum Bleedup (0.020 idle test, maximum 'leak' threshold)	2C	0	<= 1inH2O	0inH2O
Leak Check Vacuum Bleedup (0.020 idle test, maximum 'no-leak' threshold)	2D	0	<= 0inH2O	0inH2O
Delta Pressure for Upstream Hose Test	42	11	>= -6inH2O	0inH2O
Delta Pressure for Downstream Hose Test	42	12	<= 6inH2O	0inH2O
Delta Pressure for Stuck Open Valve Test	45	20	<= 1.63V	1.04V
Delta Pressure for Low Flow Test	49	30	>= 2inH2O	4inH2O
Commanded EGR Dutycycle for Low Flow Test	4B	30	<= 80%	42.9%
Total Engine Misfire Rate & Type B Threshold	50	0	<= 1.47%	0%
Cylinder 1 Misfire Rate & Type A Threshold	53	1	<= 31.5%	0.16%
Cylinder 2 Misfire Rate & Type A Threshold	53	2	<= 31.5%	0%
Cylinder 3 Misfire Rate & Type A Threshold	53	3	<= 31.5%	0.33%
Cylinder 4 Misfire Rate & Type A Threshold	53	4	<= 31.5%	0%
Cylinder 5 Misfire Rate & Type A Threshold	53	5	<= 31.5%	0%
Cylinder 6 Misfire Rate & Type A Threshold	53	6	<= 31.5%	0%
Highest Type A Misfire Rate & Threshold	54	0	<= 31.5%	0.98%
Highest Type B Misfire Rate & Threshold	55	0	<= 1.47%	0.2%
Cylinder Events Tested	56	0	<= 3k	24.4k

FIGURE 25–5 Mode $06 allows access to the results of the various monitor diagnostic tests.

- Check the condition and tension of the generator drive belt.
- Check the battery and battery connections. Look for loose and corroded connections and damaged **(Figure 25–6)** or burned wires under the hood.
- Inspect the wiring for sensors and outputs.
- Check the level and condition of the engine's coolant.
- Check the air filter. Also check the air intake system for restrictions and leaks.
- Check for exhaust system leaks.

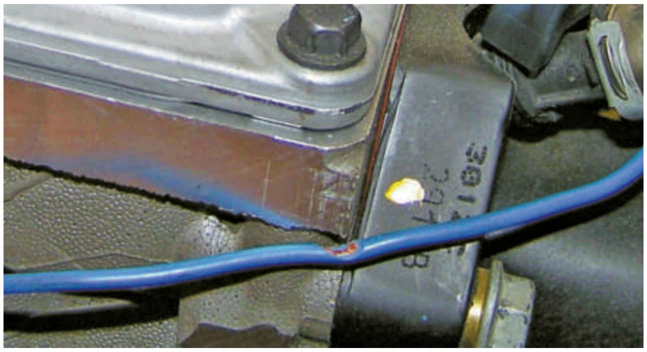


FIGURE 25–6 Check all of the wires in the engine compartment. Look for damaged or burned wires.

Caution! Before running the engine to diagnose a problem, make sure the parking brake is applied and the gear selector is placed firmly in the PARK position on automatic transmission vehicles or in the NEUTRAL position on manual transmission vehicles. Also, block the drive wheels.

Symptom-Based Diagnosis

At times, no DTCs are set by the computer but a driveability problem exists. This is when a technician must look at the various engine systems to discover the cause of the concern. What system or part to test is dictated by a description of the problem or its symptoms. Before diagnosing a problem based on its symptoms, perform a visual inspection as listed above. In addition, make sure that:

- All data observed on the scan tool is within normal ranges.
- The PCM power and ground circuits are intact and in good condition.

- All vehicle modifications are identified.
- The vehicle's tires are properly inflated and are the correct size.

Common Symptoms

Repair manuals typically have a section dedicated to symptom-based diagnosis. Although a customer may describe a problem in nontechnical terms, you should summarize the concern to match one or more of the various symptoms listed by the manufacturer. Following are some common driveability symptoms and a brief description of each.

- *Hard Start/Long Crank Hard Start:* Engine cranks OK, but it does not start unless it is cranked for a long time. Once running, it may run normally or immediately stall.
- *No Crank:* The starting system does not turn the engine over.
- *No Start (Engine Cranks):* The engine turns over normally but does not start even after a prolonged cranking.

Warning! Avoid long periods of engine cranking; raw fuel may load the exhaust system and damage the catalytic converter after the engine starts. Do not crank the engine for more than 15 seconds at a time and allow at least 2 minutes between attempts.

- *Slow Return to Idle:* When the accelerator pedal is released it takes some time for the engine to return to its normal idle speed.
- *Fast Idle:* The engine idles at a higher-than-normal speed or does not return to the normal idle speed when the throttle is released.
- *Runs On (Diesels):* A fast idle can cause the engine to attempt to run after the ignition is turned off. This is called dieseling because combustion is caused by the heat inside the combustion chamber.
- *Rough or Unstable Idle and Stalling:* The engine shakes while idling or changes idle speed constantly. This concern may cause the engine to stall.
- *Low/Slow Idle or Stalls/Quits during Deceleration:* Engine speed drops below its normal idle speed. This can cause stalling when the accelerator pedal is released.
- *Backfire:* Fuel ignites in the intake manifold or exhaust system. This causes a loud popping noise.
- *Lack of or Loss of Power:* The engine is sluggish and provides less power than is normally expected. The engine seems not to increase in speed when the accelerator pedal is depressed.
- *Cuts Out, Misses:* A steady pulsation or jerking at low engine speeds, especially during heavy engine loads. The exhaust may have a spitting sound at idle or low speeds.
- *Hesitation or Stumble:* A momentary lack of response to the accelerator pedal. This concern can occur at any vehicle speed but is more noticeable during acceleration from a stop.
- *Surges:* The power output from the engine seems to change while operating with a steady throttle or while cruising.
- *Detonation/Spark Knock:* The engine makes sharp metallic knocking sounds that are usually worse during acceleration.
- *Poor Fuel Economy:* Fuel economy is noticeably lower than expected or lower than it was before.

Figure 25–7 is a symptom chart for common concerns that may not set a DTC and the component or system that could cause the problem. Each potential

Concern	Component/System	Possible Cause
Hard Start/Long Crank	■ Starting System ■ Fuel/Ignition/Computer ■ Intake Air System ■ MAF Sensor ■ Exhaust System ■ PCV System ■ EVAP System	■ Weak battery, poor battery connections, defective starter ■ Low fuel pressure or volume, weak spark, incorrect spark timing, TP, ETC, MAF/MAP sensor faults ■ Restriction in intake air system, plugged air filter, induction air leak ■ Dirty, misreading or defective MAF sensor ■ Restricted exhaust system ■ Damaged or disconnected PCV hose ■ Fuel vapor purge during cranking

FIGURE 25–7 A symptom chart that can be used when there are no DTCs. *(continued)*

No Crank	■ Anti-Theft Devices ■ Base Engine ■ Starting system	■ Fault with key, encoder, remote, or lack of network communication ■ Seized or hydraulically locked engine ■ Defective starter, starter relay, battery, ignition/safety switch or poor battery cable connections
No Start (Engine Cranks)	■ Anti-Theft Devices ■ Fuel/Ignition/Computer ■ Intake Air System ■ Exhaust System ■ Base Engine	■ Fuel system disable, incorrect key, lack of network communication ■ Low fuel pressure or volume, no spark/weak spark, defective CKP sensor, loss of network communication, high TP sensor voltage ■ Restricted intake or leak in induction system ■ Restricted exhaust system ■ Incorrect valve timing, no or low compression
Slow Return to Idle	■ Vacuum Leaks ■ Throttle Body ■ Intake Air System Leaks	■ Cracked or dislodged PCV or other vacuum hoses ■ Binding throttle plate, broke throttle return spring ■ Leak in induction system
Fast Idle or Runs On	■ Base Engine ■ Fuel/Ignition/Computer ■ Intake Air System	■ Engine overheating ■ TP sensor, leaking injector(s), excessive fuel pressure, advanced ignition timing, incorrect heat range spark plugs ■ Vacuum leak
Low/Slow Idle or Stalls/Quits during Deceleration	■ Base Engine ■ Fuel/Ignition/Computer ■ Intake Air System ■ Automatic Transmission	■ Incorrect valve timing ■ Low fuel pressure or volume, incorrect ignition timing, idle speed too low ■ Induction system leak ■ Defective torque converter clutch
Backfires	■ Secondary Ignition ■ Fuel Delivery System ■ Base Engine ■ Exhaust System	■ Misrouted ignition wires, cracked distributor cap, moisture in distributor, carbon tracking ■ Low fuel pressure or volume ■ Incorrect valve timing ■ Exhaust leaks
Lack of or Loss of Power	■ Base Engine ■ Fuel/Ignition/Computer ■ Intake Air System ■ Exhaust System ■ Brake System ■ Automatic Transmission ■ Supercharger System ■ Turbocharger	■ Variable camshaft timing system, incorrect valve timing, low compression ■ Low fuel pressure or volume, throttle linkage, accelerator pedal position sensor/TP senor, dirty or faulty MAF sensor, EGR system, check fuel trim, O_2S and VPWR PIDs ■ Restricted air filter, induction system leak, vacuum leak ■ Restricted exhaust ■ Binding or dragging wheel brake(s), stuck parking brake ■ Automatic transmission fault, defective torque converter ■ Defective supercharger, open bypass valve ■ Damaged turbine or compressor blades, open waste gate, boost leak

FIGURE 25–7 *(continued)*

Spark Knock	■ Base Engine ■ Fuel/Ignition/Computer ■ Induction System Concerns	■ Abnormal engine temperature, coolant level and concentration, incorrect valve timing, intake valve deposits ■ Low fuel pressure or volume, dirty or faulty MAF sensor, faulty knock sensor, advanced ignition timing, restricted injectors, EGR system ■ Vacuum leak, faulty PCV valve
Poor Fuel Economy	■ Base Engine Fuel/ Ignition/Computer ■ Intake Air System ■ Exhaust System ■ Automatic Transmission ■ Brake System ■ Steering and Suspension System	■ Abnormal engine temperature, fault in variable camshaft timing system, low compression, incorrect valve timing ■ Leaking fuel injector(s), faulty fuel pressure regulator, incorrect ignition timing, weak spark, incorrect spark plug heat range, faulty ECT sensor, dirty or faulty MAF sensor, faulty O_2S, check fuel trim and O_2S PIDs ■ PCV system, vacuum leak ■ Restricted exhaust ■ Transmission fault, defective torque converter ■ Binding or dragging wheel brake, stuck parking brake ■ Low tire pressure, incorrect tire size

FIGURE 25–7 *(continued)*

problem area should be checked. It is important to realize that some problems may cause more than one symptom. In addition, remember to check if new software calibrations are available before attempting to solve a problem based on symptoms only.

Basic Testing

Diagnosis of electronic engine control systems includes much more than retrieving DTCs. Individual components and their circuits must be inspected and tested. The operation of some components can be monitored with the scan tool; however, additional tests are normally necessary. These tests include:

- *Ohmmeter Checks.* Most sensors and output devices can be checked with an ohmmeter. For example, an ohmmeter can be used to check a temperature sensor. Normally, the ohmmeter reading is low on a cold engine and high or infinity on a hot engine if the sensor is a PTC. If the sensor is an NTC, the opposite readings would be expected. Output devices such as coils or motors can also be checked with an ohmmeter.
- *Voltmeter Checks.* Many sensors, output devices, and their wiring can be diagnosed by checking the voltage to them, and in some cases, from them. Even some oxygen sensors can be checked in this manner.
- *Lab Scope Checks.* The activity of sensors and actuators can be monitored with a lab scope or a graphing multimeter. By watching their activity, the technician is doing more than testing them. Often problems elsewhere in the system will cause a device to behave abnormally. These situations are identified by the trace on a scope and by the technician's understanding of a scope and the device being monitored.

In some cases, a final check can be made only by substitution. Substitution is not an allowable diagnostic method under the mandates of OBD II, nor is it the most desirable way to diagnose problems. However, sometimes it is the only way to verify the cause of a problem. When substituting, replace the suspected part with a known good unit and recheck the system. If the system now operates normally, the original part is defective.

Testing Sensors

To monitor engine conditions, the computer uses a variety of sensors. All sensors perform the same basic function. They detect a mechanical condition (movement or position), chemical state, or temperature condition and change it into an electrical signal that can be used by the PCM to make decisions.

If a DTC directs you to a faulty sensor or sensor circuit, or if you suspect a faulty sensor, it should be

tested. Always follow the procedures outlined by the manufacturer when testing sensors and other electronic components. Also, make sure you have the correct specifications for each part tested. Sensors are tested with a DMM, scan tool, and/or lab scope or GMM.

Because the controls are different on the various types of automotive lab scopes and GMMs, make sure you follow the instructions of the scope's manufacturer. If the scope is set wrong, the scope will not break. It just will not show you what you want to be shown. To help with understanding how to set the controls on a scope, keep the following things in mind. The vertical voltage scale must be adjusted in relation to the expected voltage signal. The horizontal time base or milliseconds per division must be adjusted so the waveform appears properly on the screen. Many waveforms can be clearly displayed when the horizontal time base is adjusted correctly.

Software packages, often programmed in a lab scope or GMM, are available to help you properly interpret scope patterns and set up a lab scope **(Figure 25–8)**. These also contain an extensive waveform library that you can refer to and find what the normal waveform of a particular device should look like. The library also contains the waveforms caused by common problems. You can also add to the library by transferring waveforms to a PC from the lab scope. Another source of waveforms, both good and bad, is iATN, the International Automotive Technicians Network. The library of good and bad waveforms allows you to compare your findings with those from similar vehicles and components. After the waveforms have been transferred, notes can be added to the file. The software may also include the theory of operation, scope setup information, and diagnostic procedures for common inputs and outputs.

There are many different types of sensors; their design depends on what they are monitoring. Some sensors are simple on-off switches. Others are some form of variable resistor that changes resistance according to temperature changes. Some sensors are voltage or frequency generators, whereas others send varying signals according to the rotational speed of a device. Knowing what they are measuring and how they respond to changes are the keys to being able to accurately test an input sensor.

Some inputs to the PCM come from another control module or are simply a connection from a device. Examples of this are the battery voltage input and the heated windshield module. The battery's voltage is available on the data bus and many control modules need this information. There is no sensor involved, just a connection from the battery to the bus. The heated windshield module tells the computer when the heated windshield system is operating. This helps the PCM to accurately determine engine load and control idle speed.

How to Connect the Oscilloscope

1. Connect the scope to the computer using the USB cable.
2. Start the Oscilloscope application.
3. Plug the Positive and Negative Voltage Test Lead into Channel 1.
4. Plug the Current Probe into Channel 2.
5. Select the type of test that you want to perform from the Test drop down menu or set the voltage and timebase you prefer.

The above figure shows how to connect to the battery to perform cranking voltage and amperage tests.

FIGURE 25–8 Many different types of lab scopes are available to diagnose electronic control systems; make sure to follow the operating procedures given by the manufacturer.

SHOP TALK

Never replace a computer unless the ground and voltage supply circuits are proven to be in satisfactory condition.

Diagnosis of Computer Voltage Supply and Ground Wires

All PCMs (OBD II and earlier designs) cannot operate properly unless they have good ground connections and the correct voltage at the required terminals. A wiring diagram for the vehicle being tested must be used for these tests. Backprobe the battery terminal at the PCM and connect a digital voltmeter from this terminal to ground **(Figure 25–9)**. Always use a good engine ground.

The voltage at this terminal should be 12 volts with the ignition switch off. If 12 volts are not available at this terminal, check the computer fuse and related circuit. Turn on the ignition switch and connect the red voltmeter lead to the other battery terminals at the PCM with the black lead still grounded. The voltage measured at these terminals should also be 12 volts with the ignition switch on. When the specified voltage is not available, test the voltage supply wires to these terminals. These terminals may be connected through fuses, fuse links, or relays.

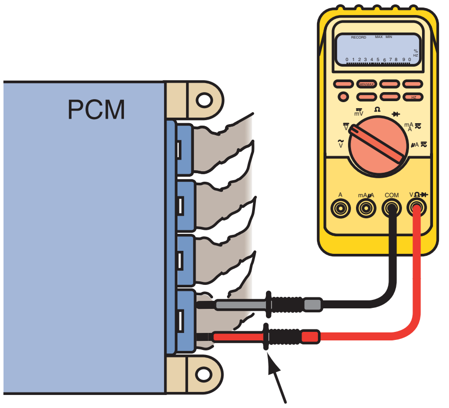


FIGURE 25–9 Using a digital voltmeter to check the PCM's circuit.

Ground Circuits

Ground wires usually extend from the computer to a ground connection on the engine or battery. With the ignition switch on, connect a digital voltmeter from the battery ground to the computer ground. The voltage drop across the ground wires should be 30 millivolts or less. If the voltage reading is greater than that or more than that specified by the manufacturer, repair the ground wires or connection.

Not only should the computer ground be checked, but so should the ground (and positive) connection at the battery. Checking the condition of the battery and its cables should always be part of the initial visual inspection before beginning diagnosis of an engine control system.

A voltage drop test is a quick way of checking the condition of any wire. To do this, connect a voltmeter across the wire or device being tested. Place the positive lead on the most positive side of the circuit. Then turn on the circuit. Ideally there should be a 0 volt reading across any wire unless it is a resistance wire, which is designed to drop voltage; even then, check the drop against specifications to see if it is dropping too much.

A good ground is especially critical for all reference voltage sensors. The problem here is not obvious until it is thought about. A bad ground will cause the reference voltage (normally 5 volts) to be higher than normal. Normally in a circuit, the added resistance of a bad ground would cause less voltage at a load. Because of the way reference voltage sensors are wired, the opposite is true. If the reference voltage to a sensor is too high, the output signal from the sensor to the computer will also be too high. As a result, the computer will be making decisions based on the wrong information. If the output signal is within the normal range for that sensor, the computer will not notice the wrong information and will not set a DTC.

To show how the reference voltage increases with a bad ground, let us look at a voltage divider circuit. This circuit is designed to provide a 5-volt reference signal off the tap. A vehicle's computer feeds the regulated 12 volts to a similar circuit to ensure that the reference voltage to the sensors is very close to 5 volts. The voltage divider circuit consists of two resistors connected in series with a total resistance of 12 ohms. The reference voltage tap is between the two resistors. The first resistor drops 7 volts **(Figure 25–10)**, which leaves 5 volts for the second resistor and for the reference voltage tap. This 5-volt reference signal will be always available at the tap, as long as 12 volts are available for the circuit.

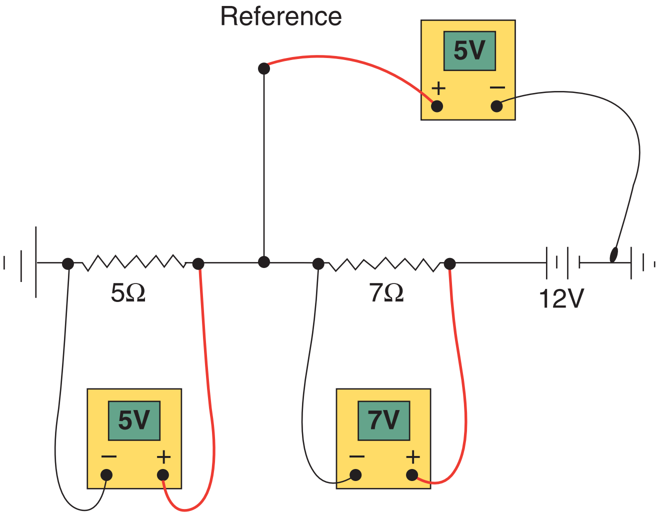


FIGURE 25–10 A voltage divider circuit with voltage values.

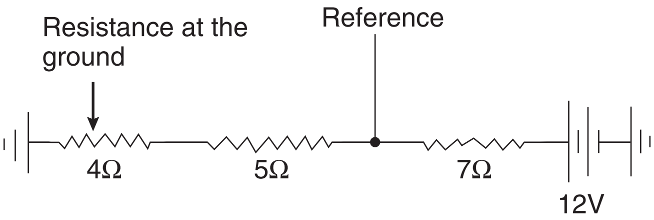


FIGURE 25–11 Voltage divider circuit with a bad ground.

If the circuit has a poor ground, one that has resistance, the voltage drop across the first resistor will be decreased. This will cause the reference voltage to increase. In **Figure 25–11**, to simulate a bad ground, a 4-ohm resistor was added into the circuit at the ground connection at the battery. This increases the total resistance of the circuit to 16 ohms and decreases the current flowing throughout the circuit. With less current flow through the circuit, the voltage drop across the first resistor decreases to 5.25 volts **(Figure 25–12)**. This means the voltage available at the tap will be higher than 5 volts; it will be 6.75 volts.

Electrical Noise Poor grounds can also allow EMI or noise to be present on the reference voltage signal. This noise causes small changes in the voltage going to the sensor. Therefore, the output signal from the sensor will also have these voltage changes. The computer will try to respond to these small rapid changes, which can cause a driveability problem. The best way to check for noise is to use a lab scope.

Connect the lab scope between the 5-volt reference signal into the sensor and the ground. The trace on the scope should be flat **(Figure 25–13)**. If noise is present, move the scope's negative probe to a known good ground. If the noise disappears, the sensor's

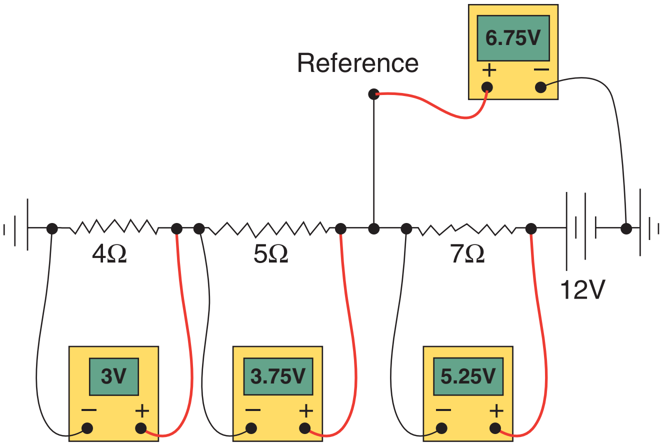


FIGURE 25–12 Figure 25–11 with voltage readings.

ground circuit is bad or has resistance. If the noise is still present, the voltage feed circuit is bad or there is EMI in the circuit from another source, such as the AC generator. Find and repair the cause of the noise.

Circuit noise may be present at the positive side or negative side of a circuit. It may also be evident by a flickering MIL, a popping noise on the radio, or by an intermittent engine miss. Noise can cause a variety of problems in any electrical circuit. The most common sources of noise are electric motors, relays and solenoids, AC generators, ignition systems, switches, and A/C compressor clutches. Typically, noise is the result of an electrical device being turned on and off. Sometimes the source of the noise is a defective suppression device. Manufacturers include these devices to minimize or eliminate electrical noise. Some of the commonly used noise suppression devices are resistor-type secondary cables and spark plugs, shielded cables, capacitors, diodes, and resistors. Capacitors or chokes are used to control noise from a motor or generator. If the source of the noise is not a poor ground or a defective component, check the suppression devices.

Clamping Diodes Clamping diodes are placed in parallel to coil windings to limit high-voltage spikes. These voltage spikes are induced by the collapsing of the magnetic field around a winding in a solenoid, relay, or electromagnetic clutch. The field collapses when current flow to the winding is stopped. The diode prevents the voltage from reaching the computer and other sensitive electronic parts. When the diode fails to suppress the voltage spikes, the transistors inside the computer can be destroyed. If the diode is bad, a negative spike will appear in a voltage trace **(Figure 25–14)**. Resistors are also used to suppress voltage spikes. They do not eliminate the spikes;

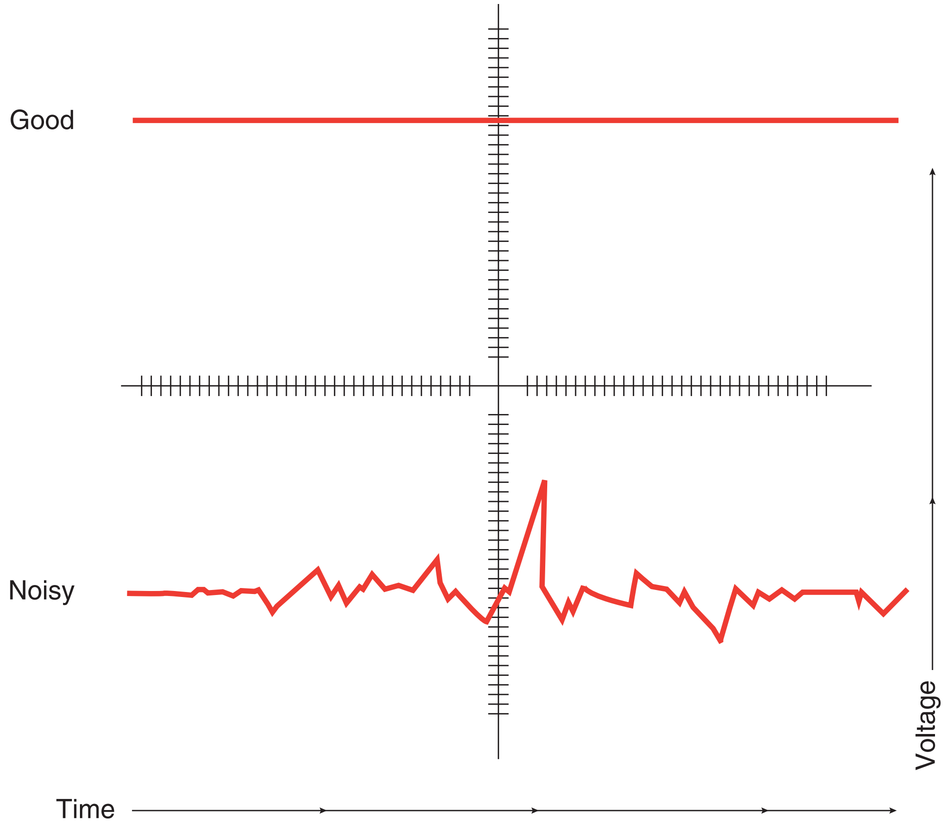


FIGURE 25–13 (Top) A good voltage signal. (Bottom) A voltage signal with noise.

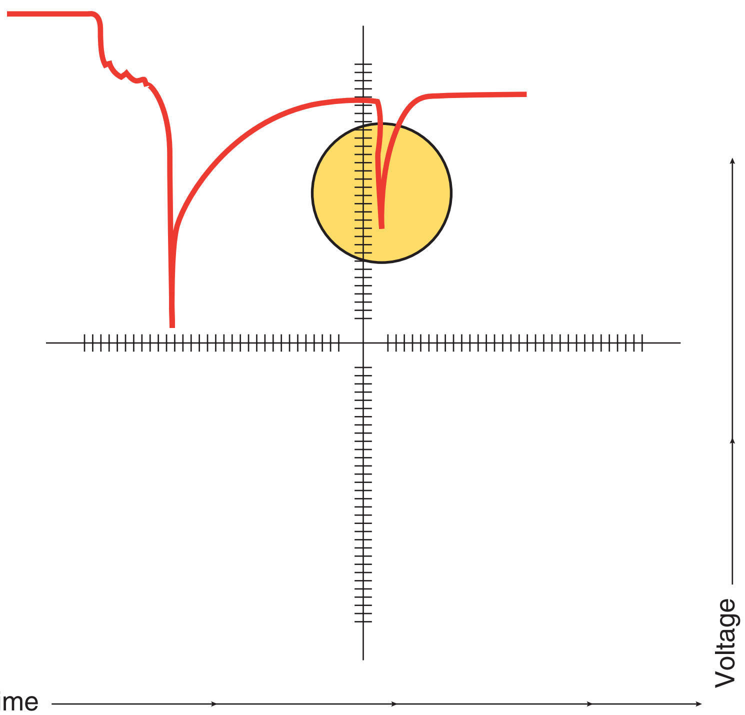


FIGURE 25–14 A trace of an electromagnetic clutch with a bad clamping diode.

rather, they limit the intensity of the spikes. If a voltage trace has a large spike and the circuit is fitted with a resistor to limit noise, the resistor may be bad.

Switches

Switches are turned on and off through an action of a device or by the actions of the driver. Switches are either normally open or normally closed. Switches send a digital signal to the PCM; they are either open or closed. Some switches are provided with a reference voltage of 5 or 12 volts by the PCM. An example of this is a neutral drive/neutral gear switch (NDS). This switch lets the PCM know when the transmission has been shifted into a gear. If the transmission is in park or neutral, the switch is closed. It sends a voltage signal of 1 volt or less to the PCM. When the transmission is placed into a gear, the switch opens and sends a signal above 5 volts to the PCM.

Some switches control the ground side of the circuit. These circuits contain a fixed resistor connected in series with the switch. When the switch is closed, the voltage signal to the PCM is low or zero. When the switch is open, there is a high-voltage signal. Common grounding switches include:

- Idle tracking switch
- Power-steering pressure switch
- Overdrive switch
- Clutch pedal position switch

Supply or power side switches are the most commonly used and work in the opposite way. They send a 5- or 12-volt signal to the PCM when they are closed. When the switch is open, there is no voltage at the PCM. Common supply side switches include:

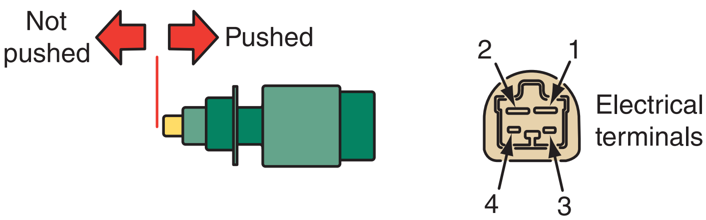
- Ignition switch
- Park/neutral switch
- Air-conditioning (A/C) demand sensor
- Brake switch
- High gear switch

Testing Switches

A switch connected to a module can be tested by watching its status with a scan tool. Locate the data and activate the switch several times. The PID should change state each time the switch is turned on and off.

A switch can be easily tested with an ohmmeter. Disconnect the connector at the switch. Refer to the wiring diagram to identify the terminals at the switch if there are more than two **(Figure 25–15)**. Connect the ohmmeter across the switch's terminals. Perform whatever action is necessary to open and close the switch. When the switch is open, the ohmmeter should have an infinite reading. When the switch is closed, there should be zero resistance. If the switch reacts in any other way, the switch is bad and should be replaced.

Switches can also be checked with a voltmeter. The signal to the PCM from the supply side switches should be 0 volts with the switch open and supply voltage when the switch is closed. This indicates to the ECM that a change has taken place. Using a voltmeter is preferred because it tests the circuit as well as the switch. If less than supply voltage is present with the switch closed, there is unwanted



Tester connection	Switch condition	Specified value
1–2	Switch pin released Switch pin pushed in	Below 1Ω 10kΩ or higher
3–4	Switch pin released Switch pin pushed in	10kΩ or higher Below 1Ω

FIGURE 25–15 Check the service information for the proper testing points for a switch.

resistance in the circuit. Again, expect the opposite readings on a ground side switch.

Some switches are adjustable and must be set so they close and open at the correct time. An example of this is the clutch switch. This switch is used to inform the computer when there is no load (clutch pedal depressed) on the engine. The switch is also connected into the starting circuit. The switch prevents starting of the engine unless the clutch pedal is fully depressed. The switch is normally open when the clutch pedal is released. When the clutch pedal is depressed, the switch closes and completes the circuit between the ignition switch and the starter solenoid. It also sends a signal of no-load to the PCM.

Most grounding switches react to some mechanical action to open or close. There are some, however, that respond to changes of conditions. These may respond to changes in pressure or temperature. An example of this type of switch is the power-steering pressure switch. This switch informs the PCM when power-steering pressures reach a particular point. When the power-steering pressure exceeds that point, the PCM knows there is an additional load on the engine and will increase idle speed.

To test this type of switch, monitor its activity with the scan tool, a DMM, or lab scope. With the engine running at idle speed, turn the steering wheel to its maximum position on one side. The data PID should change from low to high or no to yes. If testing with a DMM or scope, the voltage signal should drop as soon as the pressure in the power-steering unit has reached a high level. If the voltage does not drop, either the power-steering assembly is incapable of producing high pressures or the switch is bad.

Temperature responding switches operate in the same way. When a particular temperature is reached, the switch opens. This type of switch is best measured by removing it and submerging it in heated water. Watching the ohmmeter as the temperature increases, a good temperature responding switch will open (have an infinite reading) when the water temperature reaches the specified amount. If the switch fails this test, it should be replaced.

Temperature Sensors

Thermistors are variable resistors and serve as voltage reference sensors. Inputs from a thermistor allow the computer to observe small changes in temperature. Thermistors are used to monitor the temperature of engine coolant, inside and outside ambient air, intake air, and many other systems.

The PCM changes the operation of many components and systems based on temperature. Nearly all temperature sensors are NTC thermistors and operate in the same way. Their resistance changes with a change in temperature. The PCM supplies a reference voltage of 5 volts to the sensor. That voltage is changed by the change of the resistor's resistance and is fed back through a ground wire to the PCM. Based on the return voltage, the PCM calculates the exact temperature. When the sensor is cold, its resistance is high, and the return voltage signal is also high. As the sensor warms up, its resistance drops and so does the voltage signal.

Engine Coolant Temperature (ECT) Sensor

The engine coolant temperature (ECT) sensor is a thermistor. By measuring ECT, the PCM knows the average temperature of the engine. Temperature is used to regulate many engine functions, such as the fuel injection system, ignition timing, variable valve timing, transmission shifting, EGR and canister purge, and controlling the open- and closed-loop operational modes of the system. The ECT sensor is normally located in an engine coolant passage just before the thermostat. On cars built prior to OBD II, a coolant switch may be used. This type of sensor may be designed to remain closed within a certain temperature range or to open only when the engine is warm.

A faulty ECT sensor or sensor circuit can cause a variety of problems. The most common is the failure to switch to the closed-loop mode once the engine is warm. ECT sensor problems are often caused by wiring faults or loose or corroded connections rather than the sensor itself. Many testers are able to show where to place the probes of the tester to check things like the ECT **(Figure 25–16)**. A defective ECT sensor or circuit may cause the following problems:

1. Hard engine starting
2. Rich or lean air-fuel ratio
3. Improper operation of emission devices
4. Reduced fuel economy
5. Improper converter clutch lockup
6. Hesitation on acceleration
7. Engine stalling
8. Transmission will not shift into high gear or will shift late.

FIGURE 25–16 The procedure for testing an engine coolant temperature (ECT) sensor as shown on a scan tool.

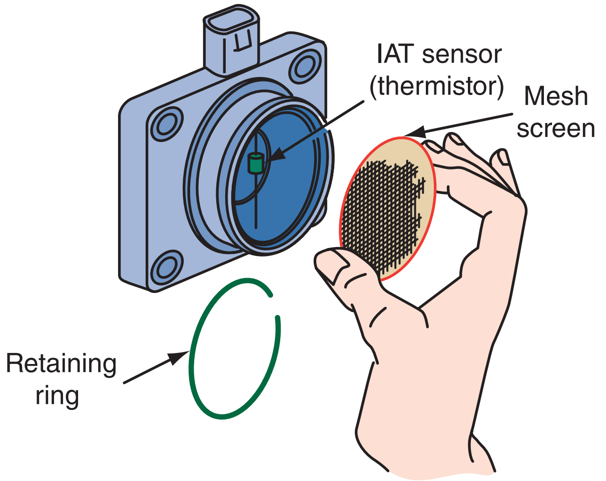


FIGURE 25–18 A typical intake air temperature (IAT) sensor incorporated into an MAF sensor.

Intake Air Temperature (IAT) Sensor

The intake air temperature (IAT) sensor is also called an air charge temperature sensor. Its resistance decreases as the incoming air temperature increases and increases as incoming air temperature decreases **(Figure 25–17)**. The PCM uses the air temperature information as a correction factor in the calculation of fuel, spark, and airflow. For example, the PCM uses this input to help calculate fuel delivery. Because cold intake air is denser, a richer air-fuel ratio is required.

On engines equipped with a MAP sensor, the IAT is installed in an intake air passage. On other engines, the IAT **(Figure 25–18)** is normally an integral part of the mass airflow (MAF) sensor. Most control systems compare the inputs from the IAT and the ECT to determine if the engine is attempting a cold start.

FIGURE 25–17 An air temperature sensor.

A defective IAT sensor may cause the following problems:

1. Rich or lean air-fuel ratio
2. Hard engine starting
3. Engine stalling or surging
4. Acceleration stumbles
5. Excessive fuel consumption

Other Temperature Sensors

Many other temperature sensors may be used on engines. Their application depends on the engine and the control system. Some turbo- or supercharged engines have two IAT sensors: one before the charger and one after. This is done to monitor the change in temperature as the air is forced into the cylinders.

Some engines have a cylinder head temperature (CHT) sensor installed in the cylinder head to measure its temperature. The primary function of this is to detect engine overheating. When high metal temperatures are reported to the PCM, it will enter into its fail-safe cooling strategy mode.

Other common temperature sensors include an engine oil temperature (EOT) sensor, fuel rail pressure temperature (FRPT) sensor, and EGR temperature sensor. Also, many vehicles built prior to OBD II use a temperature sensor to directly control the electric radiator fans.

Testing

Temperature sensor circuits should be tested for opens, shorts, and high resistance. Often if one of these problems exist, a DTC will be set. Scan tool

data can also give an indication of the condition of the sensor and related circuits. If the observed temperature is the coldest possible value, the circuit is open. If the temperature is the highest possible, the circuit has a short. Most service information give a procedure for checking for opens and shorts. A jumper wire is inserted across specific terminals of the circuit and the data is observed. This should cause the readings to go high or hot. If the connector to the sensor is disconnected, the readings should drop to cold. On some vehicles, this test will not work because the PCM will react by using a PID value. High-resistance problems will cause the PCM to respond to a lower temperature than the actual temperature. This can be verified by using a good thermometer (infrared is best) to measure the temperature and compare it to the readings on the scan tool. There will be some difference, but it should be minor if the sensor circuit is working properly. Unwanted resistance in the circuit can cause poor engine performance, poor fuel economy, and engine overheating.

Temperature sensors can be tested by removing them and placing them in a container of water with an ohmmeter connected across the sensor terminals. A thermometer is also placed in the water. When the water is heated, the sensor should have the specified resistance at any temperature **(Figure 25–19)**. Replace the sensor if it does not have the specified resistance. Manufacturers give a temperature and resistance chart for each of the temperature sensors.

Warning! Never apply an open flame or a heat gun to an ECT or IAT sensor for test purposes. This action will damage the sensor.

The wiring to the sensor can also be checked with an ohmmeter. With the wiring connectors disconnected from the sensor and the computer, connect an ohmmeter from each sensor terminal to the computer terminal to which the wire is connected. Both sensor wires should indicate less resistance than specified by the manufacturer. If the wires have high resistance, the wires or wiring connectors must be repaired.

Warning! Before disconnecting any computer system component, be sure that the ignition switch is turned off. Disconnecting components may cause high-induced voltages and computer damage.

With the sensor installed in the engine, the sensor terminals may be backprobed to connect a digital voltmeter to them. The sensor should provide the specified voltage drop at any coolant temperature **(Figure 25–20)**. To record accurate readings, make sure the meter leads have a good connection.

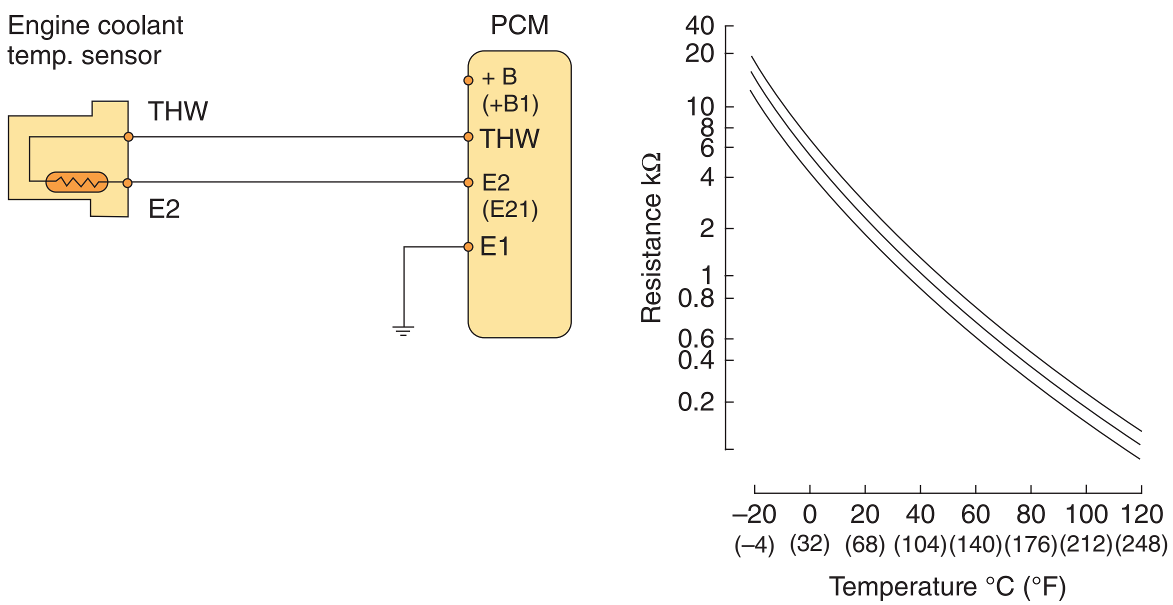


FIGURE 25–19 Specifications for an ECT sensor.

Cold—10,000-ohm resistor		Hot—909-ohm resistor	
– 20 °F	4.7V	110 °F	4.2V
0 °F	4.4V	130 °F	3.7V
20 °F	4.1V	150 °F	3.4V
40 °F	3.6V	170 °F	3.0V
60 °F	3.0V	180 °F	2.8V
80 °F	2.4V	200 °F	2.4V
100 °F	1.8V	220 °F	2.0V
120 °F	1.25V	240 °F	1.62V

FIGURE 25-20 Voltage drop specifications for an ECT sensor.

Pressure Sensors

Wheatstone bridges are used as variable resistance sensors. These are typically constructed of four resistors, connected in series-parallel between an input terminal and a ground terminal. Three of the resistors are kept at the same value. The fourth resistor is a sensing resistor. When all four of the resistors have the same value, the bridge is balanced and the voltage sensor will have a value of 0 volts. If the sensing resistor changes value, a change occurs in the circuit's balance. The sensing circuit will receive a voltage reading proportional to the amount of resistance change. If the Wheatstone bridge is used to measure temperature, temperature changes are indicated as a change in voltage by the sensing circuit. Wheatstone bridges are also used to measure pressure **(piezoresistive)** and mechanical strain.

Most pressure sensors are piezoresistive sensors. A silicon chip in the sensor flexes with changes in pressures. The amount of flex dictates the voltage signal sent out from the sensor. One side of the chip is exposed to a reference pressure, which is either a perfect vacuum or a calibrated pressure. The other side is the pressure that will be measured. As the chip flexes in response to pressure, its resistance changes. This changes the voltage signal sent to the PCM. The PCM looks at the change and calculates the pressure change.

Manifold Absolute Pressure (MAP) Sensor

A **manifold absolute pressure (MAP) sensor** senses air pressure or vacuum in the intake manifold. The sensor measures manifold air pressure against an absolute pressure. The MAP sensor uses a perfect vacuum as a reference pressure. The MAP sensor **(Figure 25–21)** measures changes in the intake manifold pressure that result from changes in engine load and speed. The PCM sends a voltage reference signal to the MAP sensor. As the pressure changes, the sensor's resistance also changes. The control module determines manifold pressure by monitoring the sensor output voltage.

The PCM uses the MAP signals to calculate how much fuel to inject in the cylinders and when to ignite the cylinders. A defective MAP sensor may cause a rich or lean air-fuel ratio, excessive fuel consumption, hard engine starting, a no-start condition, and engine surging. The MAP signal may also be used to regulate the EGR or to monitor EGR operation.

High manifold pressure (low vacuum) resulting from full throttle operation requires more fuel. Low pressure or high vacuum requires less fuel. At closed throttle, the engine produces a low MAP value. Wide-open throttle produces a high value. The highest value results when manifold pressure is the same as the pressure outside the manifold and 100 percent of the outside air is being measured. The use of this sensor also allows the control module to automatically adjust for different altitudes. A PCM with a MAP sensor relies on an IAT sensor to calculate intake air density.

Many EFI systems with MAF sensors do not have MAP sensors. However, there are a few engines with

FIGURE 25-21 A MAP sensor.

both of these sensors. These use the MAP mainly as a backup if the MAF fails. When the EFI system has a MAF, the computer calculates the intake airflow from the MAF and rpm inputs.

The MAP is the second most important sensor in the fuel management system (the CKP is more important). The basic injector pulse width is set according to the MAP signal. A defective MAP can cause a number of problems, including a no-start condition, reduced power output, and heavy engine surging.

Testing a MAP

A defective MAP sensor may cause a rich or lean air-fuel ratio, excessive fuel consumption, hard engine starting, a no-start condition, and engine surging. The sensor is mounted on the intake manifold or someplace high in the engine compartment. A hose supplies the sensor with engine vacuum. Inspect the sensor, its electrical connectors, and the vacuum hose. The hose should be checked for cracks, kinks, and proper fit.

The PCM supplies a 5-volt reference signal to the sensor. Begin your diagnosis of the MAP circuit by measuring that voltage. With the ignition switch on, backprobe the reference wire and measure the voltage. If the reference wire does not have the specified voltage, check the reference voltage at the PCM. If the voltage is within specifications at the PCM but low at the sensor, repair the wire. When this voltage is low at the PCM, check the voltage supply wires and ground wires for the PCM. If the wires are good, replace the computer.

A MAP sensor can be monitored with a scan tool through specific PIDs **(Figure 25–22)**. When using a scan tool, make sure to use the correct specifications

SHOP TALK

MAP sensors have a much different calibration on turbocharged engines than on nonturbocharged engines. Be sure you are using the proper specifications for the sensor being tested.

and follow the subsequent tests given in the service information.

With the ignition switch on, connect the voltmeter from the sensor ground wire to the battery ground. If the voltage drop across this circuit exceeds specifications, repair the ground wire from the sensor to the computer.

With the ignition on, backprobe the MAP sensor signal wire and measure the voltage. The voltage reading indicates the barometric pressure (BARO) signal from the MAP sensor to the PCM. Many MAP sensors send a barometric pressure signal to the computer each time the ignition switch is turned on and each time the throttle is in the wide-open position. If the BARO signal does not equal the MAP signal with the ignition on and the engine off, replace the MAP sensor.

To check the voltage signal of a MAP, turn the ignition switch on and connect a voltmeter to the MAP sensor signal wire. Connect a vacuum pump to the MAP sensor vacuum connection and apply vacuum to the sensor. Manufacturers list the expected voltage drop at different vacuum levels **(Figure 25–23)**. If the MAP sensor voltage is not within specifications at any vacuum, replace the sensor.

To check a MAP sensor with a lab scope, connect the scope to the MAP output and a good ground.

Sensors/Inputs	PCM Pin	Measured/PID Values				Units Measured/PID
		KOEO	Hot Idle	48 KM/H (30 MPH)	89 KM/H (55 MPH)	
MAP	E62	4*	1–1.4*	1.8–2.1*	1.9–2.3*	DCV

FIGURE 25–22 The PIDs for a typical MAP sensor.

Applied Vacuum					
in. Hg	4	8	12	16	20
kPa	14	27	40	54	68
VOLTAGE DROP	0.3–0.5	0.7–0.9	1.1–1.3	1.5–1.7	1.9–2.1

FIGURE 25–23 An example of how the voltage drop across a MAP changes with the amount of vacuum applied to the sensor.

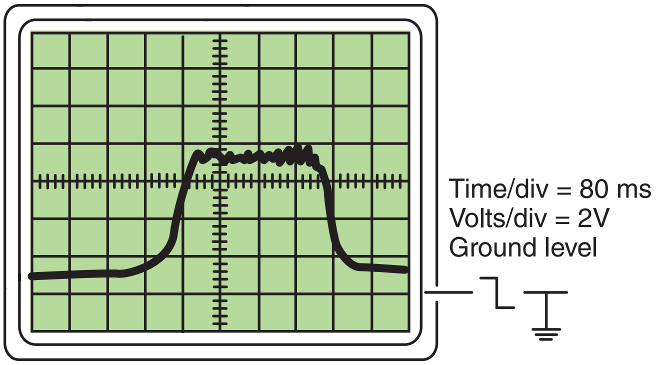


FIGURE 25–24 Trace of a normal MAP sensor.

When the engine is accelerated and returned to idle, the output voltage should increase and decrease **(Figure 25–24)**. If the engine is accelerated and the MAP sensor voltage does not rise and fall, or if the signal is erratic, the sensor or sensor wires are defective.

Some MAP sensors produce a digital voltage signal of varying frequency; begin diagnosis by checking the voltage reference wire and the ground wire.

On vehicles that use a frequency generating MAP sensor, the sensor can be checked with a DMM that measures frequency. Set the meter to read 100 to 200 Hz and connect it to the MAP sensor. Measure the voltage, duty cycle, and frequency at the sensor with no vacuum applied. Then apply about 18 in. Hg of vacuum to the MAP. Observe and record the same readings. A good MAP will have about the same amount of voltage and duty cycle with or without the vacuum. However, the frequency should decrease. Normally, a frequency of about 155 Hz is expected at sea level with no vacuum applied to the MAP. When vacuum is applied, the frequency should decrease to around 95 Hz.

A lab scope can be used to check a MAP sensor. The upper horizontal line of the trace should be at 5 volts, and the lower horizontal line should be close to zero **(Figure 25–25)**. Check the waveform for unusual movements of the trace. If the waveform is anything but normal, replace the sensor.

PROCEDURE

Continue testing by following these steps:

1. **Turn off the ignition switch, and disconnect the wiring connector from the MAP sensor.**
2. **Connect the connector on the MAP sensor tester to the MAP sensor.**
3. **Connect the MAP sensor tester battery leads to a 12-volt battery.**
4. **Connect a pair of digital voltmeter leads to the MAP tester signal wire and ground.**
5. **Turn on the ignition switch and observe the barometric pressure voltage signal on the meter. If this voltage signal does not equal specifications, replace the sensor.**
6. **Supply the specified vacuum to the MAP sensor with a vacuum pump.**
7. **Observe the voltmeter reading at each specified vacuum. If the MAP sensor voltage signal does not equal the specifications at any vacuum, replace the sensor.**

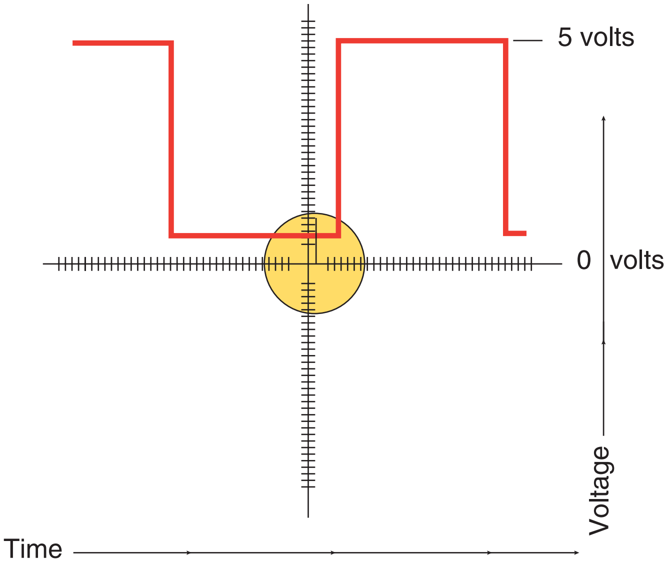


FIGURE 25–25 A good Ford MAP sensor signal.

Vapor Pressure Sensor (VPS)

The vapor pressure sensor (VPS) measures the vapor pressure in the evaporative emission control system. This sensor is capable of responding to slight pressure changes. The sensor has two chambers divided by a silicon chip. One chamber, called the reference chamber, is exposed to atmospheric pressure. The other chamber is exposed to vapor pressure. Changes in vapor pressure cause the chip to flex, which causes the signal to the PCM to change **(Figure 25–26)**. In most cases, the sensor receives a 5-volt reference voltage. The voltage signal represents the difference between vapor pressure and atmospheric pressure. The return or signal voltage will be high when the vapor pressure is high.

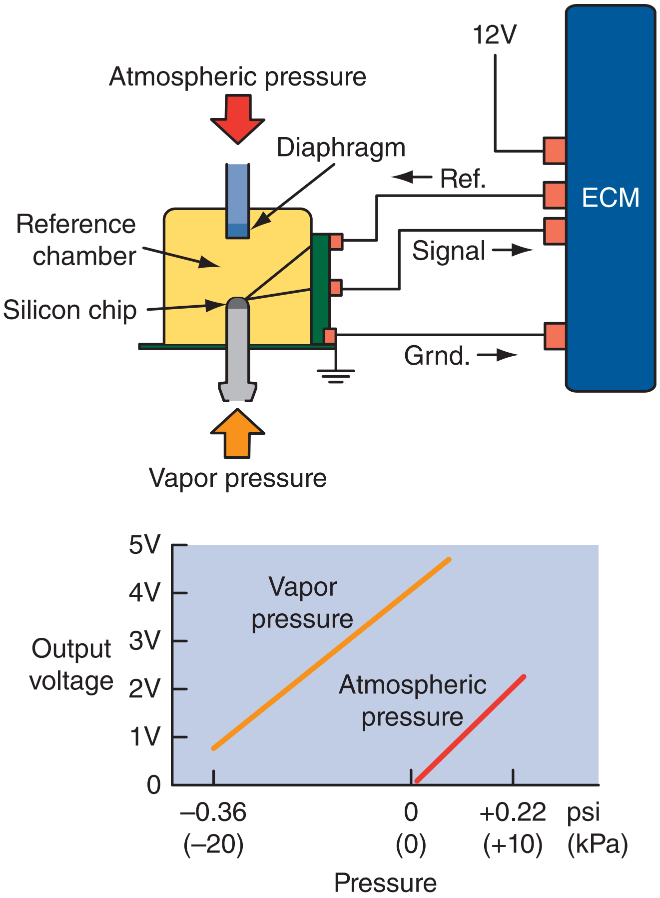


FIGURE 25–26 The operation of a vapor pressure sensor.

The sensor may be on the fuel pump or in a remote location. When the VPS is remotely mounted, a hose connects the sensor to a vapor pressure port. In some cases, the sensor has an additional hose that supplies atmospheric pressure to the VPS. If these hoses are reversed, the PCM will see high vapor pressure and set a DTC. All hoses should be checked for leaks, kinks, and secure connections. The reference voltage should also be checked. The operation of the sensor is checked in the same way as a MAP, except pressure, not vacuum, is applied to the sensor. Refer to the specifications for the amount of testing pressure to apply and the subsequent voltage signal from the sensor.

Other Pressure Sensors

Other pressure sensors are used on some engines. Their application depends on the engine and the control system. Many of these are related to the EGR system. The most commonly used is the feedback pressure EGR sensor. This sensor's voltage signal tells the PCM how much the EGR valve is open. The PCM uses this input to control the vacuum to the EGR valve and control air-fuel ratios and ignition timing.

Many port fuel injection engines have a fuel rail pressure sensor. This sensor is found on returnless fuel systems and measures fuel pressure near the fuel injectors. The PCM uses this input to adjust fuel injector pulse width. Turbo- or supercharged engines have a pressure sensor that monitors the amount of boost. Engines with gasoline direct injection have a fuel pressure sensor in the high-pressure fuel pump or fuel rail.

Mass Airflow (MAF) Sensors

The **mass airflow (MAF) sensor** measures the flow of air entering the engine **(Figure 25–27)**. This measurement of intake air volume is used to calculate engine load (throttle opening and air volume). It is similar to the relationship of engine load to MAP or vacuum sensor signal. Engine load inputs are used to control the fuel injection and ignition systems, as well as shift timing in automatic transmissions. The airflow sensor is placed between the air cleaner and throttle plate assembly or inside the air cleaner assembly.

There are different types of MAF sensors. The most commonly used design is the hot-wire MAF. In a hot-wire-type MAF **(Figure 25–28)**, a wire, called the hot wire, is positioned so the intake air flows over it. The sensor also has a thermistor, sometimes referred to as the cold wire, located beside the hot wire that measures intake air temperature. The sensor also contains a control module. Current from the PCM keeps the hot wire at a constant temperature above ambient temperature, normally 392 °F (200 °C). Airflow past the hot wire causes it to lose heat and

FIGURE 25–27 A mass airflow sensor.

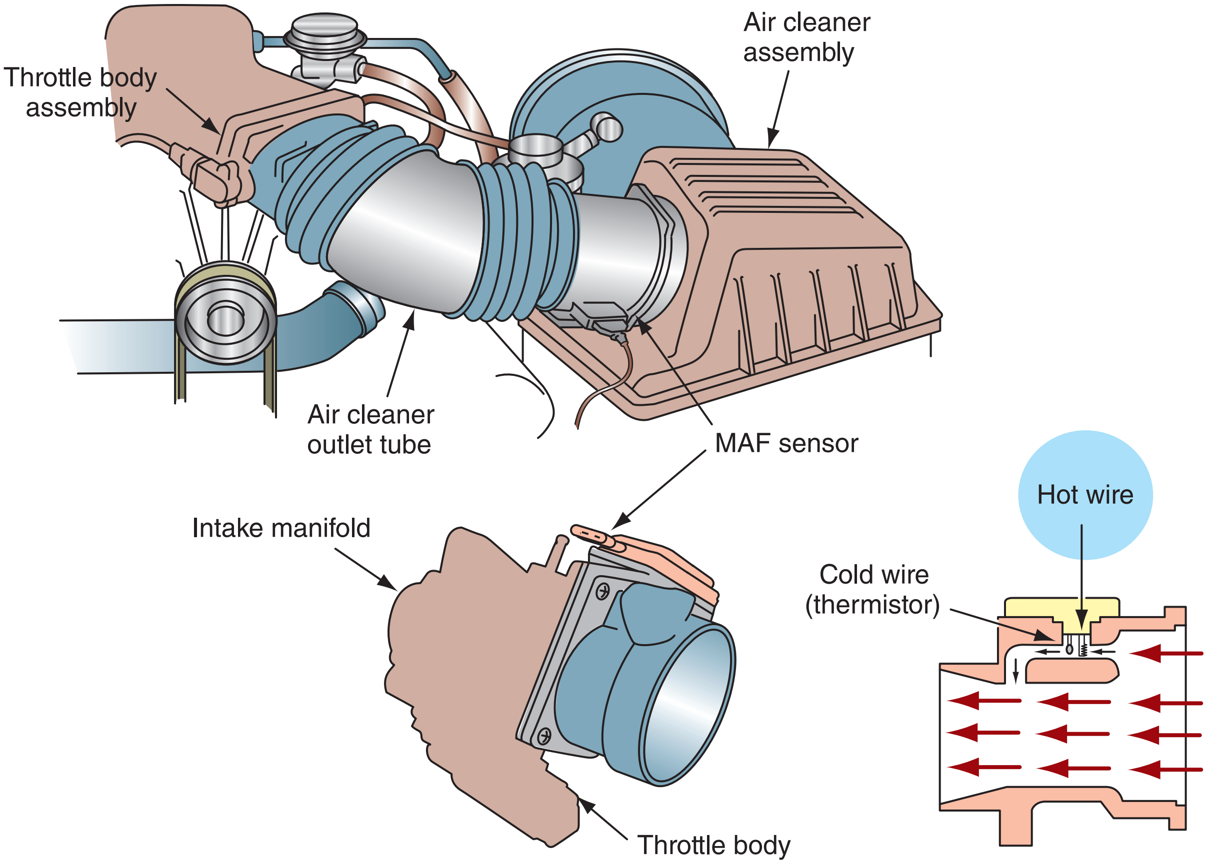


FIGURE 25–28 A hot-wire MAF.

the PCM responds by sending more current to the wire. The increased current flow keeps the hot wire at its desired temperature. The current required to maintain the hot wire's temperature is proportional to mass airflow. The sensor measures the current and sends a voltage signal to the PCM. The PCM interprets the signal to determine mass airflow. Most MAF sensors have an integrated IAT sensor and some include a humidity sensor.

Testing a MAF Sensor

The test procedure for hot-wire MAF sensors varies with the vehicle make and year. Always follow the test procedure in the appropriate service information. Most often diagnosis of a MAF sensor involves visual, circuit, and component checks. The MAF sensor passage must be free of debris to operate properly. If the passage is plugged, the engine will usually start but run poorly or stall and may not set a DTC.

Check the air inlet system (air filter, housing, and ductwork) for obstructions, blockage, proper installation, and sealing. Closely inspect the air filter element. Poor quality filters can shed fibers, which can collect on the sensing wire in the MAF. Also, if an aftermarket performance air filter is installed that requires cleaning and oiling, ensure there is not too much oil in the filter as the oil can also travel downstream and contaminate the MAF. Check the screen of the MAF sensor for dirt and other contaminants. Check the throttle plate bore for dirt buildup.

Make sure the electrical connections to the MAF are sound. Check the reference voltage to the sensor and the ground circuit. To check the MAF sensor's voltage signal and frequency, connect a voltmeter to the MAF voltage signal wire and a good ground **(Figure 25–29)**. Start the engine and observe the voltmeter reading. On some MAF sensors, this reading should be 2.5 volts. Lightly tap the MAF sensor housing with a screwdriver handle and watch the voltmeter reading. If the voltage fluctuates or the engine misfires, replace the MAF sensor. Loose internal connections will cause erratic voltage signals and

SHOP TALK

DTC P0103 (Mass or Volume Airflow Circuit High) can be set because of debris blocking the MAF sensor screen.

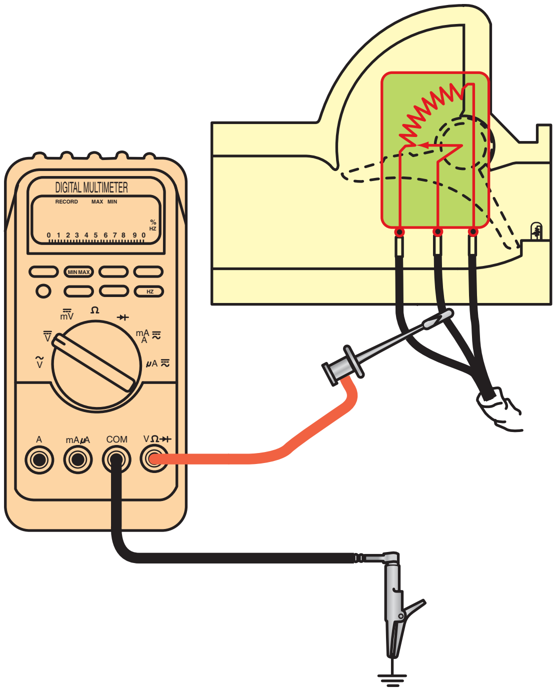


FIGURE 25–29 A voltmeter connected to measure the signal from a MAF sensor.

engine misfiring and surging. Most MAF sensors can be checked by supplying power and a ground to the correct sensor terminals, connecting a voltmeter to the signal wire, and blowing air through the sensor.

Some MAF sensors output a digital frequency signal. To check, set the DMM so that it can read the frequency of DC voltage. With it still connected to the signal wire and ground, the meter should read about 30 Hz with the engine idling. Now increase the engine speed and record the meter reading at various speeds. Graph the frequency readings. The MAF sensor frequency should increase smoothly and gradually in relation to engine speed. If the MAF sensor frequency reading is erratic, replace the sensor **(Figure 25–30)**.

A MAF sensor can be monitored with a scan tool through specific PIDs. When using a scan tool, make sure to use the correct specifications and follow the subsequent tests given in the service information. Normally the engine is run at 1,500 rpm for 5 seconds and then allowed to idle. The MAF return signal and operation of the sensor can be observed **(Figure 25–31)**. Often the manufacturer recommends that the sensor be observed at different speeds.

While diagnosing some MAF sensors with a scan tool, the test may display grams per second. This mode provides an accurate test of the MAF sensor. The grams-per second reading should normally be 4 to 7 with the engine idling. This reading should gradually increase as the engine speed increases. When the engine speed is constant, the grams-per-second reading should remain constant. If the grams-per-second reading is erratic at a constant engine speed or if this reading varies when the sensor is tapped lightly, the sensor is defective. A MAF sensor DTC may not be present with an erratic grams-per-second reading, but the erratic reading indicates a defective sensor.

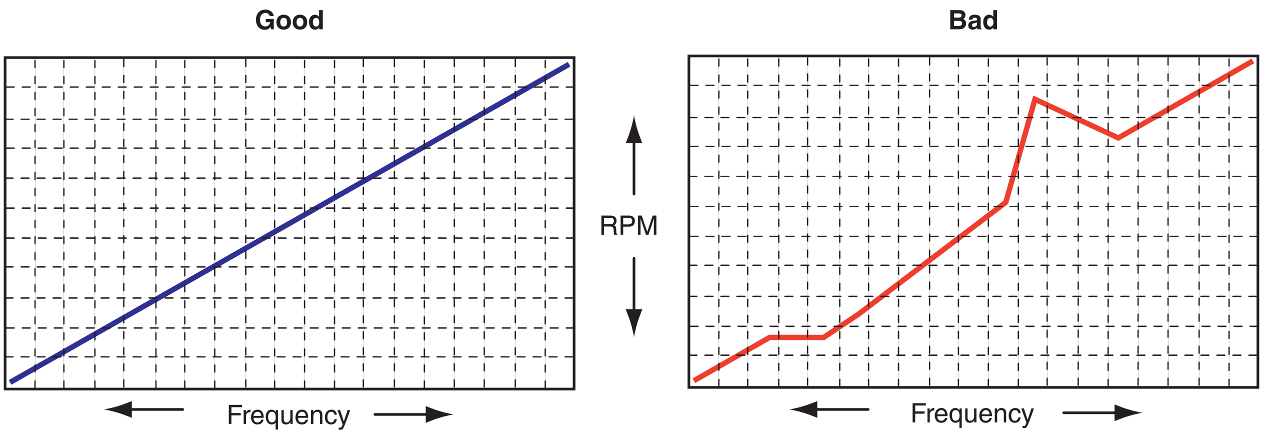


FIGURE 25–30 Satisfactory and unsatisfactory MAF sensor frequency readings.

Sensors/Inputs	PCM Pin	Measured/PID Values				Units Measured/PID
		KOEO	Hot Idle	48 KM/H (30 MPH)	89 KM/H (55 MPH)	
MAF	E25	0	0.6	1.1	1.3	DCV

FIGURE 25–31 The PIDs for a typical MAF sensor.

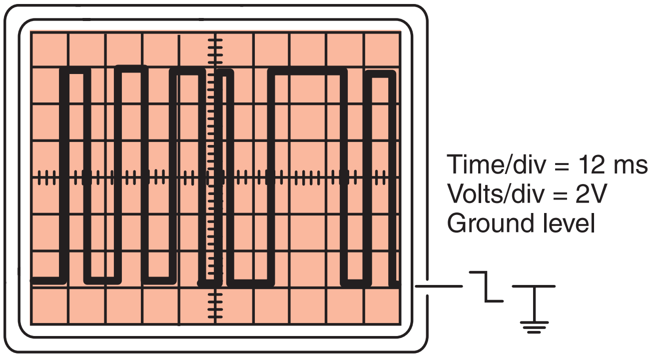


FIGURE 25–32 The trace of a defective frequency varying MAF sensor.

Driveability concerns such as a hesitation along with DTCs for a lean exhaust condition are often caused by misreporting MAF sensors. Set the scan tool to record MAF, rpm, throttle, engine load, and O_2 activity and perform a test drive. Under WOT acceleration, the MAF should reach at least 100 grams/second as the transmission shifts from first to second. If the gm/sec reading is low and the O_2 readings are low, suspect a dirty or defective MAF. For systems that report MAF output in lbs/min, look for about 0.5 lbs/min at idle and up to 13 lbs/min or more under WOT acceleration.

Frequency varying types of MAF sensors can be tested with a lab scope. The waveform should appear as a series of square waves. When the engine speed and intake air flow increase, the frequency of the MAF sensor signals should increase smoothly and proportionately to the change in engine speed. If the MAF or connecting wires are defective, the trace will show an erratic change in frequency **(Figure 25–32)**.

Oxygen Sensors (O_2S)

The exhaust gas oxygen sensor (O_2S) **(Figure 25–33)**, or air-fuel ratio sensor, is the key sensor in the closed-loop mode. The O_2S is threaded into the exhaust manifold or into the exhaust pipe near the engine. The PCM uses an O_2S to ensure that the air-fuel ratio is correct for the catalytic converter. The PCM adjusts the amount of fuel injected into the cylinders based on the O_2S signal.

OBD II standards require an O_2S before and after the catalytic converter **(Figure 25–34)**. The O_2S before the converter is used for short-term air-fuel ratio adjustments. This sensor is referred to as Sensor 1. On V-type engines, one sensor is referred to as Bank 1 Sensor 1, based on the sensor being on the same bank as cylinder 1, and the other as Bank 2 Sensor 1. The O_2S after the catalytic converter is used to determine catalytic converter efficiency and for fuel control. This sensor is referred to as Sensor 2. With two catalytic converters, one sensor is Bank 1 Sensor 2 and the other is Bank 2 Sensor 2. Often Sensor 2 is called the catalyst monitor sensor. Some engines have more than two O_2S in an exhaust bank. The sensor with the highest number designation is the catalyst monitor sensor.

O_2S generate a voltage signal based on the amount of oxygen and other gases present in the exhaust gas. A perfectly balanced, stoichiometric, air-fuel mixture of 14.7:1 produces an output of

FIGURE 25–33 A typical oxygen sensor.

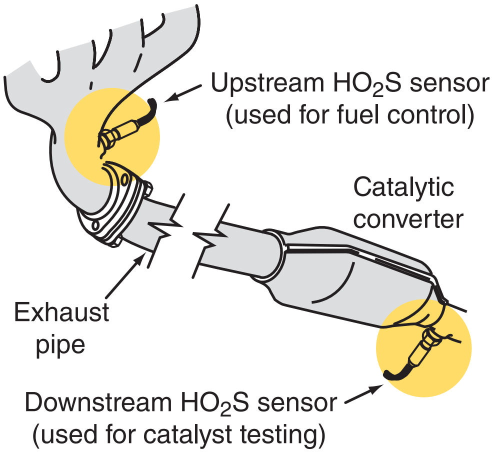


FIGURE 25–34 The pre- and postcatalytic oxygen sensors in an OBD II system.

SHOP TALK

Often O_2S are called "lambda" sensors. The term *lambda* is used to refer to "air-fuel ratio" and "normal." Technically it refers to normal and is represented by the Greek letter λ. It is best to think of lambda as meaning a reference point for normal or ideal air-fuel mixture. This mixture is typically called stoichiometric. A lambda sensor measures the variance from stoichiometric, which is about the same thing an O_2S does.

around 0.5 volt. This equals a lambda of 1.0. When the sensor detects an excess in oxygen, the reading is lean and the computer enriches the air-fuel mixture to the engine. When the sensor reading is rich, the computer leans the air-fuel mixture.

Heated Oxygen Sensors

To generate an accurate signal, an O_2S must operate at a minimum temperature of 750 °F (400 °C). Current O_2S have a built-in heating element to quickly heat them and keep them hot at idle and light load conditions. The heater is controlled by the PCM. Early O_2S did not have a heater and required some time for the exhaust to warm them. This resulted in extended periods of open-loop operation.

Heated oxygen sensors (HO_2S) have three or four wires connected to them. The additional wires provide voltage for the internal heater in the sensors. HO_2S are sometimes referred to as heated exhaust gas sensors (HEGOs). The heater is not on all of the time. The PCM opens and closes, duty cycles, the ground for the heater circuit as needed. The cycling of current to the heater protects the ceramic material of the heater from being overheated, which would cause it to break.

Zirconium Dioxide Oxygen (ZrO_2) Sensors

Zirconium dioxide oxygen (ZrO_2) sensors are the most commonly used O_2S, although they are being replaced with air-fuel ratio sensors on current vehicles. These have a zirconia (zirconium dioxide) element, platinum electrodes **(Figure 25–35)**, and a heater. The zirconia element has one side exposed to the exhaust stream, and the other side open to the atmosphere through the sensor's wires. Each side has a platinum electrode attached to the zirconium dioxide element. The platinum electrodes conduct the voltage generated. Contamination or corrosion of the platinum electrodes or zirconia elements will reduce the voltage signal output. This type of O_2S is sometimes referred to as a narrow range sensor because it is effective only with air-fuel ratios around 14.7:1. This type of sensor acts more like a lambda switch; the output varies high or low depending on whether the exhaust gases are rich or lean compared to lambda.

Titanium Dioxide (TiO_2) Sensors Titanium dioxide oxygen (TiO_2) sensors are found on a few vehicles. These sensors do not generate a voltage signal. Instead they act like a variable resistor, altering a 5-volt reference signal supplied by the control module.

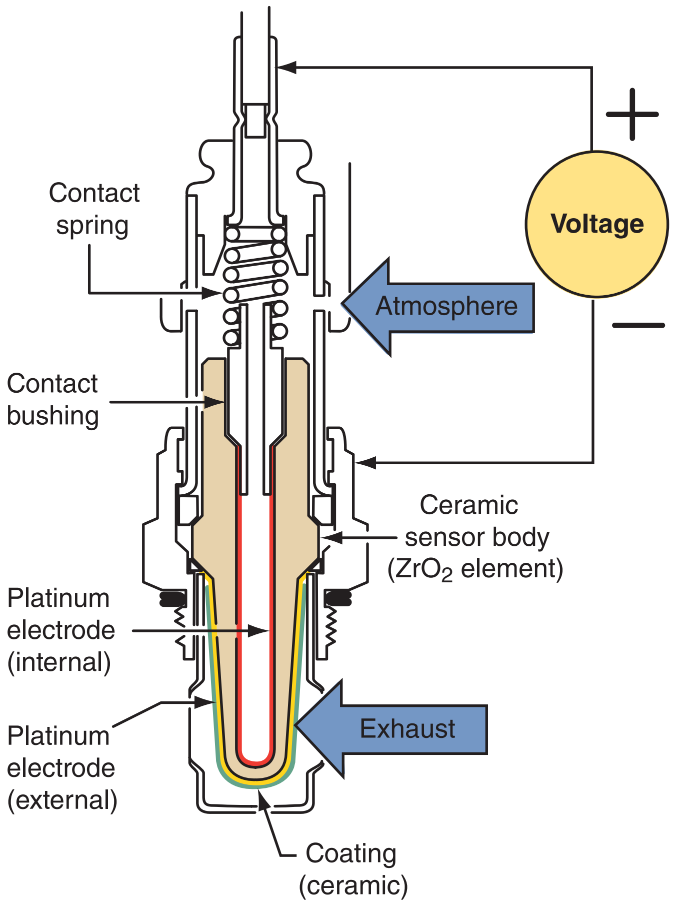


FIGURE 25–35 The voltage signal from an O_2S results from the difference in voltage at the two platinum plates inside the sensor.

Titanium sensors send a low-voltage signal (below 2.5 volts) with low oxygen content and a high-voltage signal (above 2.5 volts) with high oxygen content. Variable-resistance O_2S do not need an outside air reference. This eliminates the need for internal venting to the outside.

Air-Fuel Ratio (A/F) Sensor

The A/F sensor will undoubtedly replace all modern O_2 sensors within the next few years. Most new vehicles use an A/F sensor because it is more precise and covers a wide range of air-fuel mixtures. The ECM's AFR sensor circuitry always tries to keep a perfect air/fuel ratio (14.7:1), through an electronic module that controls its current.

Although an (A/F) sensor looks like a typical O_2S, internally it is different. It also operates differently; its voltage output increases as the mixture becomes leaner. The sensor does not directly produce a voltage signal; rather, it changes current. A detection circuit in the PCM monitors the change and strength of the

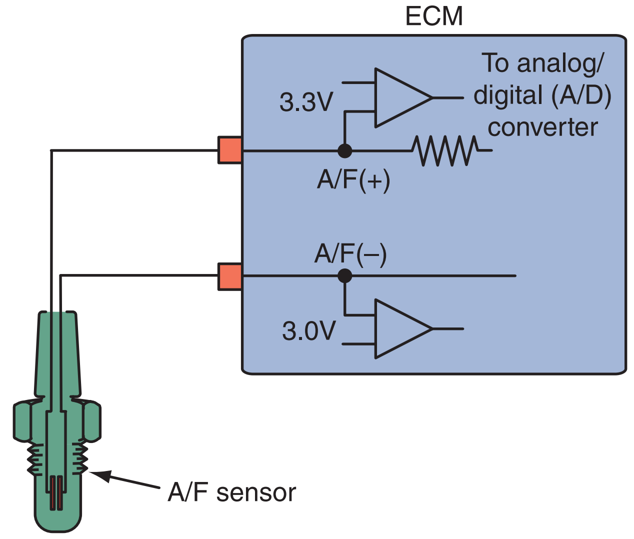


FIGURE 25–36 The detection circuit for an A/F sensor.

current flow from the A/F sensor and generates a voltage signal proportional to the exhaust oxygen content **(Figure 25–36)**. Based on the voltage signal, the PCM is able to calculate the air-fuel ratio over a wide range of conditions and quickly adjust the amount of fuel required to maintain a stoichiometric ratio. The wide range of operation allows the sensor to measure very lean conditions. When the engine is running in lean, the oxygen content of the exhaust is higher than a normal O_2S is capable of measuring. An A/F sensor also operates at a much higher temperature, (1,200°F, 650°C), than a conventional O_2S.The temperature of the sensor is very critical and the ECM controls the heater circuit pulse-width controlled heater circuit.

The detection circuit is always measuring the direction and how much current is being produced. When the mixture is at a stoichiometric ratio, no current is generated by the sensor. The voltage signal from the detection circuit is 3.3 volts **(Figure 25–37)**.

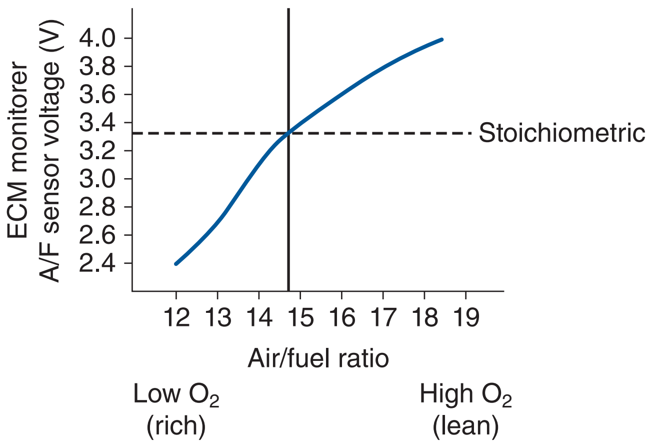


FIGURE 25–37 A chart showing the voltage outputs from an A/F sensor at different air-fuel ratios.

When the fuel mixture is rich (low exhaust oxygen content), the A/F produces a negative current flow and the detection circuit will produce a voltage below 3.3 volts. A lean mixture, which has more oxygen in the exhaust, produces a positive current flow, and the detection circuit will produce a voltage signal above 3.3 volts.

Checking Oxygen Sensors and Circuits

Keep in mind that several things can cause an O_2S to appear bad other than a faulty sensor. Common causes of abnormal O_2S operation include incorrect fuel pressure, a malfunctioning AIR system, an EGR leak, a leaking injector, a vacuum leak, an exhaust leak, and a contaminated MAF sensor. It is important to determine if it is the O_2S itself or some other factor that is causing the O_2S to behave abnormally.

The accuracy of the O_2S reading can be affected by air leaks in the intake or exhaust manifold. A misfiring spark plug that allows unburned oxygen to pass into the exhaust also causes the sensor to give a false lean reading. An O_2S can be contaminated and become lazy. *Lazy* is a term used to describe a common symptom; it takes a longer-than-normal time for the sensor to switch from lean to rich or rich to lean. A contaminated sensor may stop switching and provide a continuously low or high signal as well. In some cases, Mode $06 data can be used to check sensor switch rates and voltage levels. This data can be used to determine the condition of the sensor before it sets a DTC. O_2S and their heaters should also be checked for excessive resistance, opens, and shorts to ground.

Identifying the Cause of O_2S Contamination

Many things can cause an O_2S to become contaminated. Before simply replacing a contaminated sensor, find out why and how it was contaminated. Begin by examining the engine for leaks; oil, coolant, and other liquids can plug the pores of the sensor and cause it to respond slowly and inaccurately to the amount of oxygen in the outside air or in the exhaust. If no leaks are evident, check the

SHOP TALK

The engine must be at normal operating temperature before the O_2S is tested. Always refer to the specifications and testing procedures supplied by the manufacturer.

vehicle's service history. It is possible that recent problems that may or may not have been corrected are the cause of the contamination. For example, if the engine had some service done to it, RTV that was not designed for use around O_2S may have been used.

Using incorrect engine oil, particularly oils with high levels of sulfated ash, phosphorous, and sulfur (SAPS)—has been found to contaminate both catalytic converters and oxygen sensors. This has led to the reduction in SAPS in newer engine oil specifications.

You may also discover the cause by removing the sensor. The color and smell of the sensor may indicate the problem. If the sensor has a sweet smell, it is undoubtedly contaminated by engine coolant. If it smells burnt, there is a good chance that oil has melted onto the sensor. Silicone and engine coolant will leave white deposits on the sensor. Brown coloring may indicate oil contamination, and black means it was contaminated by a rich air-fuel mixture.

Testing with a Scan Tool The OBD II O_2S monitor checks for sensor circuit faults, slow response rate, switch point voltages, and malfunctions in the sensor's heater circuit. There is a separate DTC for each condition for each sensor **(Figure 25–38)**. The catalyst monitor sensor (Sensor 3) is not monitored for response rate; however, its peak rich and lean voltage values are. In most cases, the O_2S is monitored by the PCM once per trip. The PCM tests the sensor by looking at the return signal after the air-fuel ratio has been changed. The faster the sensor responds, the better the sensor. Diagnostic Mode 5 and Mode 6 report the results of this monitor test.

The PCM will store a code when the sensor's output is not within the desired range. The normal range is between 0 and 1 volt and the sensor should constantly toggle between about 0.2 to 0.8 volts. If the range that the sensor toggles in is within the specifications, the computer will think everything is normal and respond accordingly. This, however, does not mean the sensor is working properly.

Watching the scan tool while the engine is running, the O_2S voltage should move to nearly 1 volt and then drop back to close to 0 volts. Immediately after it drops, the voltage signal should move back up. This immediate cycling is an important function of an O_2S. If the response is slow, the sensor is lazy and should be replaced. With the engine at about 2,500 rpm, the O_2S should cycle from high to low ten to forty times in 10 seconds. The toggling is the result of the computer constantly correcting the air-fuel ratio in response to the feedback from the O_2S. When the O_2S reads lean, the computer will richen the mixture. When the O_2S reads rich, the computer will lean the mixture. When the computer does this, it is in control of the air-fuel mixture.

If the voltage is continually high, the air-fuel ratio may be rich or the sensor may be contaminated by RTV sealant, antifreeze, or lead from leaded gasoline. If the O_2S voltage is continually low, the air-fuel ratio may be lean, the sensor may be defective, or the wire between the sensor and the computer may have a high-resistance problem. If the O_2S voltage signal remains in a midrange position, the computer may be in open loop or the sensor may be defective.

If the scan tool you are using has the ability to graph data, use this function to examine sensor activity. Using the graphing function may allow you to look at several pieces of information at once, such as O_2 sensor activity and fuel trim.

Testing with a DMM There are a number of ways an O_2S can be checked. Photo Sequence 24 covers the use of the min/max function on a DMM If a defect in the O_2S signal wire is suspected, backprobe it at the computer and connect a digital voltmeter from the signal wire to ground with the engine idling. The difference between the voltage readings at the sensor and at the computer should not exceed the vehicle manufacturer's specifications. A typical specification for voltage drop across the average sensor wire is 0.02 volt.

Definition	(Bank 1 Sensor 1)	(Bank 1 Sensor 2)	(Bank 2 Sensor 1)	(Bank 2 Sensor 2)	(Bank 1 Sensor 3)
HEATER RESISTANCE	P0053	P0054	P0059	P0060	P0055
HIGH VOLTAGE	P0132	P0138	P0152	P0158	P0144
SLOW RESPONSE	P0133	P0139	P0153	P0159	
HEATER CIRCUIT	P0135	P0141	P0155	P0161	P0147
SIGNALS SWAPPED	P0040 (Bank 1 Sensor 1/Bank 2 Sensor 1)		P0041 (Bank 1 Sensor 2/Bank 2 Sensor 2)		

FIGURE 25–38 A bad oxygen sensor can cause a number of problems and set a variety of DTCs.

PHOTO SEQUENCE 24

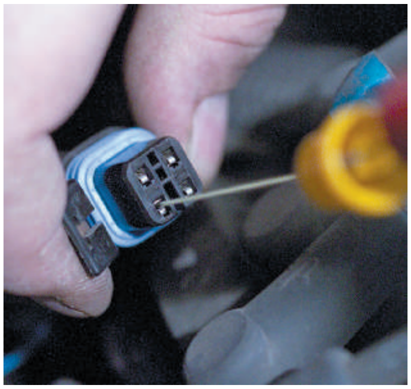
Testing an Oxygen Sensor

P24-1 Locate the oxygen sensor in a wiring diagram for the vehicle and identify what part of the sensor each wire is connected to.

P24-2 Connect the positive lead of the meter to the power wire for the sensor's heater. Connect the meter's negative lead to a good ground.

P24-3 Place the meter where you can see it from the driver's seat.

P24-4 Start the engine and observe the voltage reading as the engine initially starts.



P24-5 Turn off the engine and move the positive meter lead to the sensor's signal wire. Keep the negative lead grounded.

P24-6 Restart the engine and allow it to reach normal operating temperature. Look at the meter to make sure the sensor's signal is toggling from low to high voltage.

P24-7 Press the Min/Max button on the meter and observe the voltage. This reading will be the minimum voltage and should be about 0.1 volt.

P24-8 Press the Min/Max button again to observe the maximum voltage reading. This should be about 0.9 volt.

P24-9 Press the Min/Max button again to read the average voltage. This reading should be about 0.45 volt. Repeat this test at different speeds to get a good look at how well the O_2 sensor responds.

Now check the sensor's ground. With the engine idling, connect the voltmeter from the sensor case to the sensor ground wire on the computer. Typically the maximum allowable voltage drop across the sensor ground circuit is 0.02 volt. If the voltage drop across the sensor ground exceeds specifications, repair the ground wire or the sensor ground in the exhaust manifold.

With the O_2S wire disconnected, connect an ohmmeter across the heater terminals in the sensor connector. If the heater does not have the specified resistance, replace the sensor.

Most engines are fitted with heated O_2S. A PTC thermistor inside the O_2S heats up as current passes through it. The PCM turns on the circuit based on ECT and engine load (determined from the MAF or MAP sensor signal). The higher the temperature of the heater, the greater its resistance. If the heater is not working, the sensor warm-up time is extended and the computer stays in open loop longer. In this mode, the computer supplies a richer air-fuel ratio. As a result, the engine's emissions are high and its fuel economy is reduced.

To test the heater circuit, disconnect the O_2S connector and connect a voltmeter between the heater voltage supply wire and ground **(Figure 25–39)**. With the ignition switch on, 12 volts should be supplied on this wire. If the voltage is less than 12 volts, repair the fuse in this voltage supply wire or the wire itself.

SHOP TALK

ZrO_2 and TiO_2 sensors produce an analog signal. A/F ratio sensors only produce a signal after their current output has been sent to the PCM; make sure you refer to the manufacturer's information before making a judgment on an A/F sensor.

Testing with a Lab Scope A lab scope or GMM allows a look at the operation of the O_2S while it responds to changes in the air-fuel mixture. Connect the lab scope to the sensor's signal wire and a good ground. Set the scope to display the trace at 200 millivolts per division and 500 milliseconds per division.

The O_2S can be biased rich or lean, or not work at all, or work too slowly. Begin your testing by allowing the engine and O_2S to warm up. Watch the waveforms **(Figure 25–40)**. If the sensor's voltage toggles between 0 and 500 millivolts, it is toggling below its normal range and is not operating normally. It is biased low or lean. As a result, the computer will be constantly adding fuel to try to reach the upper limit of the sensor. Something is causing the sensor to be biased lean. If the toggling only occurs at the higher limits of the voltage range, the sensor is biased rich.

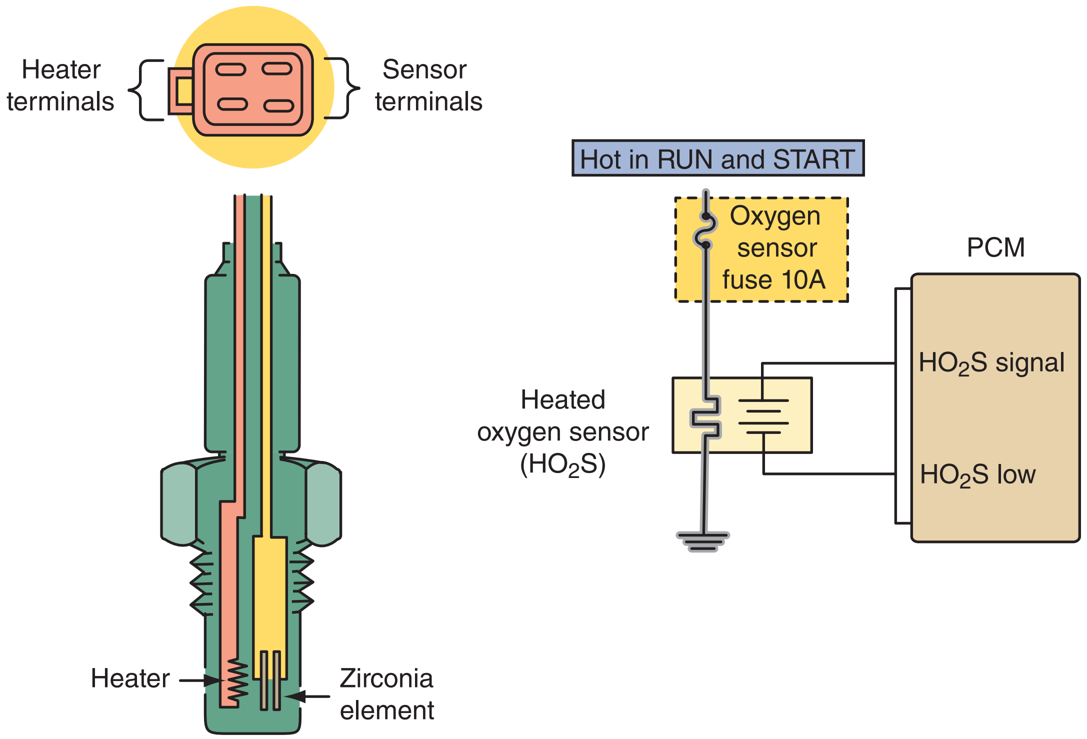


FIGURE 25–39 Using a wiring diagram to identify the terminals on a heated oxygen sensor.

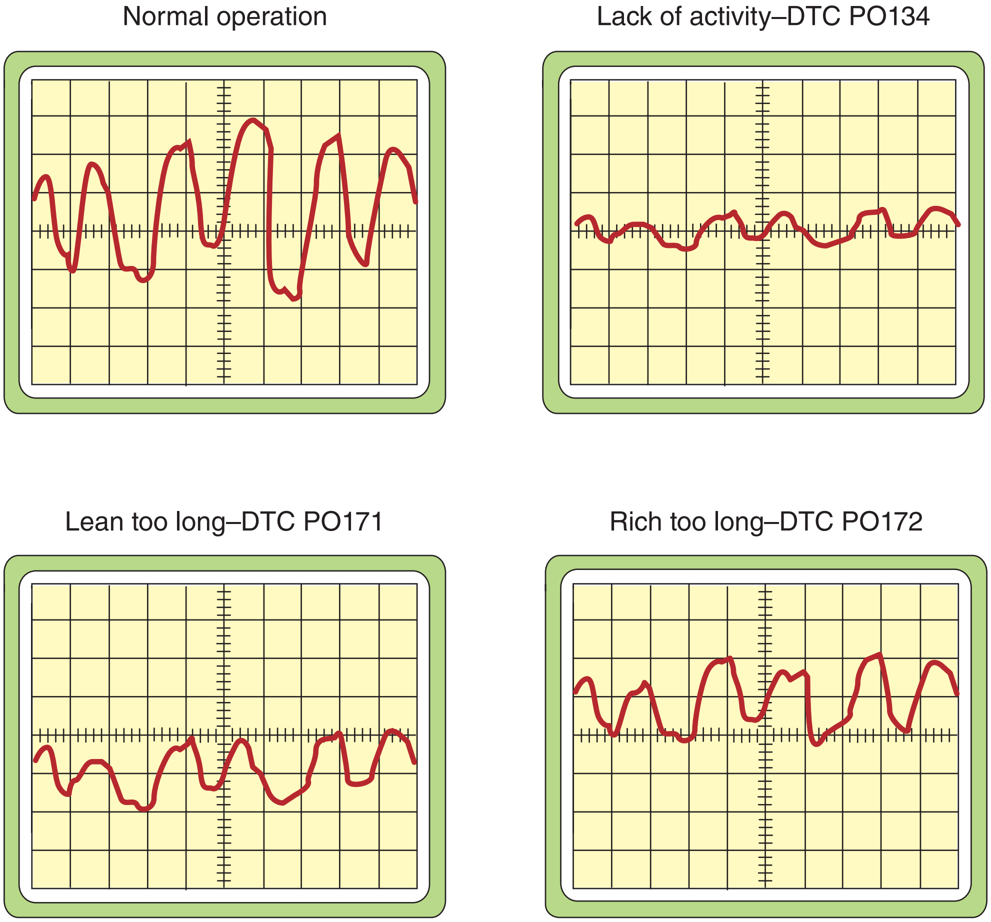


FIGURE 25–40 Normal and abnormal O_2S waveforms.

When the mixture is rich, combustion has a better chance of being complete. Therefore, the oxygen levels in the exhaust decrease. The O_2S output will respond to the low O_2 with a high-voltage signal. Remember that the PCM will always try to do the opposite of what it receives from the O_2S. When the O_2 shows lean, the PCM goes rich, and vice versa. When a lean exhaust signal is not caused by an air-fuel problem, the PCM does not know what the true cause is and will richen the mixture in response to the signal. This may make the engine run worse than it did.

SHOP TALK

Some PCMs are programed with a bias for the O_2S. This means the voltage output of the sensor does not exactly reflect how the PCM interprets the signals from the sensor. Normally, the bias is added to the actual reading. Make sure to refer to the service information to identify any voltage biases that may occur. If you do not do this, you will end up with a faulty diagnosis.

The signals from the front (upstream) and rear (downstream) O_2S should be compared. This will not only help in determining the effectiveness of the catalytic converter, but it will also help determine the condition of each sensor. Use a two-channel scope or GMM. Connect the meter to the signal wire in both harnesses. Start the engine and allow the sensors to warm up. Then raise the engine's speed to 2,000 to 2,500 rpm and observe the waveforms **(Figure 25–41)**. In the waveform, it is evident that the upstream sensor is toggling correctly, and the upstream sensor shows the catalyst is working properly.

The voltage signal from an upstream O_2S should have seven cross counts within 5 seconds with the engine running without a load at 2,500 rpm. The downstream O_2S should have less cross counts and have a lower amplitude than the upstream sensor.

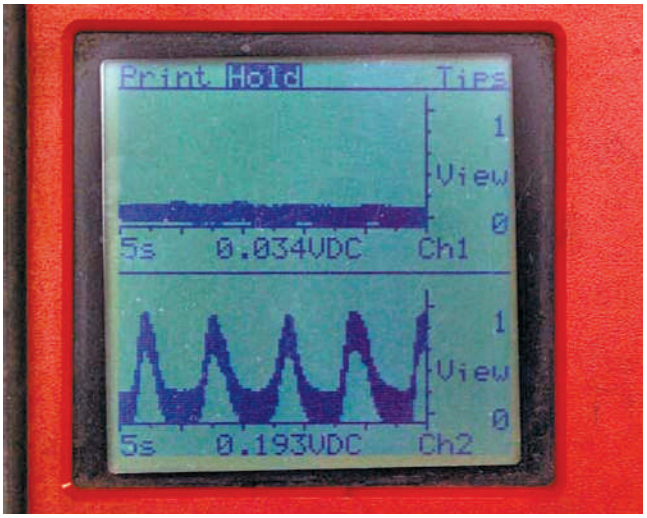


FIGURE 25–41 A comparison of the upstream and the downstream O_2 sensors.

O_2 signal **cross counts** are the number of times the O_2 voltage signal changes above or below 0.45 volt in a second. If there are not enough cross counts, the sensor is contaminated or lazy. It should be replaced. The downstream O_2S signal does not toggle when the converter is warmed up and the engine is idling. This is because the converter is using all of the oxygen that is in the exhaust.

Another check of the responsiveness of an O_2S involves its reaction to an overly rich and lean mixtures. Insert the hose of a propane enrichment tool into the power brake booster vacuum hose or simply install it into the nozzle of the air cleaner assembly. This will drive the mixture rich. Most good O_2S will produce almost 1 volt when driven full rich. The typical specification is at least 800 millivolts. If the voltage does not go high, the O_2S is bad and should be replaced. Now, remove the propane bottle and cause a vacuum leak by pulling off an intake vacuum hose. Watch the scope to see how the O_2S reacts. It should drop to under 175 millivolts. If it does not, replace the sensor. These tests check the O_2S, not the system; therefore, they are reliable O_2S checks.

Testing Air-Fuel Ratio (A/F) Sensors

A/F sensors cannot be tested in the same way as an O_2S. The A/F sensor has two signal wires. The PCM supplies 3 volts to one wire and 3.3 volts to the other. If a voltmeter is connected across these two wires, the difference in potential will be measured. This reading has no meaning because the 0.3-volt difference will always be there regardless of the oxygen content. The heater circuit can be checked with a voltmeter, and the heater can be checked with an ohmmeter.

To observe the changes in voltage in relationship to changes in oxygen content, use a scan tool that has the correct software. Some scan tools are not able to read the data from the sensor detection circuit, and a PID for the A/F sensor will not be available. Some scan tools will convert the range of the voltage signals to 0 to 1 volt. This is done by dividing the output from the detection circuit by 5. To calculate the actual voltage signal, multiply the measured voltage by 5. A reading of 0.66 volt equals 3.3 volts, which is the amount that should be present when the mixture is stoichiometric. The voltage from an A/F sensor will increase as the mixture goes lean and decrease with a rich mixture.

Unless there is a large change in the air-fuel ratio, the voltage readings will toggle very little **(Figure 25–42)**. The air-fuel ratio is tightly controlled by the PCM and only minor adjustments are normally made. However, if the output voltage of the A/F sensor stays at 3.3 volts regardless of conditions, the sensor circuit may be open. If voltage from the sensor stays at 2.8 volts or less, or 3.8 volts or more, the sensor circuit may be shorted.

The action of the sensor can also be observed with an ammeter. Place the ammeter in series with the 3.3-volt signal wire. Separate the connector to the sensor. Use jumper wires to connect the terminals for the heater and the 3-volt signal wire. Then connect the positive lead of the meter to the 3.3-volt signal wire terminal on the PCM side of the connector and the negative lead to the terminal in the other half of the connector. Run the engine and observe the meter. When the mixture is stoichiometric, there should be 0 amps. When the mixture is rich, there should be negative current flow. And when there is a lean mixture, the current should move to positive.

The A/F sensor monitor is similar to the O_2S monitor but has different operating parameters. The monitor checks for sensor circuit malfunctions and slow response rate and for problems in the sensor's heater circuit. If a fault is found, a DTC that identifies the sensor and type of fault will be set. The PCM tests the performance of A/F sensors by measuring the signal response as the amount of fuel injected into the cylinders is changed. A good sensor will respond very quickly. The results of the monitor test are not reported in Mode 5. Mode 6 is used to determine if the A/F sensors passed or failed the test.

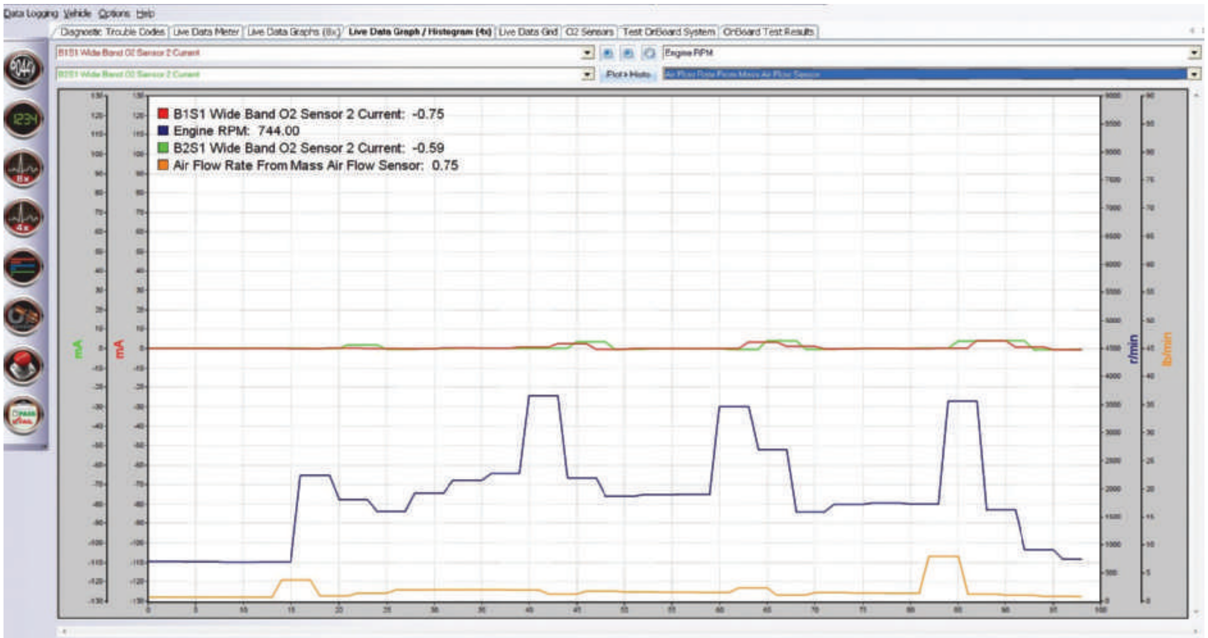


FIGURE 25–42 Wide-band sensors produce small changes in current flow at different air/fuel ratios.

HO_2S and A/F Sensor Repair

If the HO_2S wiring, connector, or terminal is damaged, the entire O_2S assembly should be replaced. Do not attempt to repair the assembly. In order for this sensor to work properly, it must have a clean air reference. The sensor receives this reference from the air that is present around the sensor's signal and heater wires. Any attempt to repair the wires, connectors, or terminals could result in the obstruction of the air reference and degraded O_2S performance.

Additional guidelines for servicing an HO_2S follow:

- Do not apply contact cleaner or other materials to the sensor or wiring harness connectors. These materials may get into the sensor, causing poor performance.
- Ensure that the sensor pigtail and harness wires are not damaged in such a way that the wires inside are exposed. This could provide a path for foreign materials to enter the sensor and cause performance problems.
- Ensure that neither the sensor nor the wires are bent sharply or kinked. Sharp bends, kinks, and so on could block the reference air path through the lead wire.
- Do not remove or defeat the O_2S ground wire. Vehicles that utilize the ground wired sensor may rely on this ground as the only ground contact to the sensor. Removal of the ground wire will cause poor engine performance.
- To prevent damage due to water intrusion, be sure that the sensor's seal remains intact on the wiring harness.
- Use a socket or tool designed to remove the sensor; failure to do this may result in damage to the sensor and/or wiring.

If suggested by the manufacturer, apply a light coat of antiseize lubricant to the threads of the sensor before installing it.

Position Sensors

Position sensors are used to monitor the position of something from totally closed to totally open positions. They are basically potentiometers. A wiper arm is connected to a moving part on one end and the other end is in contact with a resistor; the resistor is supplied with a reference voltage. As the part moves, so does the wiper arm. As the wiper arm moves on the resistor, the voltage changes and the available voltage at the point where the wiper arm contacts the resistor is the signal voltage sent to the PCM. The PCM then interprets the part's position according to the voltage.

Reference Voltage Sensors To get an exact look at what is happening in a system, the computer sends a constant, predetermined voltage signal to a sensor. The sensor reacts to operating conditions and sends a voltage signal back to the computer.

This type of sensor is called a **reference voltage (Vref) sensor**. The voltage sent out by the computer is called the reference voltage and normally has a value of 5 to 9 volts. The reference voltage is sent out to a sensor through a reference voltage regulator in the computer. The regulator keeps the reference voltage at a predetermined value. Because the computer knows that a certain voltage value has been sent out, it can indirectly interpret things like motion, temperature, and component position, based on what comes back.

Most reference voltage sensors are variable resistors or potentiometers. They modify the reference voltage and the return voltage represents a condition. The computer will use the return voltage to calculate the condition and order changes to system operation, if necessary.

Throttle Position (TP) Sensor **Throttle position (TP) sensors (Figure 25–43)** send a signal to the PCM regarding the rate of throttle opening and the relative throttle position. The wiper arm in the sensor is rotated by the throttle shaft **(Figure 25–44)**. As the throttle shaft moves, the wiper arm moves to a new location on the resistor. The return voltage signal tells the PCM how much the throttle plates are open. As the signal tells the PCM that the throttle is opening, the PCM enriches the air-fuel mixture to maintain the proper air-fuel ratio. The TP sensor is mounted on the throttle body. A separate idle contact switch or wide-open throttle (WOT) switch may also be used to signal when the throttle is in those positions.

A basic TP sensor has three wires. One wire carries the 5-volt reference signal, another serves as the ground for the resistor, and the third is the signal wire. When the throttle plates are closed, the signal voltage will be around 0.6 to 0.9 volt. As the throttle opens, there is less resistance between the beginning of the resistor and the place of wiper arm contact. Therefore, the voltage signal increases. At WOT the signal will be approximately 3.5 to 4.7 volts. Often the terminals in the connector for the sensor are gold plated. The plating makes the connector more durable and corrosion resistant.

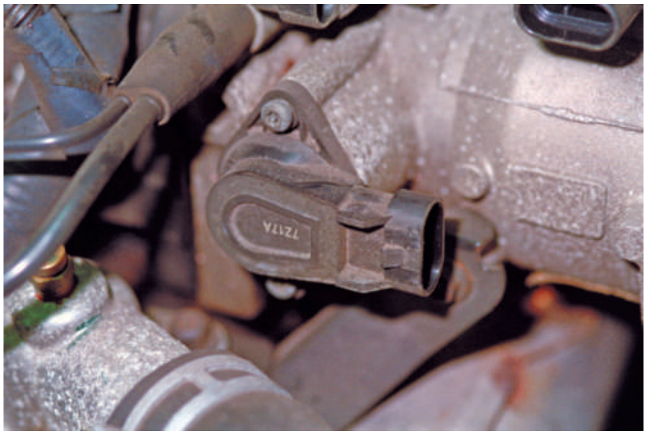


FIGURE 25–43 A throttle position (TP) sensor.

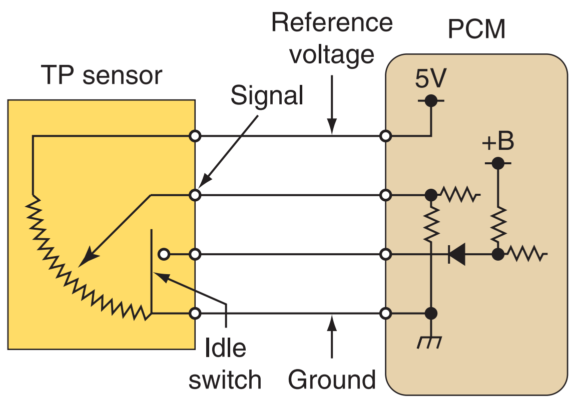


FIGURE 25–44 Basic circuit for a TP sensor.

TP Sensors for Electronic Throttle Control The TP sensor for electronic throttle systems has two wiper arms and two resistors in a single housing **(Figure 25–45)**. Therefore, they have two signal wires. This is done to ensure accurate throttle plate position in case one sensor fails. Some of these TP sensors have different voltage signals on the signal wire. However, they work in the same way. One of the signals starts at a higher voltage and has a different change rate. Other designs of this sensor have a signal that decreases with throttle opening and the other increases with the opening. In either case, the PCM uses both signals to determine throttle opening and depends on one if the other sends an out-of-range signal.

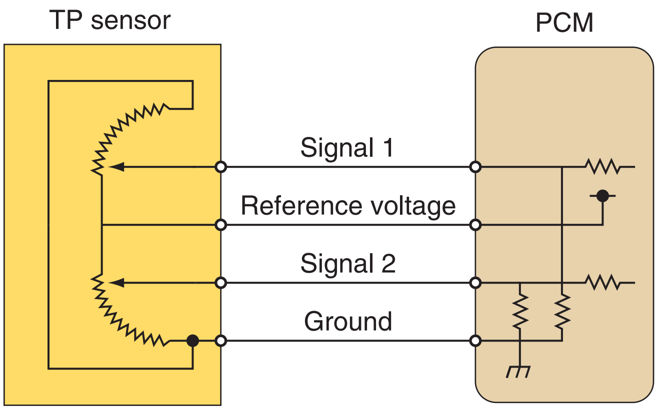


FIGURE 25–45 Basic circuit of a TP sensor for an electronic throttle system.

Testing a TP Sensor

The most common symptoms of a bad or misadjusted TP sensor are engine stalling, improper idle speed, and hesitation or stumble during acceleration. The fuel mixture leans out because the computer does not receive the right signal telling it to add fuel as the throttle opens. Eventually, the O_2S senses the problem and adjusts the mixture, but not before the engine stumbles.

The initial setting of the sensor is critical. The voltage signal that the computer receives is referenced to this setting. Most service information lists the initial TP sensor setting to the nearest 0.01 volt, a clear indication of the importance of this setting.

With the ignition switch on, connect a voltmeter between the reference wire to ground. Normally, the voltage reading should be 5 volts. If the reference wire is not supplying the specified voltage, check the voltage on this wire at the computer terminal. If the voltage is within specifications at the computer but low at the sensor, repair the reference wire. When this voltage is low at the computer, check the voltage supply wires and ground wires on the computer. If these wires are satisfactory, replace the computer.

With the ignition switch on, connect a voltmeter from the sensor signal wire to ground. Slowly open the throttle and observe the voltmeter. The voltmeter reading should increase smoothly and gradually. Typical TP sensor voltage readings would be 0.5 to 1 volt with the throttle in the idle position, and 4 to 5 volts at WOT. If the TP sensor does not have the specified voltage or if the voltage signal is erratic, replace the sensor.

A TP sensor can also be checked with an ohmmeter. Most often, the total resistance of the sensor is given in the specifications. If the sensor does not meet these, it should be replaced.

Adjustment of the TP sensor can be made on some engines. Incorrect TP sensor adjustment may cause inaccurate idle speed, engine stalling, and acceleration stumbles. Follow these steps to adjust a typical TP sensor:

1. Backprobe the TP sensor signal wire and connect a voltmeter from this wire to ground.
2. Turn on the ignition switch and observe the voltmeter reading with the throttle in the idle position.
3. If the TP sensor does not provide the specified voltage, loosen the TP sensor mounting bolts and move the sensor housing until the specified voltage is indicated on the voltmeter **(Figure 25–46)**.
4. Hold the sensor in this position and tighten the mounting bolts to the specified torque.

TP sensors can also be tested with a lab scope. Connect the scope to the sensor's output and a good ground and watch the trace as the throttle is opened and closed. The resulting trace should look smooth and clean without any sharp breaks or spikes in the signal **(Figure 25–47)**. A bad sensor will typically have a glitch (a downward spike) somewhere in the trace **(Figure 25–48)** or will not have a smooth transition from high to low. These glitches are an indication of an open or short in the sensor.

The action of a TP sensor can also be monitored on a scan tool. Compare the position, expressed in a percentage, to the voltage specifications for that throttle position.

Be careful; some TP sensors have four wires. The additional wire is connected to an idle switch. Normally, when the switch is closed there will be 0 volts and battery voltage when the switch is open. Check the wiring diagram before measuring voltage here and before deciding if the switch and circuit are good.

SHOP TALK

When the throttle is opened gradually to check the TP sensor voltage signal, tap the sensor lightly and watch for fluctuations on the voltmeter pointer, indicating a defective sensor.

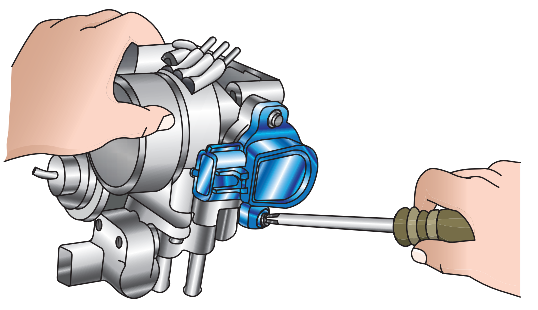


FIGURE 25–46 Loosen the TP sensor's mounting screws to adjust the sensor.

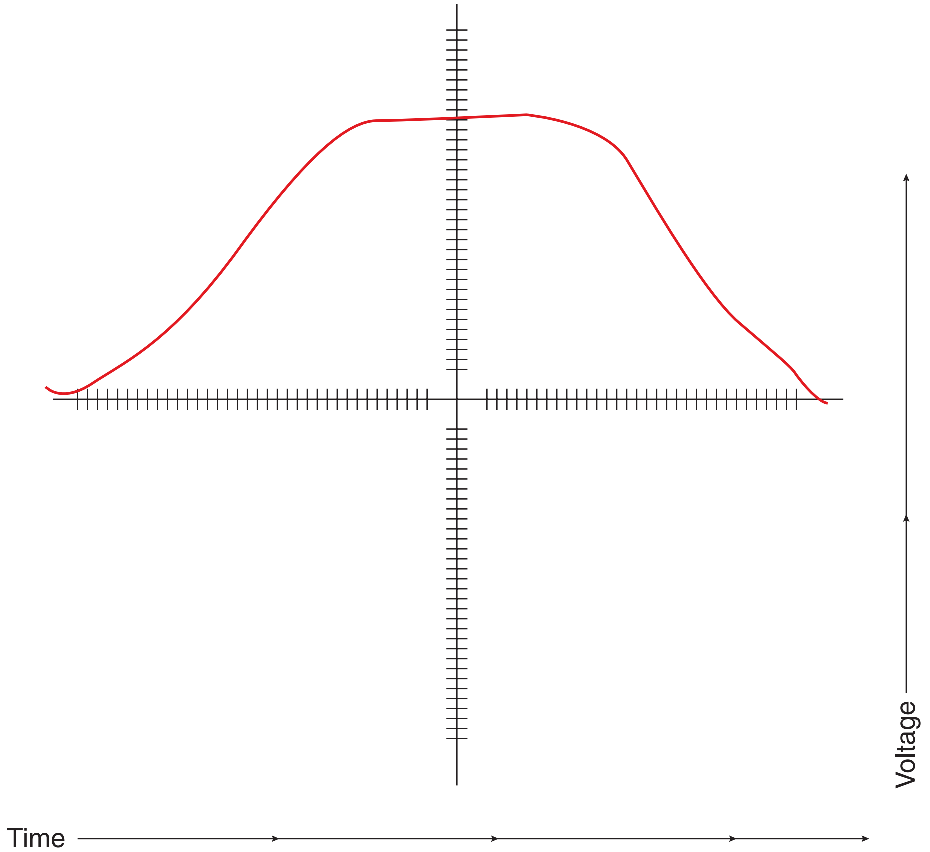


FIGURE 25–47 The waveform of a normal TP sensor as the throttle opens and closes.

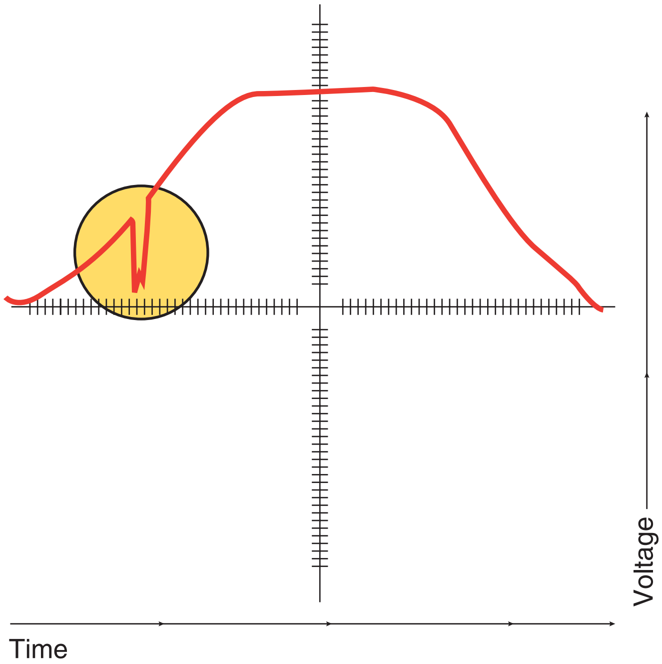


FIGURE 25–48 The waveform of a defective TP sensor. Notice the glitch while the throttle opens.

EGR Valve Position Sensor

Manufacturers use a variety of sensors or switches to determine when and how far the EGR valve is open. This information is used to adjust the air-fuel mixture and EGR flow rates. The exhaust gases introduced by the EGR valve into the intake manifold reduce the available oxygen and thus less fuel is needed in order to maintain low HC levels in the exhaust. Most EGR valve position sensors are linear potentiometers mounted on top of the EGR valve and detect the height of the EGR valve. When the EGR valve opens, the potentiometer stem moves upward and a higher voltage signal is sent to the PCM. These sensors work in the same way as a TP sensor.

Most EGR valve position sensors have a 5-volt reference wire, voltage signal wire, and ground wire. To test one, measure the voltage at the signal wire with the ignition on and the engine not running. The

meter should read about 0.8 volt. Then connect a vacuum pump to the EGR valve and slowly increase the vacuum to about 20 in. Hg. The voltage signal should smoothly increase to 4.5 volts at 20 in. Hg. If the signal voltage does not reach the specified voltage, replace the sensor.

These sensors can also be checked with a lab scope or GMM. Watch the rise of the waveform as vacuum is applied. Also look for any glitches in the waveform. These are hard to see on a voltmeter unless they are very severe. The trace should be clean and smooth.

Accelerator Pedal Position (APP) Sensor

The APP sensor is used with electronic throttle control systems. It converts accelerator pedal movement into electrical signals. Like the TP sensor for the electronic throttle system, the APP is based on two potentiometers. The PCM uses the signals from this sensor to determine power or torque demand. In turn, the PCM opens or closes the throttle plate and adjusts the amount of fuel that is injected into the cylinders.

An APP is tested in the same way as other variable resistor sensors.

Speed Sensors

Speed sensors measure the rotational speed of something. The PCM uses these signals in a number of ways, depending on the system. Speed sensors are either Hall-effect switches or magnetic pulse generators. Identifying the type of sensor used in a particular application dictates how the sensor should be tested.

Magnetic pulse generators use the principle of magnetic induction to produce a voltage signal. They are also called permanent magnet (PM) generators. These sensors are often used to send data to the computer about the speed of the monitored component. This data can provide information about vehicle speed, shaft speed, and wheel speed. The signals from speed sensors are used for instrumentation, cruise control systems, antilock brake systems, ignition systems, speed-sensitive steering systems, and automatic ride control systems. A magnetic pulse generator is also used to inform the computer about the position of a monitored device. This is common in engine controls where the PCM needs to know the position of the crankshaft in relation to rotational degrees.

The major components of a pulse generator are a timing disc and a pickup coil. The timing disc or reluctor is attached to a rotating shaft or cable. The number of teeth on the timing disc depends on the application. If only the number of revolutions is required, the timing disc may have one tooth, whereas if it is important to track quarter revolutions, the timing disc needs at least four teeth. The teeth will generate a voltage that is constant per revolution of the shaft. For example, a vehicle speed sensor may be designed to deliver 4,000 pulses per mile. The number of pulses per mile remains constant regardless of speed. The computer calculates how fast the vehicle is going based on the frequency of the signal. The timing disc is also known as an armature, reluctor, trigger wheel, pulse wheel, or timing core.

The **pickup coil** is also known as a stator, sensor, or pole piece. It remains stationary while the timing disc rotates in front of it. The changes of magnetic lines of force generate a small voltage signal in the coil. A pickup coil consists of a permanent magnet with fine wire wound around it.

An air gap is maintained between the timing disc and the pickup coil. As the timing disc rotates in front of the pickup coil, the generator sends a pulse signal **(Figure 25–49)**. As a tooth on the timing disc aligns with the core of the pickup coil, it repels the magnetic field. The magnetic field is forced to flow through the coil and pickup core **(Figure 25–50)**.

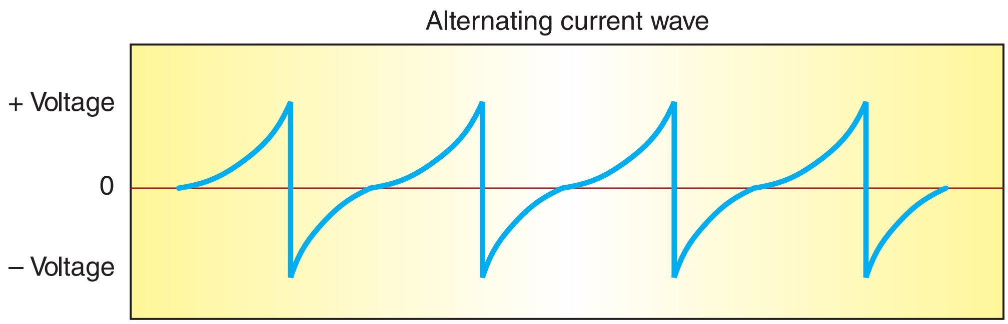


FIGURE 22–49 A pulsed voltage signal.

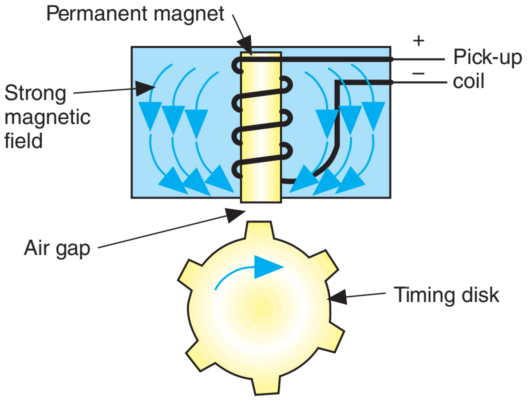


FIGURE 22–50 A strong magnetic field is produced in the pickup coil as the teeth align with the core.

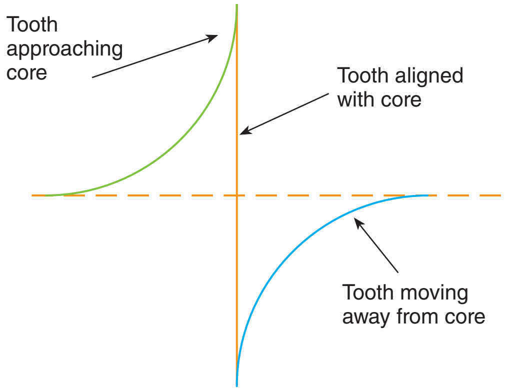


FIGURE 22–52 The waveform produced by a magnetic pulse generator.

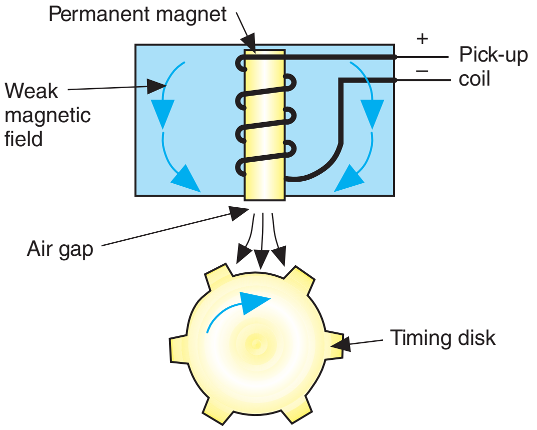
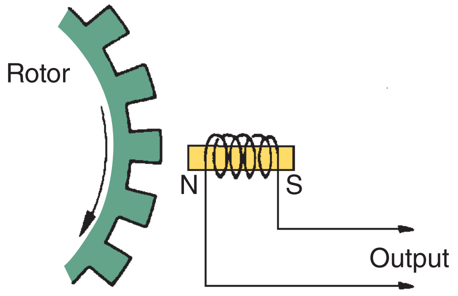


FIGURE 22–51 The magnetic field expands and weakens as the teeth pass the core.



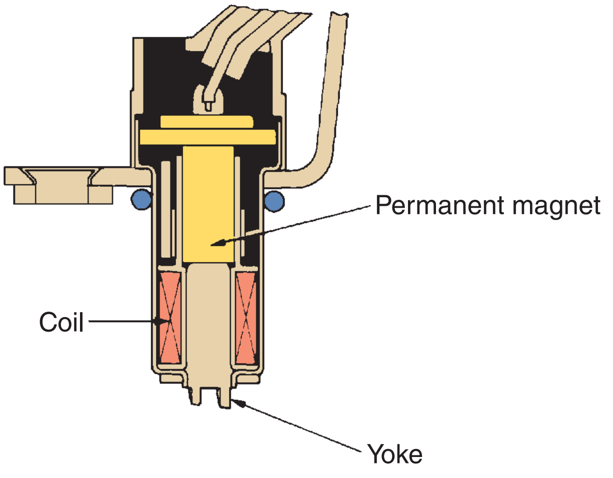


FIGURE 25–53 A vehicle speed sensor (VSS).

When the tooth passes the core, the magnetic field is able to expand **(Figure 25–51)**. This action is repeated every time a tooth passes the core. The moving lines of magnetic force cut across the coil windings and induce a voltage signal.

When a tooth approaches the core, a positive current is produced as the magnetic field begins to concentrate around the coil. When the tooth and core align, there is no more expansion or contraction of the magnetic field and the voltage drops to zero. When the tooth passes the core, the magnetic field expands, and a negative current is produced **(Figure 25–52)**. The resulting pulse signal is sent to the CPU.

Vehicle Speed Sensor (VSS)

The most common **vehicle speed sensor (VSS)** is a magnetic pulse generator (variable reluctance) sensor **(Figure 25–53)**. However, some use a Hall-effect switch. A VSS generates a waveform at a frequency that is proportional to the vehicle's speed. When the vehicle is moving at a low speed, the sensor produces a low-frequency signal. As vehicle speed increases, so does the frequency of the signal. The PCM uses the VSS signal to help control the fuel injection system, ignition system, cruise control, EGR flow, canister purge, transmission shift timing, variable steering, and torque

converter clutch lock-up timing. The signal is also used to initiate diagnostic routines. The VSS is also used on some vehicles to limit the vehicle's speed. When a predetermined speed is reached, the PCM limits fuel delivery.

The VSS is mounted on the transmission or transaxle case in the speedometer cable opening where it can measure the rotational speed of the output shaft. On earlier models, the VSS was connected to the speedometer cable. The rotation of a trigger wheel on the output shaft creates a pulsating voltage in the sensor. The frequency of the voltage increases with an increase in speed.

Troubleshooting a VSS

A defective VSS may cause different problems depending on the control systems. If the PCM does not receive a VSS signal, it will set a DTC; it may also set a code if the signal does not correlate with other inputs. A defective VSS circuit can cause increased fuel consumption, poor idle, improper converter clutch lockup, improper cruise control operation, and inaccurate speedometer operation.

A VSS should be carefully inspected before it is tested. Check the wiring harness and connectors at the sensor and the control modules that rely on the VSS signal. Make sure the connections are tight and not damaged.

The voltage in the VSS circuit should be checked for evidence of an open, short, or high resistance. Most of these measurements can be taken at the PCM connector; refer to the service information to identify the exact measuring points.

The VSS can be tested with a scan tool or lab scope **(Figure 25–54)**; however, make sure to follow the manufacturers' test procedures when doing this. The action of a VSS is best observed while the vehicle is moving. Connect a lab scope, GMM, or scan tool and operate the vehicle at the reference speeds given in the service information. Compare the measurements to specifications. If the measurements meet the specifications, the VSS is working properly and any VSS-related problem is probably caused by the PCM. If the measurements are outside the specifications and the wiring is sound, the sensor is bad.

A VSS can also be checked with the vehicle on a hoist. The vehicle should be positioned so the drive wheels are free to rotate. Backprobe the VSS output wire and connect the voltmeter leads from this wire to ground. Select the 20 volts AC scale on the voltmeter. Then start the engine.

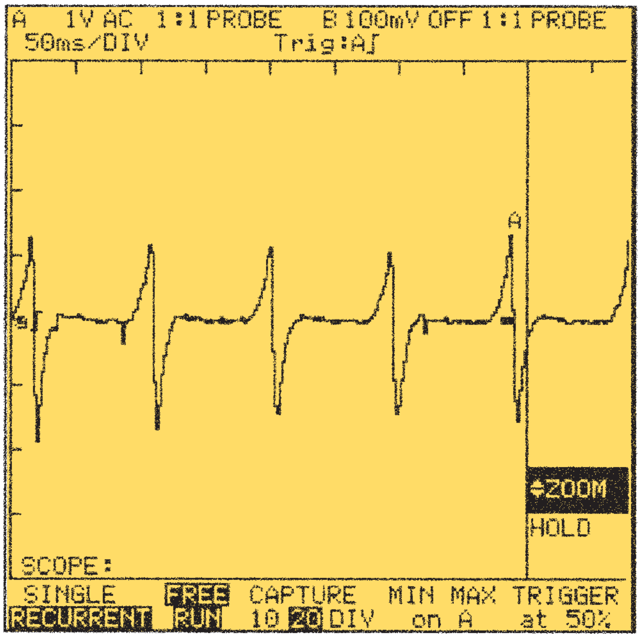


FIGURE 25–54 The waveform for a good VSS (PM generator).

Place the transmission in a forward gear. If the VSS voltage signal is not 0.5 volt or more, replace the sensor. If the VSS signal is correct, backprobe the VSS terminal at the PCM and measure the voltage with the drive wheels rotating. If 0.5 volt is available at this terminal, the trouble may be in the PCM.

When 0.5 volt is not available at this terminal, turn the ignition switch off and disconnect the wire from the VSS to the PCM. Connect the ohmmeter leads across the wire. The meter should read near 0 ohms. Repeat the test with the ohmmeter leads connected to the VSS ground terminal and the PCM ground terminal. This wire should also have near 0 ohms resistance. If the resistance in these wires is more than specified, repair the wires.

Speed sensors can also be checked with an ohmmeter. Most manufacturers list a resistance specification. The resistance of the sensor is measured across the sensor's terminals. The typical range for a good sensor is 800 to 1,400 ohms of resistance.

The **Hall-effect switch** performs the same function as a magnetic pulse generator. It operates on the principle that if a current is allowed to flow through thin conducting material exposed to a magnetic field, another voltage is produced **(Figure 25–55)**.

A Hall-effect switch contains a permanent magnet and a thin semiconductor layer made of gallium arsenate crystal (Hall layer) and a shutter wheel **(Figure 25–56)**. The Hall layer has a negative and a

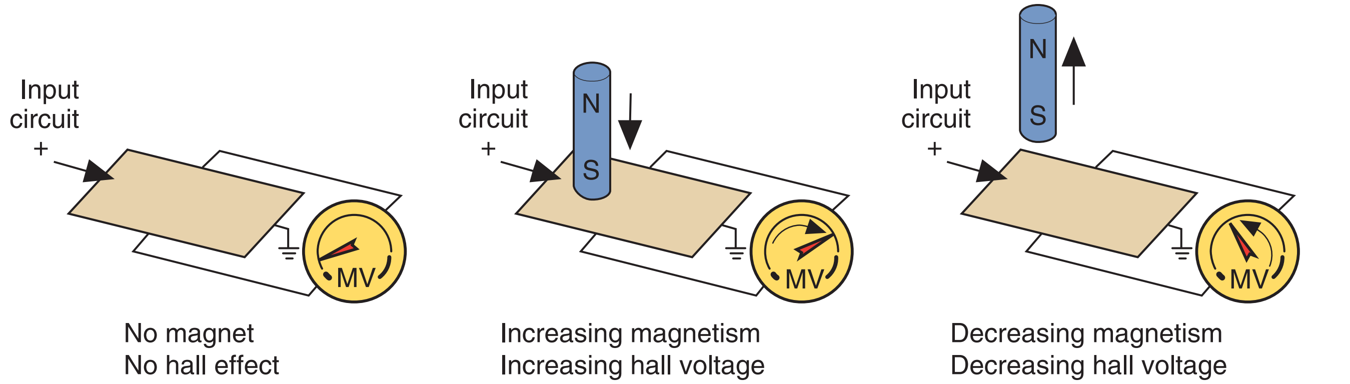


FIGURE 25–55 Hall-effect principles of voltage induction.

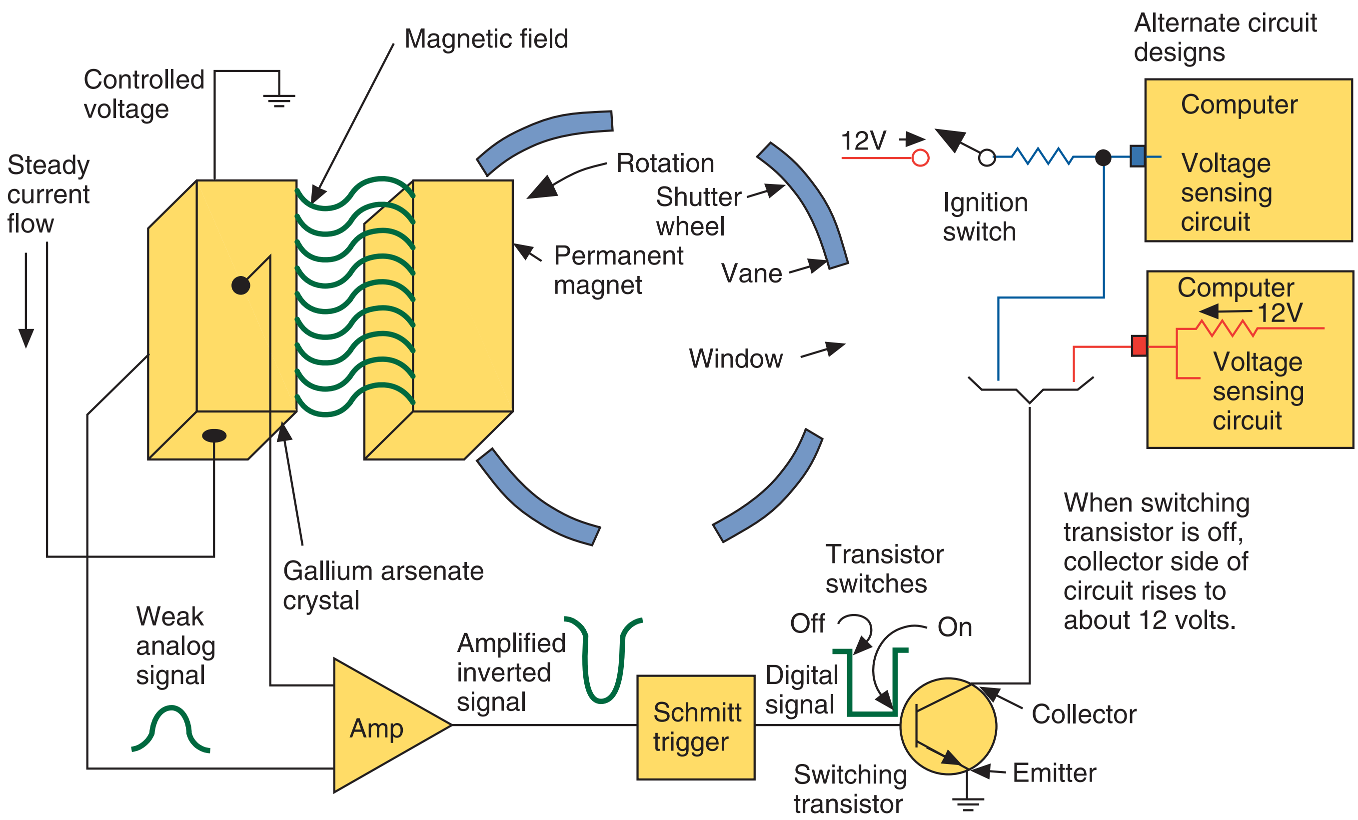


FIGURE 25–56 Typical circuit of a Hall-effect switch.

positive terminal connected to it. Two additional terminals located on either side of the Hall layer are used for the output circuit.

The permanent magnet is located directly across from the Hall layer so its lines of flux bisect the layer at right angles to the current flow. The permanent magnet is stationary, and there is a small air gap between it and the Hall layer.

A steady current is applied to the crystal of the Hall layer. This produces a signal voltage perpendicular to the direction of current flow and magnetic flux. The signal voltage produced is a result of the effect the magnetic field has on the electrons. When the magnetic field bisects the supply current flow, the electrons are deflected toward the Hall layer negative terminal, which results in a weak voltage potential being produced in the Hall switch.

The shutter wheel consists of a series of alternating windows and vanes. It creates a magnetic shunt that changes the strength of the magnetic field from the permanent magnet. The shutter

wheel is attached to a rotating component. As the wheel rotates, the vanes pass through the air gap. When a shutter vane enters the gap, it intercepts the magnetic field and shields the Hall layer from its lines of force. The electrons in the supply current are no longer disrupted and return to a normal state. This results in low-voltage potential in the signal circuit of the Hall switch.

Hall sensors are also used as current sensors. The sensing element is mounted on a magnetic core surrounding a conductor, typically a battery cable. When current flows through the conductor, the magnetic field is amplified by the magnetic core and detected by the Hall sensor. The Hall sensor outputs a voltage based on the strength of the field. The PCM monitors the Hall sensor output to determine generator output or if a component is drawing power from the battery when the car is turned off.

Hall-Effect Sensors To test a Hall-effect switch, disconnect its wiring harness. Connect a voltage source of the correct low-voltage level across the positive and negative terminals of the Hall layer. Then connect a voltmeter across the negative and signal voltage terminals. Insert a metal feeler gauge between the Hall layer and the magnet. Make sure the feeler gauge is touching the Hall element. If the sensor is operating properly, the meter will read close to battery voltage. When the feeler gauge blade is removed, the voltage should decrease. On some units, the voltage will drop to near zero. Check the service information to see what voltage you should observe when inserting and removing the feeler gauge.

When observing a Hall-effect sensor on a lab scope, pay attention to the downward and upward pulses. These should be straight. If they appear at an angle **(Figure 25–57)**, this indicates the transistor is faulty, causing the voltage to rise slowly. The waveform should be a clean and flat square wave. Any change from a normal trace means the sensor should be replaced.

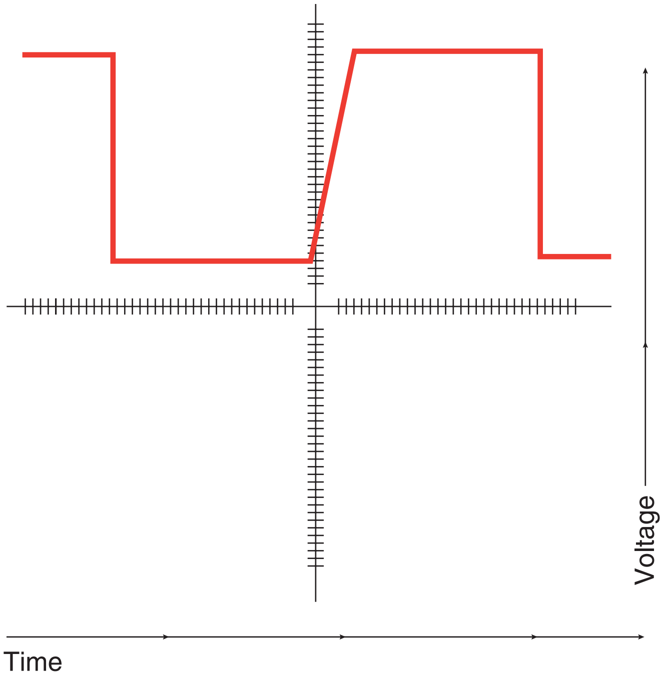


FIGURE 25–57 A Hall-effect switch with a bad transistor.

Other Speed Sensors

Speed sensors are used in several other places. Most commonly they are used to monitor the speed of various shafts within an automatic transmission. They provide the PCM signals that may indicate slipping inside the transmission. Some vehicles also have a speed sensor built into engine's cooling fan clutch.

Position/Speed Sensors

Position/speed sensors tell the PCM the speed, change of speed, and position of a component. The two most commonly used are the camshaft position sensor and crankshaft position sensor. The inputs from these sensors are used to control ignition timing, fuel injection delivery, and variable valve timing. The sensor does this using a Hall-effect switch or magnetic pulse generator; both designs generate a voltage signal.

These sensors are most often magnetic pulse generators. The sensor is mounted close to a pulse wheel or rotor that has notches or teeth. As each tooth moves past the sensor, an AC voltage pulse is induced in the sensor's coil. As the rotor moves faster, more pulses are produced. Speed is calculated by the frequency of the signal, which is the number of pulses in a second. To provide a clean strong signal, the distance between the sensor and the rotor has a specification. If the sensor is too far away from the rotor, the signal will be weak. The ECM determines the speed that the component is revolving based on the number of pulses.

Magnetic pulse generators create an AC voltage signal and their wiring harness is normally a twisted and/or shielded pair of wires.

Crankshaft Position (CKP) Sensor

The rotor for a **crankshaft position (CKP) sensor** has several teeth (the number varies with application) equally spaced around the outside of the rotor. One or more teeth are missing at fixed locations. These missing teeth provide a reference point for the PCM to determine crankshaft position **(Figure 25–58)**. For example, the pulse wheel may have a total of thirty-five teeth spaced 10 degrees apart and an empty space where the thirty-sixth tooth would have been. The thirty-five teeth are used to monitor crankshaft speed; the gap is used to identify which pair of cylinders is approaching TDC. The input from the camshaft position sensor signals is used in order to determine which of these two cylinders is on its firing stroke and which is on the exhaust stroke.

Input from the CKP **(Figure 25–59)** is critical to the operation of the ignition system. This input is also used by the PCM to determine if a misfire has occurred. This is done by looking at the time intervals between the teeth. If a misfire occurs, the transition from one tooth to another will be slower than normal.

Checking a CKP Like all electrical devices, the sensor and its wiring should be checked for corrosion and damage. If the PCM detects abnormal signals it will set a DTC. The CKP is checked during several monitor tests. On engines with both a CKP and camshaft position sensor, the PCM will compare those two inputs and set a code if they do correlate with each other.

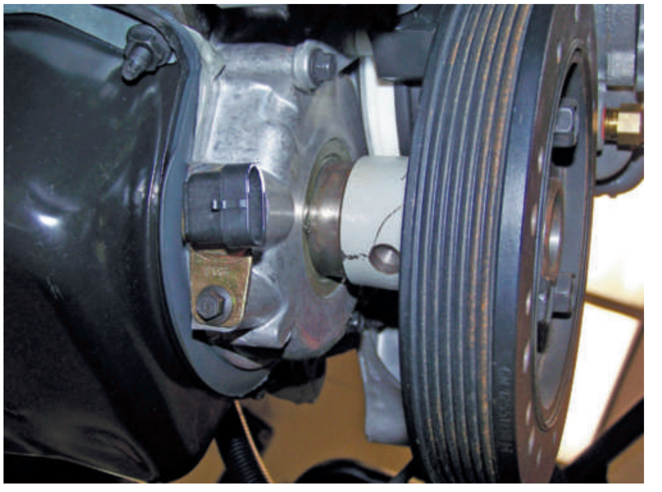


FIGURE 25–59 A crankshaft position (CKP) sensor.

The operation of the sensor can be monitored with a scan tool and lab scope. The waveforms from most CKP sensors will have a number of equally spaced pulses and one double pulse or sync signal, as shown in **Figure 25–60**. The number of evenly spaced pulses equals the number of cylinders that the engine has. A Hall-effect sensor generates a digital signal. Carefully examine the trace. Any glitches indicate a problem with the sensor or sensor circuit.

Replacing a CKP Although the exact procedure for replacing a CKP varies with manufacturer and engine, there are some common steps. The gap between the sensor and the rotor must be set

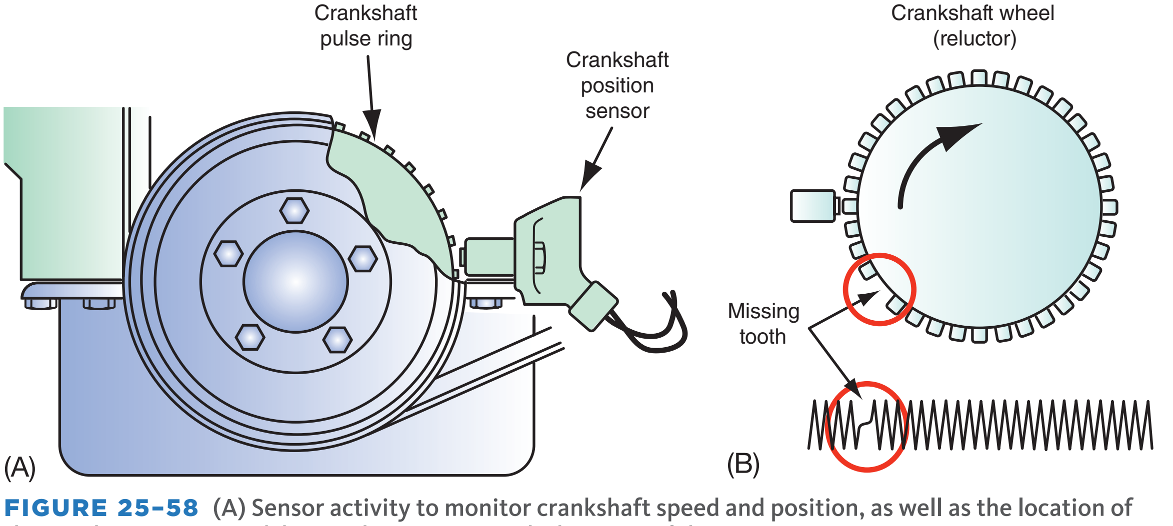


FIGURE 25–58 (A) Sensor activity to monitor crankshaft speed and position, as well as the location of the number one piston. (B) How the missing tooth shows on a labscope.

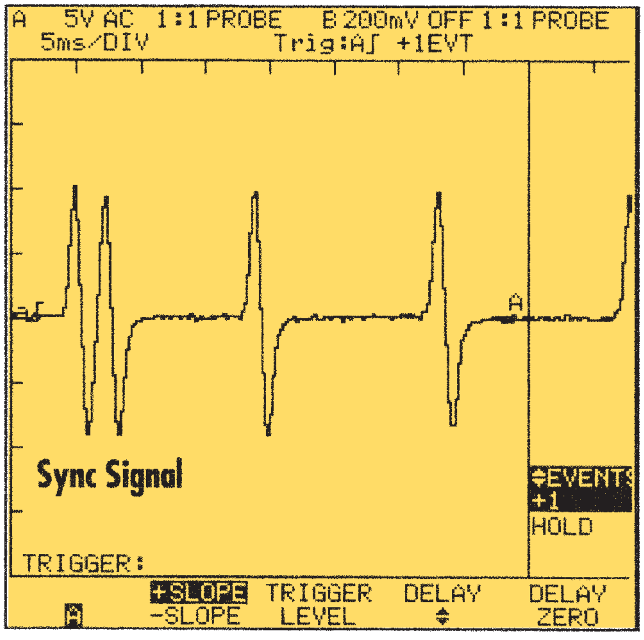


FIGURE 25–60 The trace of a good crankshaft position sensor.

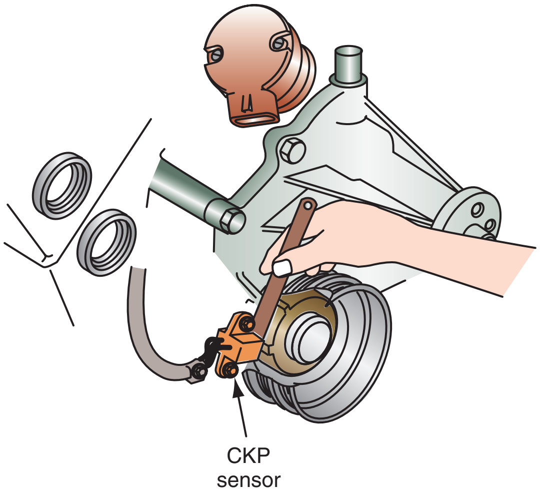


FIGURE 25–61 The gap between the CKP (PIP) sensor and the rotor is critical.

correctly **(Figure 25–61)**. This is done in several ways, depending on application. Often this is done with a special alignment tool or spacer that comes with the replacement sensor. If the sensor has an O-ring, make sure to apply a light coat of oil onto the seal. Failure to do this will prevent the sensor from being fully seated, which will affect its output signals and allow for oil leakage.

Camshaft Position (CMP) Sensor

The camshaft position (CMP) sensor monitors the position of the camshaft **(Figure 25–62)**. The CMP's

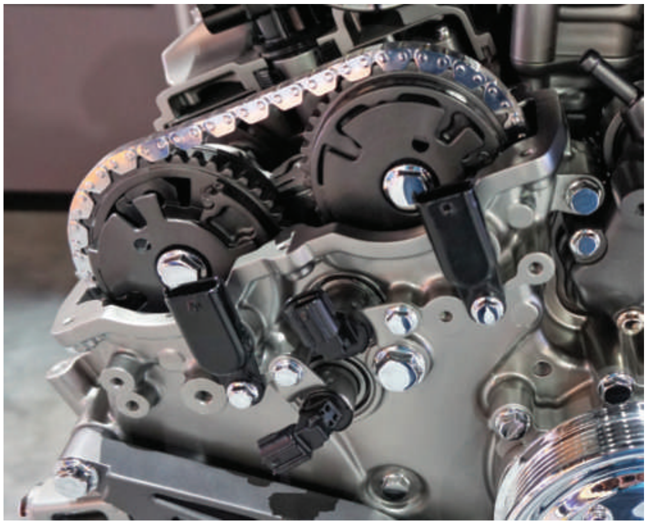


FIGURE 25–62 Camshaft sensors mounted to the ends of the intake and exhaust camshafts.

output is used with the CKP to determine when cylinder number 1 is on its compression stroke. This information is used for control of the fuel injection, direct ignition, and variable valve timing systems. Engines with variable valve timing typically have two CMPs, one for each engine bank. On some engines, a bad CMP will prevent the misfire monitor from completing.

CMP sensors can be magnetic pulse generators or Hall-effect sensors **(Figure 25–63)**. The type of sensor is identified by the number of wires connected to the sensor: A magnetic pulse sensor has two wires and the Hall-effect sensor has three.

CMP Sensor Service Most diagnostic procedures for the CKP apply to the CMP sensor. There are many DTCs related to the CMP. If one of these is set, follow the testing procedures given by the manufacturer. These include a thorough inspection of the sensor and its wiring. When observing a CMP on a lab scope, make sure you know what type the sensor is. Magnetic pulse generators create an analog signal, whereas Hall-effect sensors provide a digital signal. Magnetic pulse generators can also be checked with an ohmmeter **(Figure 25–64)**. The procedures may also include a verification of camshaft timing. Make sure to lubricate the O-ring when installing a new sensor and tighten the retaining bolt to specifications.

GO TO Chapter 11 for the procedure for verifying and adjusting camshaft timing.

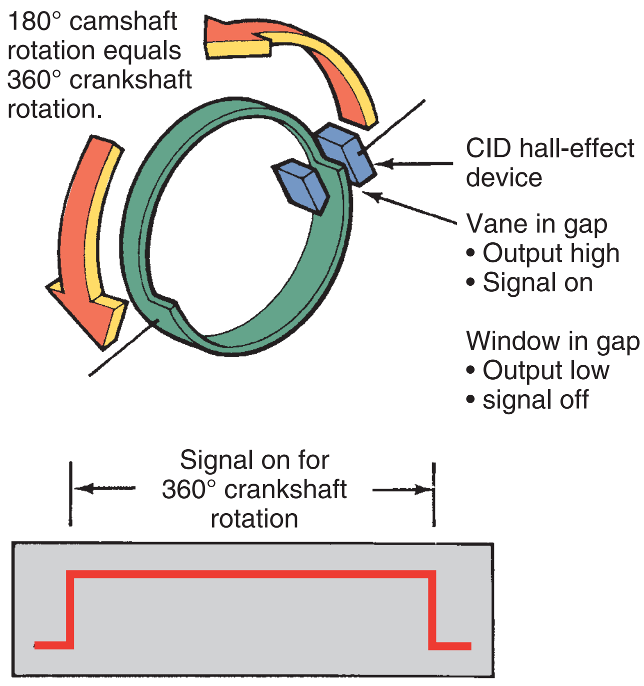


FIGURE 25–63 A Hall-effect camshaft sensor and its resultant signal.

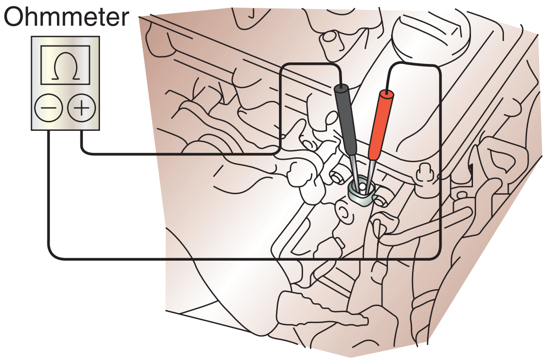


FIGURE 25–64 Checking a camshaft sensor with an ohmmeter.

Magnetoresistive (MR) sensors are similar in appearance to magnetic pulse generators, each having only two wires, but differ in operation. An MR sensor has battery voltage supplied to the sensor and a signal return wire. As a trigger wheel moves past the sensor, it causes a change in the magnetic field within the sensor. This change causes a small current output in the sensor. The current flow results in a change in voltage output. The sensor produces a digital signal that is sent back to the computer on the signal return wire.

An advantage of MR sensors is that they can monitor speed, direction of rotation, and zero speed. MR sensors are also able to operate with a larger air gap between the sensor and the trigger wheel.

Knock Sensor (KS)

The knock sensor (KS) tells the PCM that detonation is occurring in the cylinders. In turn, the computer retards the timing **(Figure 25–65)**. The KS is a piezoelectric device that works like a microphone and converts engine knock vibrations into a voltage signal. Piezoelectric devices generate a voltage when pressure or a vibration is applied to them. Engine knock typically is within a specific frequency range and a KS is set to detect vibrations within that range. The KS is located in the engine block, cylinder head, or intake manifold.

Testing a KS

A defective KS may cause engine detonation or reduced spark advance and fuel economy. When a KS is removed and replaced, the sensor must be tightened to its specified torque. The procedure for checking a KS varies, depending on the vehicle make and year. The KS is checked with several monitors by the PCM. The PCM checks the input from the sensor for abnormal readings that may be caused by an open, short, or high resistance. Always follow the vehicle manufacturer's recommended test procedure and specifications.

A KS can be checked by observing it on a scope while tapping the engine at a point close to the sensor. The waveform should react to the tapping. This test may not work on all KS. The sensor will not respond to the tapping if it is not synchronized to the CKP signal, which is the normal situation on some engines.

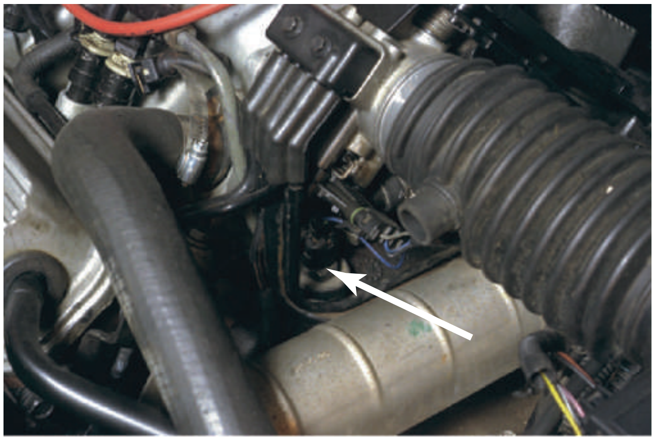


FIGURE 25–65 A knock sensor (KS).

A KS and its circuit can also be checked with a voltmeter. Check the voltage input at the sensor and the power feed from the PCM. If the specified voltage is not available to the sensor, backprobe the KS wire at the PCM and measure the voltage. If the voltage is satisfactory at this terminal, repair the KS wire. If the voltage is not within specifications at the PCM, replace the PCM.

A scan tool can also be used to diagnose a KS. During a road test, open the throttle quickly and observe the scan tool. There should be at least one count when the throttle is opened.

Computer Outputs and Actuators

Once the PCM's programming instructs that a correction or adjustment must be made in the controlled system, an output signal is sent to a control device or actuator. These actuators—solenoids, switches, relays, or motors—physically act or carry out the command sent by the PCM.

Actuators are electromechanical devices that convert an electrical current into mechanical action. This mechanical action can then be used to open and close valves, control vacuum to other components, or open and close switches. When the PCM receives an input signal indicating a change in one or more of the operating conditions, the PCM determines the best strategy for handling the conditions. The PCM then controls a set of actuators to achieve a desired effect or strategy goal. In order for the computer to control an actuator, it must rely on a component called an output driver.

The circuit driver usually applies the ground circuit of the actuator **(Figure 25–66)**. The ground can be applied steadily if the actuator must be activated for a selected amount of time, or the ground can be pulsed to activate the actuator in pulses. Output drivers are transistors or groups of transistors that control the actuators. These drivers operate by the digital commands from the PCM. If an actuator cannot be controlled digitally, the output signal must pass through an A/D converter before flowing to the actuator. The major actuators in a computer-controlled engine include the following components:

- *Air Management Solenoids.* Secondary air by-pass and diverter solenoids control the flow of air from the air pump to either the exhaust manifold (open loop) or the catalytic converter (closed loop).
- *Evaporative Emission (EVAP) Canister Purge Valve.* This valve is controlled by a solenoid. The valve controls when stored fuel vapors in the canister are drawn into the engine and burned. The computer only activates this solenoid valve when the engine is warm and above idle speed.
- *EGR Flow Solenoids.* EGR flow may be controlled by electronically controlled vacuum solenoids.

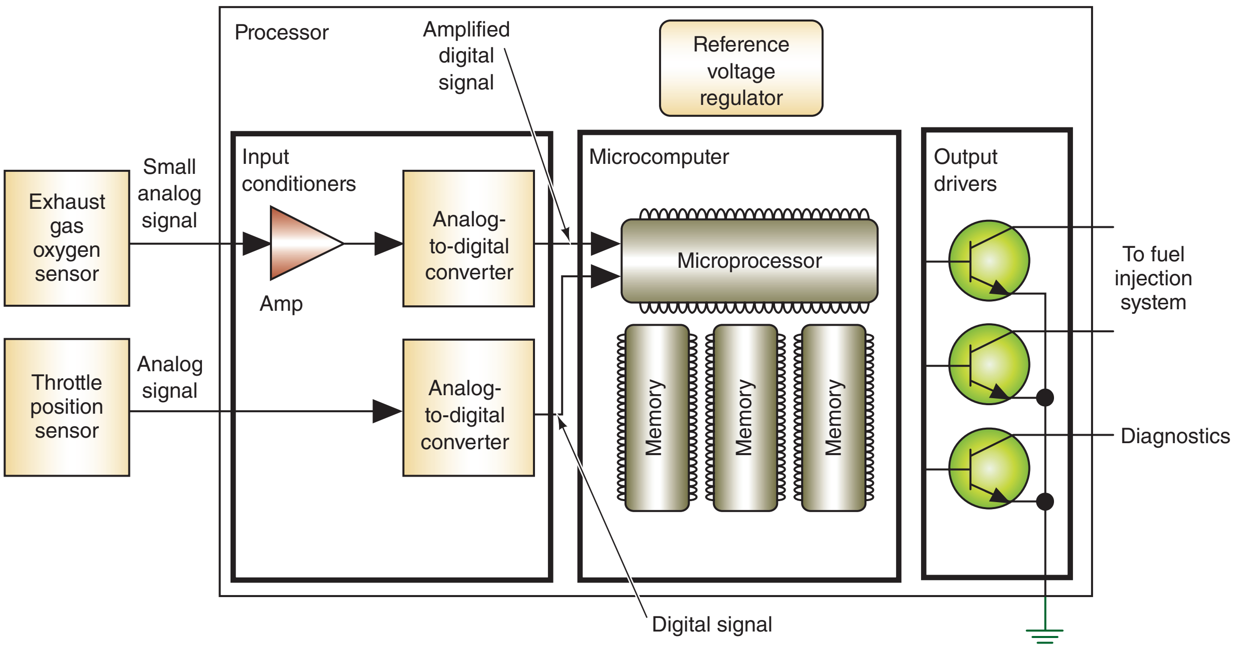


FIGURE 25–66 Output drivers in the computer usually supply a ground for the actuator solenoids and relays.

The solenoid valves supply manifold vacuum to the EGR valve when EGR is required or may vent vacuum when EGR is not required.

- *Fuel Injectors.* These solenoid valves deliver the fuel spray in fuel-injected systems.
- *Idle Speed Controls.* These actuators are small electric motors. On carbureted engines, this idle speed motor is mounted on the throttle linkage. On fuel-injected systems a stepper motor may be used to control the amount of air bypassing the throttle plate.
- *Ignition Module.* This is actually an electronic switching device triggered by a signal from the control computer. The ignition module may be a separate unit or may be part of the PCM.
- *Motors and Lights.* Using electrical relays, the computer is used to trigger the operation of electric motors, such as the fuel pump, or various warning light or display circuits.
- *Other Solenoids.* Computer-controlled solenoids may also be used in the operation of cruise control systems, torque converter lock-up clutches, automatic transmission shift mechanisms, and many other systems where mechanical action is needed.

Electronic Throttle Control

Like modern aircraft, the acceleration on some late-model vehicles works on the "drive-by-wire" principle, which is typically called electronic throttle control (ETC). ETC interprets gas pedal movement by the driver and allows for precise throttle control, which helps to improve fuel economy and performance while reducing emissions.

Instead of a throttle cable and mechanical linkage to the throttle body, the connection is made through wires **(Figure 25–67)**. Although these systems are electronically controlled and operated, some still have a mechanical backup system or resort to partial throttle if something goes wrong with the electronic system.

One or two position sensors are attached to the accelerator pedal assembly, sending position and rate of change information to the PCM. The pedal's sensor sends a varying voltage signal to the PCM, which controls an electric motor connected to the throttle plates. A coiled spring in the pedal assembly gives the gas pedal a normal feel. The position or rate of change in the position of the pedal is merely a request to the PCM for throttle opening. The PCM processes this request along with various other inputs and its programming. It then sends commands to a driver unit that powers the electric motor attached to the throttle. Signals from a TP sensor allow the PCM to track the position of the throttle plate.

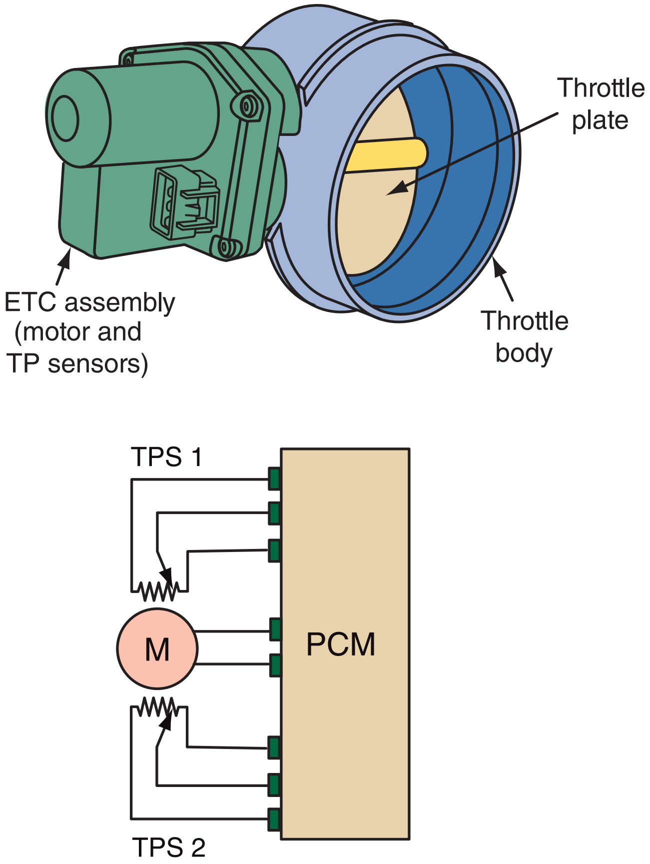


FIGURE 25–67 An electronic throttle control assembly and its basic electrical connections.

Electronic throttles are easily adaptable to support cruise control and traction control systems. In the latter, if the wheels spin, the system can close the throttle until wheel spin is no longer detected. Throttle control is also integrated into automatic shifting. With electronic control, the throttle can be closed slightly to reduce engine output during a shift, providing smoother gear changes.

Testing Actuators

Most systems allow for testing the actuator through a scan tool. Actuators that are duty cycled by the computer are more accurately diagnosed through this method. Prior to diagnosing an actuator, make sure the engine's compression, ignition system, and intake system are in good condition. Serial data can be used to diagnose outputs using a scanner. The displayed data should be compared against specifications to determine the condition of any actuator. Also, when an actuator is suspected to be faulty,

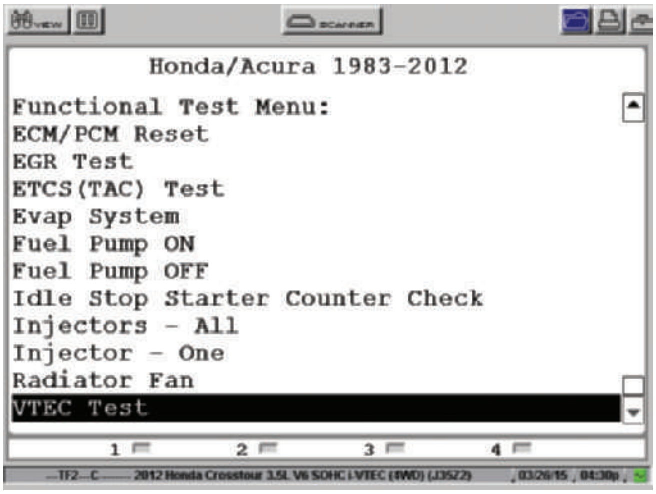


FIGURE 25–68 A screen showing output control tests.

make sure the inputs related to the control of that actuator are within normal range. Faulty inputs will cause an actuator to appear faulty.

Many control systems have operating modes that can be accessed with a scan tool to control the operation of an output. Common names for this mode are the output state control (OSC), output test mode (OTM), actuator test mode and functional test mode **(Figure 25–68)**. In this mode, an actuator can be enabled or disabled; the duty cycle or the movement of the actuator can be increased or decreased. While the actuator is being controlled, related PIDs are observed as an indication of how the system reacted to the changes. The actuators that can be controlled by this mode vary. Common output able to be controlled via the scan tool include: fuel injectors, fuel pump, idle speed or throttle control motors, cooling fans, EGR solenoids and valves, and EVAP solenoids. Always refer to the service information to determine what can be checked and how it should be checked.

Testing with a DMM

If the actuator is tested by other means than a scanner, always follow the manufacturer's recommended procedures. Because many actuators operate with 5 to 7 volts, never connect a jumper wire from a 12-volt source unless directed to do so by the appropriate service procedure. Some actuators are easily tested with a voltmeter by testing for input voltage to the actuator. If there is the correct amount of input voltage, check the condition of the ground. If both of these are good, then the actuator is faulty. If an ohmmeter needs to be used to measure the resistance of an actuator, disconnect it from the circuit first.

When checking anything with an ohmmeter, logic can dictate good and bad readings. If the meter reads infinite, this means there is an open. Based on what you are measuring across, an open could be good or bad. The same is true for very low resistance readings. Across some things, this would indicate a short. For example, you do not want an infinite reading or very low resistance across the windings of a solenoid. You want some resistance, typically between 50 and 120 ohms. However, you want an infinite reading from one winding terminal to the case of the solenoid. If you have low resistance, the winding is shorted to the case.

Testing Actuators with a Lab Scope

Most computer-controlled circuits are ground-controlled circuits. The PCM energizes the actuator by providing the ground. On a scope trace, the on-time pulse is the downward pulse. On positive-feed circuits, where the computer is supplying the voltage to turn a circuit on, the on-time pulse is the upward pulse. One complete cycle is measured from one on-time pulse to the beginning of the next on-time pulse.

Actuators are electromechanical devices, meaning they are electrical devices that cause some mechanical action. When actuators are faulty, it is because they are electrically faulty or mechanically faulty. By observing the action of an actuator on a lab scope, you will be able to watch its electrical activity. Normally if there is a mechanical fault, this will affect its electrical activity as well. Therefore, you get a good sense of the actuator's condition by watching it on a lab scope.

To test an actuator, you need to know what it basically is. Most actuators are solenoids. The computer controls the action of the solenoid by controlling the pulse width of the control signal. You can see the turning on and off of the solenoid **(Figure 25–69)** by watching the control signal. The voltage spikes are caused by the discharge of the coil in the solenoid.

Some actuators are controlled pulse-width modulated signals **(Figure 25–70)**. These signals show a changing pulse width. These devices are controlled by varying the pulse width, signal frequency, and voltage levels.

Both waveforms should be checked for amplitude, time, and shape. You should also observe changes to the pulse width as operating conditions change. A bad waveform will have noise, glitches, or rounded corners. You should be able to see evidence that the actuator immediately turns off and on according to the commands of the computer.

A fuel injector is actually a solenoid. The PCM's signals to an injector vary in frequency and pulse width. Frequency varies with engine speed, and the pulse width varies with fuel control. Increasing an

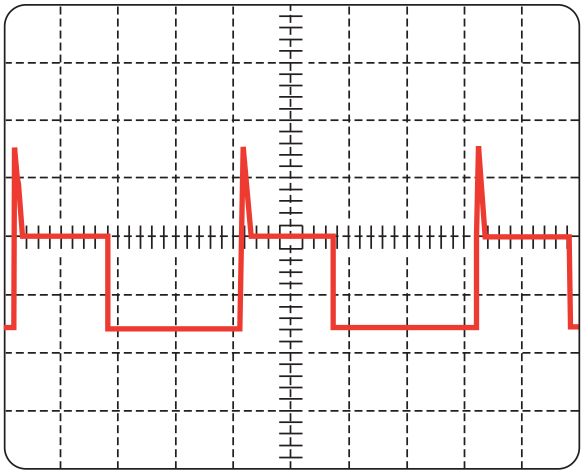


FIGURE 25–69 A typical solenoid control signal.

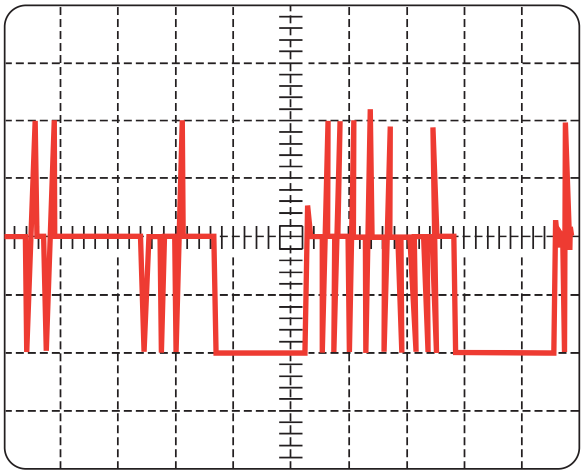


FIGURE 25–70 A typical pulse-width modulated solenoid control signal.

injector's on time increases the amount of fuel delivered to the cylinders. The trace of a normally operating fuel injector is shown in **Figure 25–71**.

Testing with a Current Probe Some actuators, such as fuel injectors and fuel pumps are commonly tested with a current probe or current clamp. Using a scope, testing both voltage and current, allows you to see exactly what is happening in the circuit and in the component being tested. Begin by connecting the scope positive and negative leads to the component's electrical connection. Next, clamp the current probe around either the power or ground wire for the component. You will need to observe the correct polarity of the current probe to the circuit or the pattern on the scope may not be displayed. Set the scope to display one channel for voltage and a second channel for amperage. The voltage, amperage, and time base settings will vary depending on the component being tested. Some scopes have presets for current probes. For scopes without this preset, you will need to select a voltage scale based on the current probe used.

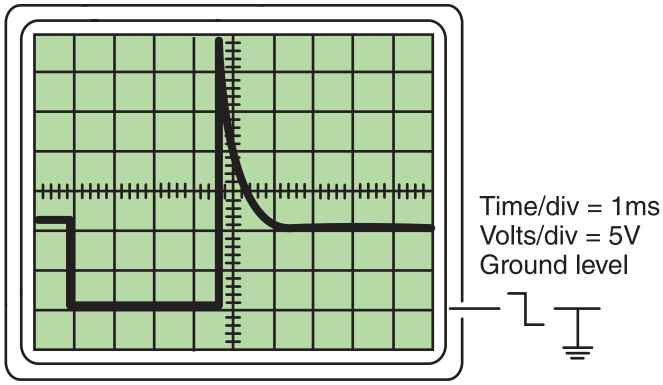


FIGURE 25–71 The trace of a normally operating fuel injector.

Once the scope is configured, operate the circuit and obtain the voltage and amperage waveforms **(Figure 25–72)**. In this case, the fuel injector signal from the PCM is shown with the current draw by the injector in operation. The slight dip in the leading edge of the current waveform shows where the injector pintle opened. Based on the information in the image, you can conclude that the PCM, wiring, and injector are operating correctly. The unknown in this example is how well the fuel sprays from the injector nozzle.

Repairing the System

After isolating the source of the problem, the repairs should be made. The system should then be rechecked to verify that the repair took care of the problem. This may involve road testing the vehicle in order to verify that the complaint has been resolved.

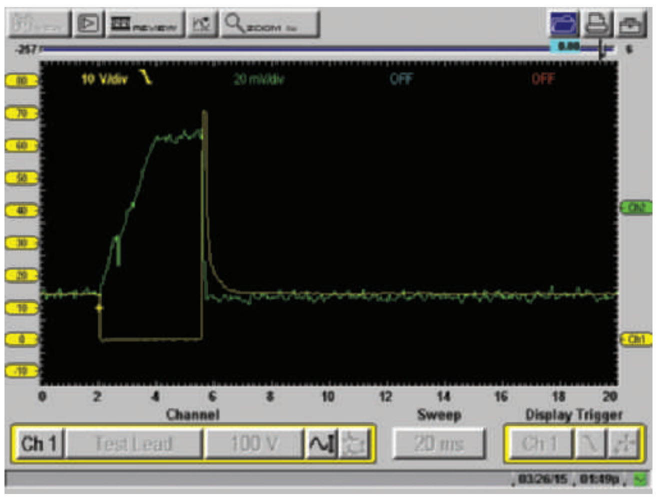


FIGURE 25–72 The voltage and current waveforms for a normally operating fuel injector.

When servicing or repairing OBD II circuits, the following guidelines are important:

- Do not connect aftermarket accessories into an OBD II circuit.
- Do not move or alter grounds from their original locations.
- Always replace a relay in an OBD II circuit with an exact replacement. Damaged relays should be thrown away, not repaired.
- Make sure all connector locks are in good condition and are in place.
- After repairing connectors or connector terminals, make sure the terminals are properly retained and the connector is sealed.
- When installing a fastener for an electrical ground, be sure to tighten it to the specified torque.

Verification of repair is more comprehensive for vehicles with OBD II system diagnostics than earlier vehicles. Following a repair, the technician should perform the following steps:

1. Review the fail records and the freeze frame data for the DTC that was diagnosed. Record the fail records or freeze frame data.
2. Use the scan tool's clear DTCs or clear information functions to erase the DTCs.
3. Operate the vehicle within the conditions noted in the fail records or the freeze frame data.
4. Monitor the status information for the specific DTC until the diagnostic test associated with that DTC runs.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2008	**Make:** Dodge	**Model:** Ram 1500	**Mileage:** 108,540	**RO:** 18510
Concern:	Customer states check engine light is on; engine idles rough sometimes and stalls occasionally.			
The technician took the car for a road test and did not witness any surging. However, back in the shop, the engine idled very poorly. She performed a quick inspection and found a code P0123 was set—TP sensor voltage high. Using a DMM, she found sensor reference voltage was 5 volts. While watching the scan data with the engine running, she wiggled the sensor connector, which caused the TP voltage to jump and the engine to stumble.				
Cause:	Found P0123 stored. TP sensor voltage changes and engine speed changes when TP sensor connector moves. Inspection of harness connector shows no problems. Found internal TP sensor connections intermittently open.			
Correction:	Replaced TP sensor, cleared DTC. Engine operating normally.			

KEY TERMS

Crankshaft position (CKP) sensor
Cross counts
Hall-effect switch
Heated oxygen sensor (HO_2S)
Magnetic pulse generators
Magnetoresistive
Manifold absolute pressure (MAP) sensor
Mass airflow (MAF) sensor
Pickup coil
Piezoresistive
Reference voltage (Vref) sensor
Throttle position (TP) sensor
Vehicle speed sensor (VSS)

SUMMARY

- Troubleshooting electronic engine control systems involves much more than retrieving trouble codes.
- The following can be used to check individual system components: visual checks, ohmmeter checks, voltmeter checks, and lab scope checks.
- Service bulletin information is absolutely essential when diagnosing engine control system problems.
- All PCMs (OBD II and earlier designs) cannot operate properly unless they have good ground connections and the correct voltage at the required terminals.
- A voltage drop test is a quick way of checking the condition of any electrical conductor or terminal connector.

- Poor grounds can also allow EMI or noise to be present on the reference voltage signal. The best way to check for noise is to use a lab scope.
- It is important to understand how a sensor works and what it measures before testing it.
- Sensors measure temperature, chemical characteristics, pressure, speed, position, and sound.
- Most sensors can be checked with a voltmeter, ohmmeter, scan tool, lab scope, and GMM.
- Most computer-controlled actuators are electromechanical devices that convert the output commands from the computer into mechanical action. These actuators are used to open and close switches, control vacuum flow to other components, and operate valves depending on the system's requirements.
- Most systems allow for testing of the actuator through a scan tool.
- When checking anything with an ohmmeter, logic can dictate good and bad readings. If the meter reads infinite, this means there is an open. Based on what you are measuring across, an open could be good or bad. The same is true for very low-resistance readings. Across some things, this would indicate a short.
- Actuators can be accurately tested with a lab scope.

REVIEW QUESTIONS

Short Answer

1. OBD II systems use several modes of operation. List three of them.
2. List the four ways that individual components can be checked. A typical normal oxygen sensor signal will toggle between ___ and ___ volts.
3. Explain how a bad circuit ground can affect a sensor's reference voltage.
4. When an engine is running lean, the voltage signal from the oxygen sensor will be ___ (low or high).
5. List six steps involved in performing a visual inspection.
6. Many control systems have operating modes that can be accessed with a scan tool to control the operation of an output. What are the names of the two most common modes for controlling outputs?

True or False

1. *True or False?* A bad ground can cause an increase in the reference voltage to a sensor.
2. *True or False?* An A/F ratio sensor can be tested in the same way as an oxygen sensor.

Multiple Choice

1. Which of the following statements about zirconium oxygen sensors is *not* true?
   a. The normal operating range for an O_2S is between 0 and 1 volt.
   b. If the sensor's voltage toggles between 0 volts and 500 millivolts, it is operating normally.
   c. The voltage signal from an upstream O_2S should have seven cross counts within 5 seconds with the engine running without a load at 2,500 rpm.
   d. Engine control systems monitor the activity of the O_2S and store a code when the sensor's output is not within the desired range.
2. The catalyst monitor test may fail for all of these reasons, *except* ___.
   a. defective upstream or downstream oxygen sensor circuits
   b. a leaking exhaust
   c. fuel contaminants
   d. ignition system misfire
3. A defective IAT sensor or circuit may cause the following problems, *except* ___.
   a. hard engine starting
   b. rich or lean air-fuel ratio
   c. improper converter clutch lockup
   d. reduced fuel economy
4. Which of the following is the least likely cause of a no-start condition?
   a. Faulty CKP sensor
   b. Faulty KS
   c. Fuel or ignition system faults
   d. Faulty PCM wiring

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that an oxygen sensor can be a voltage-producing sensor. Technician B says that an oxygen sensor is a thermistor sensor. Who is correct?
   a. Technician A
   b. Both A and B
   c. Technician B
   d. Neither A nor B

2. While discussing zirconium O_2S diagnosis: Technician A says that the voltage signal on a satisfactory O_2S should always be cycling between 0.5 volt and 1 volt. Technician B says that a contaminated O_2S may produce a continually high voltage signal. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. While discussing ECT sensor diagnosis: Technician A says that a defective ECT sensor may cause hard cold engine starting. Technician B says that a defective ECT sensor may cause improper operation of emission control devices. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. While discussing Hall-effect vehicle speed sensor tests: Technician A says to use an ohmmeter to test the resistance of the coil. Technician B says that the voltage generated by the sensor can be measured by connecting a voltmeter across the sensor's terminals. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. While discussing TP sensor diagnosis: Technician A says that a four-wire TP sensor contains an idle switch. Technician B says that in some applications, the TP sensor mounting bolts may be loosened and the TP sensor housing rotated to adjust the voltage signal with the throttle in the idle position. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. While diagnosing the cause of a hard starting condition: Technician A checks the ECT sensor. Technician B checks the MAP sensor. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. While discussing testing OBD II system components: Technician A says that a testlight can be used to test O_2S output. Technician B says that a digital voltmeter can be used to test the O_2S. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. When testing a frequency varying MAF: Technician A says that the frequency should increase with an increase in engine speed. Technician B says that when observed on a lab scope, the signal from the sensor should be a square wave. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. Technician A says that a faulty MAF sensor can cause the engine to run lean. Technician B says that a faulty MAP sensor can cause the engine to not start. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While discussing the MIL on OBD II systems: Technician A says that the MIL will flash if the PCM detects a fault in a sensor or circuit. Technician B says that as soon as the PCM has detected a fault, it will turn on the MIL. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER 26

IGNITION SYSTEMS

OBJECTIVES

- Name and describe different types of ignition systems.
- Name the two major electrical circuits used in all ignition systems and their common components.
- Describe the operation of ignition coils, spark plugs, and ignition cables.
- Explain how high voltage is induced in the coil secondary winding.
- Describe spark timing systems, including electronic switching systems and their related engine position sensors.
- Describe the operation of a distributorless ignition system.

The ignition system in today's vehicles is an integral part of the electronic engine control system. The engine control module (ECM), or powertrain control module (PCM), controls all functions of the ignition system and constantly corrects the spark timing. The desired ignition timing is calculated by the PCM according to inputs from a variety of sensors. These inputs allow the PCM to know the current operating conditions. The PCM matches those conditions to its programming and controls ignition timing accordingly. It is important to remember that there has always been a need for engine speed- and load-based timing adjustments. Electronic systems are very efficient at making these adjustments. Many of the inputs used for ignition system control are also used to control other systems, such as fuel injection. These inputs are available on the CAN buses **(Figure 26–1).**

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2008	**Make:** Ford	**Model:** Focus	**Mileage:** 132,148	**RO:** 18604
Concern:	Car towed in, crank no-start. Customer states it died while driving.			
Given this customer concern, use what you learn in this chapter to determine the possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

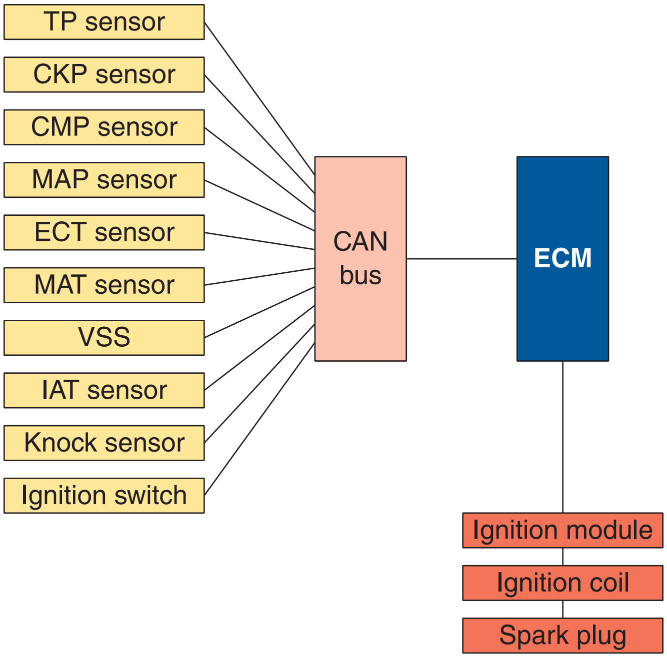


FIGURE 26–1 Many of the inputs used for ignition system control are also used to control other systems and are available on the CAN buses.

There are three basic ignition system designs: distributor-based (DI) systems, distributorless ignition systems, and **direct ignition systems (DIS)**. The latter two designs are designated as electronic ignition (EI) systems by the SAE. DIS is the commonly used design on today's engines. Regardless of the type, all modern ignition systems are designed to perform the same functions: to generate sufficient voltage to force a spark across the spark plug gap, to time the arrival of the spark to coincide with the movement of the engine's pistons, and to vary the spark arrival time based on varying operating conditions.

Basic Circuitry

All ignition systems consist of two interconnected electrical circuits: a **primary** (low-voltage) **circuit** and a **secondary** (high-voltage) **circuit (Figure 26–2)**.

Depending on the exact type of ignition system, components in the primary circuit include the following:

- Battery
- Ignition switch
- Ignition coil primary winding
- Triggering device
- Switching device or control module (igniter)

The secondary circuit includes these components:

- Ignition coil secondary winding
- Distributor cap and rotor (some systems)
- High-voltage cables (some systems)
- Spark plugs

Primary Circuit Operation

When the ignition switch is on, voltage from the battery is supplied to the positive connection of the primary winding of the ignition coil. This path to the coil may be through the ignition switch, ignition control module, or PCM depending on the system. The negative connection of the primary winding is connected to a switching device. This can be an ignition control module or the PCM. When the switch is closed, current flows through the circuit. The current flow through the ignition coil's primary winding creates a magnetic field. As the current continues to flow, the magnetic field gets stronger. When the triggering device signals to the switching unit that the piston is approaching TDC on the compression stroke, the circuit opens and current flow is stopped. This causes the magnetic field around the primary winding to collapse across the secondary winding. The movement of the magnetic field across the winding induces a high voltage in the secondary winding. The action of the secondary circuit begins at this point.

Secondary Circuit Operation

The secondary circuit carries high voltage to the spark plugs. The exact manner in which the secondary circuit delivers these high-voltage surges depends on the system. Until 1984 all ignition systems used some type of distributor to accomplish this job. However, in an effort to reduce emissions, improve fuel economy, and boost component reliability, auto manufacturers are now using distributorless or electronic ignition (EI) systems.

DI Systems In a distributor ignition system, the high voltage from the secondary winding is delivered to the distributor by an ignition cable or through an internal connection in the distributor cap. The distributor then distributes the high voltage to the individual spark plugs through a set of ignition cables **(Figure 26–3)**. The cables are arranged in the distributor cap according to the firing order of the engine.

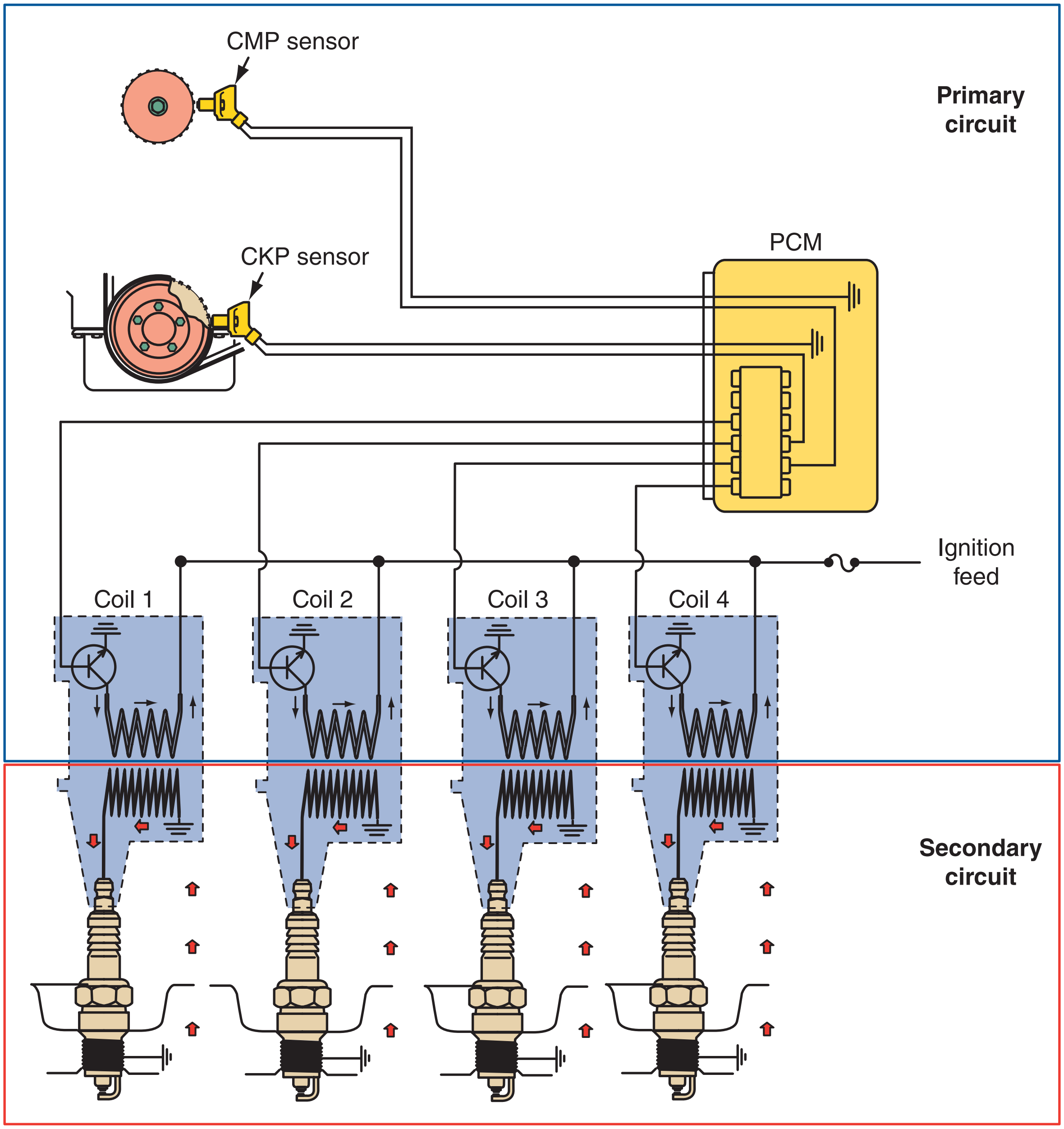


FIGURE 26–2 Ignition systems have a primary (low voltage) and a secondary (high voltage) circuit.

FIGURE 26–3 A typical distributor ignition engine.

A rotor driven by the distributor shaft rotates and completes the electrical path from the secondary winding of the coil to the individual spark plugs. The distributor delivers the spark to match the compression stroke of the piston. The distributor assembly may also have the capability of advancing or retarding ignition timing.

The distributor cap is mounted on top of the distributor assembly and an alignment notch in the cap fits over a matching lug on the housing. Therefore, the cap can only be installed in one position, which ensures the correct firing sequence.

The rotor is positioned on top of the distributor shaft, and a projection inside the rotor fits into a slot

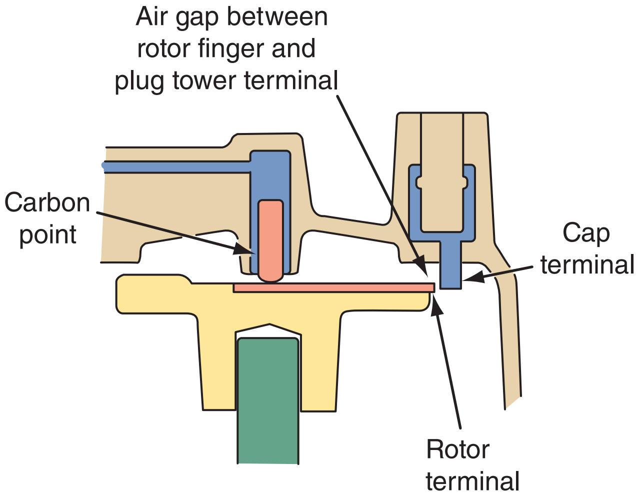


FIGURE 26–4 The relationship of a rotor and distributor cap.

in the shaft. This allows the rotor to be installed in only one position. A metal strip on the top of the rotor makes contact with the center distributor cap terminal, and the outer end of the strip rotates past the cap terminals **(Figure 26–4)**. This action completes the circuit between the ignition coil and the individual spark plugs according to the firing order.

EI Systems EI systems have no distributor; spark distribution is controlled by an electronic control unit and/or the vehicle's computer **(Figure 26–5)**. Instead of a single ignition coil for all cylinders, each cylinder may have its own ignition coil, or two cylinders may share one coil. The coils are wired directly to the spark plug they control. An ignition control module, tied into the vehicle's computer control system, controls the firing order and the spark timing and advance.

The energy produced by the secondary winding is voltage. This voltage is used to establish a complete circuit so current can flow. The excess energy is used to maintain the current flow across the spark plug's gap. Distributorless ignition systems are capable of producing much higher energy than conventional ignition systems. This is because having multiple coils allows for increased current flow and coil charge time.

Since DI and EI systems are firing spark plugs with approximately the same air gap across the electrodes, the voltage required to start firing the spark plugs in both systems is similar. If the additional energy in the EI systems is not released in the form of voltage, it will be released in the form of current flow. This results in higher firing current and longer spark plug firing times. The average firing time across the spark plug electrodes in an EI system is 1.5 milliseconds compared to approximately 1 millisecond in a DI system. This extra time may seem insignificant, but it is very important. Current emission standards demand leaner air-fuel ratios, and this additional spark duration on EI systems helps to prevent cylinder misfiring with leaner air-fuel ratios. For this reason, car manufacturers have equipped their engines with EI systems.

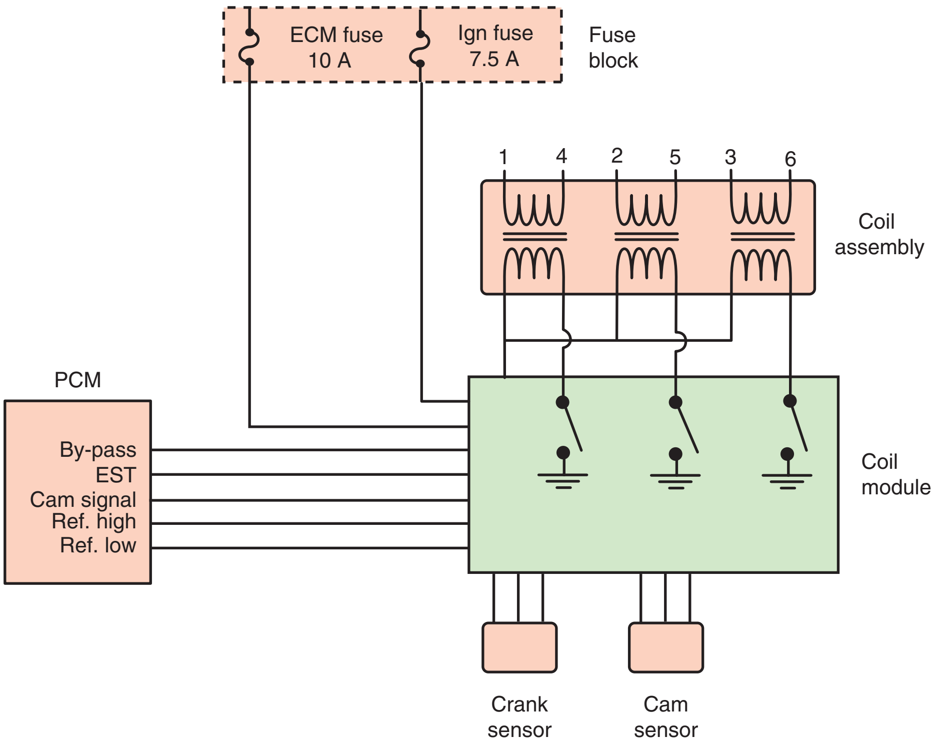


FIGURE 26–5 An electronic ignition system for a six-cylinder engine.

Ignition Components

All ignition systems share a number of common components. Some, such as the battery and ignition switch, perform simple functions. The battery supplies low-voltage current to the ignition primary circuit. The current flows when the ignition switch is in the start or run position. Full-battery voltage is always present at the ignition switch, as if it were directly connected to the battery.

Ignition Coils

To generate a spark to begin combustion, the ignition system must deliver high voltage to the spark plugs. Because the amount of voltage required to bridge the gap of the spark plug varies with the operating conditions, most late-model vehicles can easily supply 30,000 to 60,000 volts or more to force a spark across the air gap. Since the battery delivers 12 volts, a method of stepping up the voltage must be used. Multiplying battery voltage is the job of a coil.

The ignition coil is a pulse transformer that transforms battery voltage into short bursts of high voltage. The trade-off is that the large amount of current flow in the primary circuit is proportionally decreased in the secondary. The result is the low voltage high current of the primary is changed into a high voltage, low amperage spark from the secondary.

As explained previously, when a magnetic field moves across a wire, voltage is induced in the wire. If a wire is bent into loops forming a coil and a magnetic field is passed through the coil, an equal amount of voltage is generated in each loop of wire. The more loops of wire in the coil, the greater the total voltage induced. If the speed of the magnetic field is doubled, the voltage output doubles.

An ignition coil uses these principles and has two coils of wire wrapped around an iron or steel core **(Figure 26–6)**. An iron or steel core is used because it has low **inductive reluctance**. In other words, iron freely expands or strengthens the magnetic field around the windings. The first, or primary, coil is normally composed of 100 to 200 turns of 20-gauge wire. This coil of wire conducts battery voltage and current. When a current is passing through the primary coil, it magnetizes the iron core. The strength of the magnet depends directly on the number of wire loops and the amount of current flowing through those loops. The secondary coil of wires may consist of 15,000 to 25,000, or more, turns of very fine copper wire.

Because of the effects of counter EMF on the current flowing through the primary winding, it takes some time for the coil to become fully magnetized or saturated. Therefore, current flows in the primary winding for some time between firings of the spark plugs. The period of time during which there is primary current flow is often called **dwell**. The length of the dwell period is important.

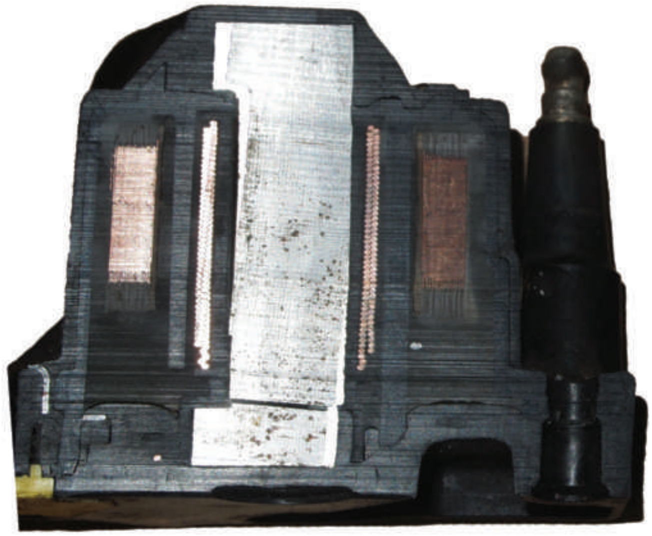


FIGURE 26–6 An inside look at an ignition coil.

When current flows through a conductor, it will immediately reach its maximum value as allowed by the resistance in the circuit. If a conductor is wound into a coil, maximum current will not be immediately achieved. As the magnetic field begins to form as the current begins to flow, the magnetic lines of force of one part of the winding pass over another part of the winding **(Figure 26–7)**. This tends to cause an opposition to current flow. This occurrence is called **reactance**. Reactance causes a temporary resistance to current flow and delays the flow of current from reaching its maximum value. When maximum current flow is present in a winding, the winding is said to be saturated and the strength of its magnetic field will also be at a maximum.

Saturation can only occur if the dwell period is long enough to allow for maximum current flow through the primary windings. A less-than-saturated coil will not be able to produce the voltage it was designed to produce. If the energy from the coil is too low, the spark plugs may not fire long enough or may not fire at all. If the current is applied longer than needed to fully saturate the winding, the coil will overheat.

A typical coil requires 2 to 6 milliseconds to become saturated. The actual required time depends on the resistance of the coil's primary winding and the voltage applied to it. Some systems electronically limit the primary current flow at low speeds to prevent the coil from overheating. When the engine reaches higher speeds, the current limitation feature is disabled. An example of a waveform representing

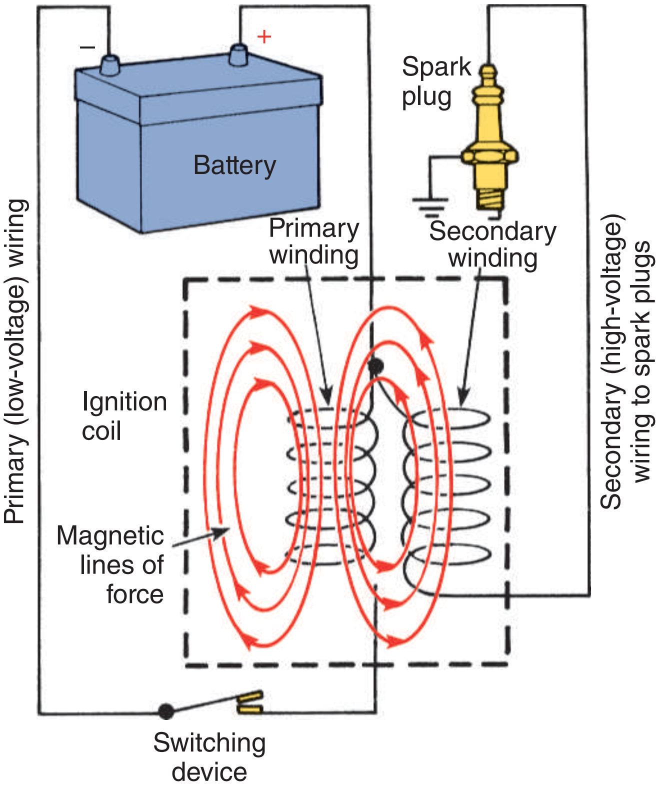


FIGURE 26–7 Current passing through the coil's primary winding creates magnetic lines of force that cut across and induce voltage in the secondary windings.

current flow through the coil primary is shown in **Figure 26–8**. When the primary coil circuit is suddenly opened, the magnetic field instantly collapses. The sudden collapsing of the magnetic field produces a very high voltage in the secondary windings. This high voltage is used to push current across the gap of the spark plug.

Ignition Coil Construction Older engines were equipped with ignition coils that were contained in a metal housing filled with oil to help cool the windings. Today's coils are air cooled. This is now possible because an individual coil is not responsible for providing the firing voltage for all spark plugs. Today's coils fire just one plug. Many different coil designs are found on today's vehicles **(Figure 26–9)**. The actual design depends on the ignition system and the application.

A laminated soft iron core is positioned in the center of each coil. The secondary winding is wound around the core and the primary winding is wound around the secondary winding. The two ends of the primary winding are on the outside of the coil housing and are labeled as positive and negative. One end of the secondary winding is internally connected to the positive terminal of the primary winding; the other

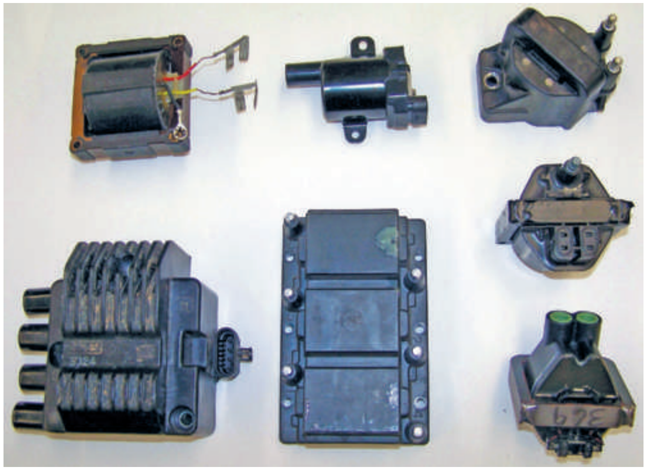


FIGURE 26–9 Many different ignition coil designs can be found on today's vehicles.

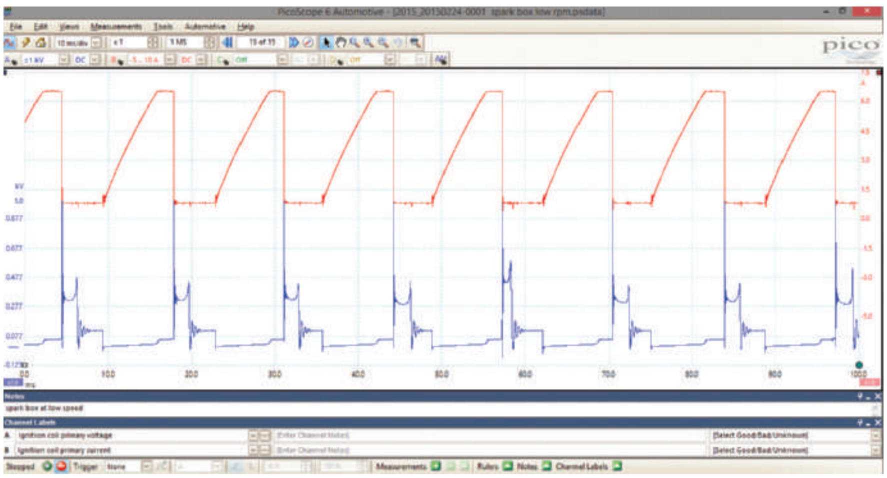


FIGURE 26–8 Waveforms showing the increasing (ramping up) amount of current in an ignition coil's primary winding before the field collapses and causes a sudden decrease in current.

end is connected to the spark plug circuit. The wires used to make up the windings are covered with insulation to prevent the wires from shorting to each other.

Secondary Voltage The typical amount of secondary coil voltage required to jump the spark plug gap is 10,000 volts. Most coils have at least 25,000 volts available from the secondary. The difference between the required voltage and the maximum available voltage is referred to as secondary reserve voltage. This reserve voltage is necessary to compensate for higher voltages that occur due to high cylinder pressures during heavy load situations, like wide open throttle acceleration, and increased secondary resistances as the spark plug gap increases through use. The maximum available voltage must always exceed the required firing voltage or ignition misfire will occur. If there is an insufficient amount of voltage available to push current across the gap, the spark plug will not fire.

In most ignition systems with a distributor, only one ignition coil is used. The high voltage of the secondary winding is directed, by the distributor, to the various spark plugs in the system. Therefore, there is one secondary circuit with a continually changing path.

While distributor systems have a single secondary circuit with a continually changing path, distributorless systems have several secondary circuits, each with an unchanging path.

Spark Plugs

Spark plugs provide the crucial **air gap** across which the high voltage from the coil causes an arc or spark. The main parts of a spark plug are a steel shell; a ceramic core or insulator, which acts as a heat conductor; and a pair of electrodes, one insulated in the core and the other grounded on the shell. The shell holds the ceramic core and electrodes in a gas-tight assembly and has threads for plug installation in the engine **(Figure 26–10)**. The insulator material may be alumina silicate or a black-glazed, zirconia-enhanced ceramic insulator to provide for increased durability and strength. The shell may be coated with corrosion resistance material and/or materials that prevent the threads from seizing to the cylinder head.

A terminal post on top of the center electrode is the connecting point for the spark plug cable. Current flows through the center of the plug, through a resistor and arcs from the tip of the center electrode to the ground electrode. The center electrode is surrounded by the ceramic insulator and is sealed to the insulator with copper and glass seals. These seals prevent combustion gases from leaking out of the

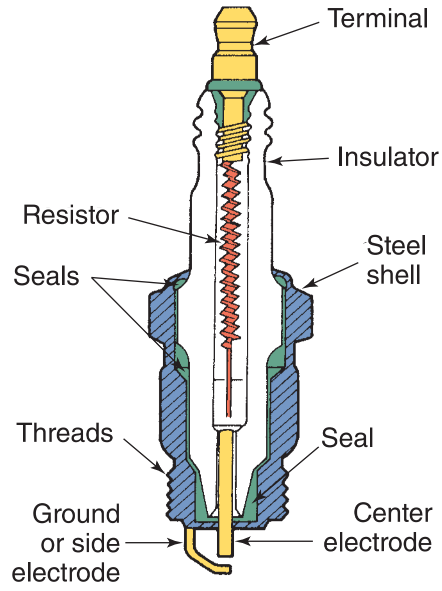


FIGURE 26–10 Components of a typical spark plug.

cylinder. Ribs on the insulator increase the distance between the terminal and the shell to help prevent electric arcing on the outside of the insulator. The steel spark plug shell is crimped over the insulation, and a ground electrode, on the lower end of the shell, is positioned directly below the center electrode. There is an air gap between these two electrodes.

Spark plugs come in many different sizes and designs to accommodate different engines.

Size Automotive spark plugs are available with a thread diameter of 12 mm, 14 mm, 16 mm, and 18 mm. The 18-mm spark plugs are mostly found on older engines and have a tapered seat that seals, when tightened properly, into a tapered seat in the cylinder head. The 12-mm, 14-mm, and 16-mm plugs can have a tapered seat or a flat seat that relies on a thin steel gasket to seal in its bore in the cylinder head. All spark plugs have a hex-shaped outer shell that accommodates a socket wrench for installation and removal. A 12-mm plug has a $^{5}/_{8}$- or $^{11}/_{16}$-inch (16 or 18 mm) hex, a 14-mm plug with a tapered seat has a $^{5}/_{8}$-inch (16 mm) hex, and 14-mm gasketted, and 18-mm plugs have a $^{13}/_{16}$-inch (20.6 mm) hex on the shell. The 16-mm plugs, used on certain Ford V8 engines, may have a $^{9}/_{16}$-inch or $^{5}/_{8}$-inch hex on the shell. A tapered plug should never be used in an engine designed to use a gasketted plug, or vice versa **(Figure 26–11)**.

Reach One important design characteristic of spark plugs is the **reach (Figure 26–12)**. This refers to the length of the shell from the contact surface at the

FIGURE 26–11 The two different spark plug seats.

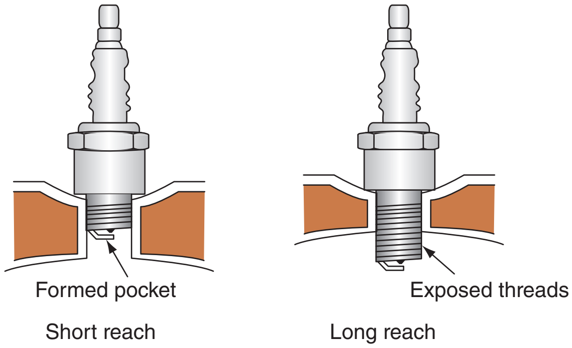


FIGURE 26–12 Spark plug reach: long versus short.

seat to the bottom of the shell, including both threaded and non-threaded sections. Reach is crucial because the plug's air gap must be properly placed in the combustion chamber to produce the correct amount of heat. When a plug's reach is too short, its electrodes are in a pocket and the arc is not able to adequately ignite the mixture. If the reach is too long, the exposed plug threads can get so hot they will ignite the air-fuel mixture at the wrong time and cause preignition. *Preignition* is a term used to describe abnormal combustion, which is caused by something other than the heat of the spark.

Heat Range When the engine is running, most of the plug's heat is concentrated on the center electrode. Heat is quickly dissipated from the ground electrode because it is attached to the shell, which is threaded into the cylinder head. Coolant circulating in the head absorbs the heat and moves it through the cooling system. The heat path for the center electrode is through the insulator into the shell and then to the cylinder head. The **heat range** of a spark plug is determined by the length of the insulator before it contacts the shell. In a cold-range spark

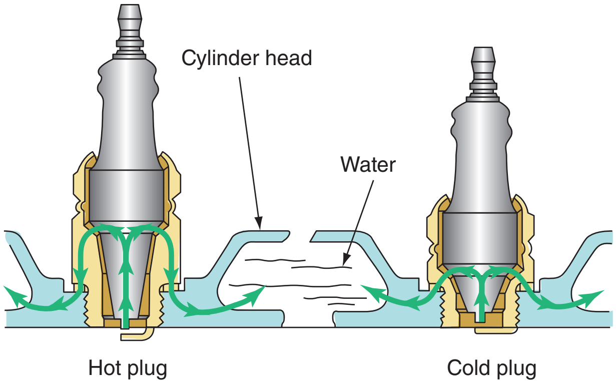


FIGURE 26–13 Spark plug heat range: hot versus cold.

plug, there is a short distance for the heat to travel up the insulator to the shell. The short heat path means the electrode and insulator will maintain little heat between firings **(Figure 26–13)**.

In a hot spark plug, the heat travels farther up the insulator before it reaches the shell. This provides a longer heat path and the plug retains more heat. A spark plug needs to retain enough heat to clean itself between firings, but not so much that it damages itself or causes preignition of the air-fuel mixture in the cylinder.

The heat range is indicated by a code within the plug number imprinted on the side of the spark plug, usually on the porcelain insulator.

Resistor Plugs Most automotive spark plugs have a resistor (normally about 5 kiloohms) between the top terminal and the center electrode. The resistance increases firing voltage. Some spark plugs use a semiconductor material to provide for this resistance. The resistor also reduces RFI, which can interfere with, or damage, radios, computers, and other electronic accessories, such as GPS systems. If an engine was originally equipped with resistor plugs, resistor plugs should be installed when the originals are replaced.

Warning! Using a non-resistor plug on some engines may cause erratic idle, high-speed misfire, engine run-on, power loss, and abnormal combustion.

Spark Plug Gaps The correct spark plug air gap is essential for achieving optimum engine performance and long plug life. A gap that is too wide requires higher voltage to jump the gap. If the required voltage is greater than what is available, the result is **misfiring.** Misfiring results from the inability of the

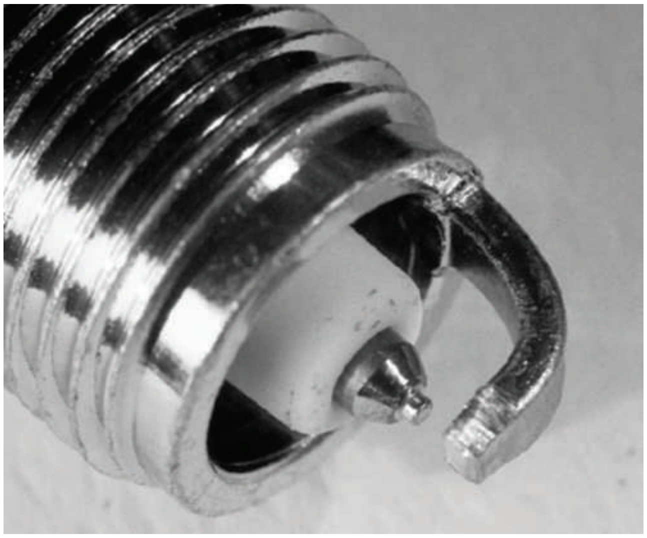
ignition to jump the gap or maintain the spark. A gap that is too narrow requires lower voltages and can lead to rough idle and prematurely burned electrodes, due to higher current flow.

Electrodes The materials used in the construction of a spark plug's electrodes determine the longevity, power, and efficiency of the plug. The construction and shape of the tips of the electrodes are also important.

The electrodes of a standard spark plug are made with copper and some use a copper-nickel alloy. Copper is a good electrical conductor and offers some resistance to corrosion. Copper melts at 1,981 °F (1,083 °C) so it is more than suitable for use in an internal combustion engine.

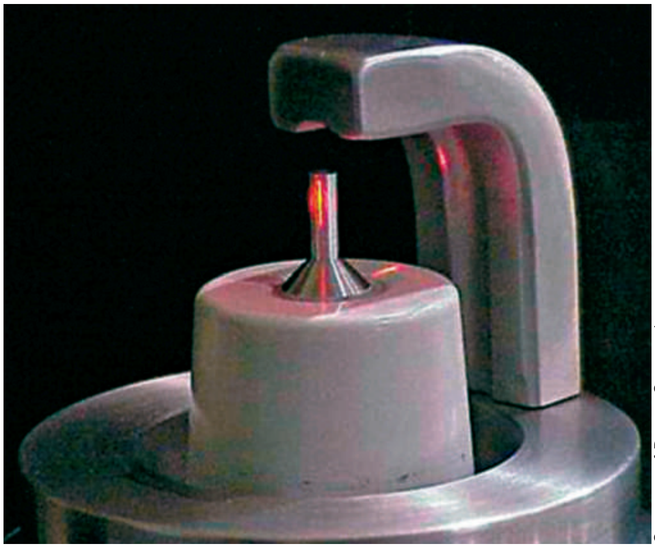
Platinum electrodes are used to extend the life of a plug **(Figure 26–14)**. Platinum melts at 3,200 °F (1,760 °C) and is highly resistant to corrosion. Although platinum is an extremely durable material, it is an expensive precious metal; therefore, platinum spark plugs cost more than copper plugs. Also, platinum is not as good a conductor as copper. Spark plugs are available with only the center electrode made of platinum (called single-platinum) and with the center and ground electrodes made of platinum (called double-platinum). Some platinum plugs have a very small center electrode combined with a sharp pointed ground electrode designed for better performance.

Until recently, platinum was considered the best material to use for electrodes because of its durability. However, iridium is six times harder, eight times stronger, and has a melting point 1,200 °F higher than platinum. Iridium is a precious, silver-white metal and one of the densest materials found on earth.



Courtesy of Bob Freudenberger.

FIGURE 26–14 A platinum-tipped spark plug.



Courtesy of Denso Corporation.

FIGURE 26–15 This spark plug has a small diameter iridium center electrode and a grooved ground electrode.

A few spark plugs use an iridium alloy as the primary metal complimented by rhodium to increase oxidation wear resistance. This iridium alloy is so durable that it allows for an extremely small center electrode. A typical copper/nickel plug has a 2.5 mm diameter center electrode and a platinum plug has a 1.1 mm diameter. An iridium plug can have a diameter as small as 0.4 mm **(Figure 26–15)**, which means the firing voltage requirements are decreased. Iridium is also used as an alloying material for platinum.

Another rare and hard material used to make electrodes is yttrium. Yttrium has a silvery-metallic luster and has a melting point of 2,773 °F (1,523 °C). Yttrium is fairly stable in air but oxidizes readily when heated. (Moon rocks contain yttrium.) Yttrium produces a highly adhesive oxide layer that makes the spark plug very durable and reliable, thereby extending its service life.

Electrode Designs Spark plugs are available with many different shapes and numbers of electrodes. When trying to ascertain the advantages of each design, remember the spark is caused by electrons moving across an air gap. The electrons will always jump in the direction of the least electrical resistance. Therefore, if there are four ground electrodes to choose from, the electrons will jump to the closest. Also, keep in mind that the contents and pressure of the air in the air gap influences the resistance of the air gap. Again, the electrons will jump across the path of least resistance. Therefore, spark plugs with four ground electrodes do not typically supply a spark to all four electrodes **(Figure 26–16)**.

The shape of the ground electrode may also be altered. A flat, conventional electrode tends to crush

FIGURE 26–16 A spark plug with four ground electrodes.

the spark, and the overall volume of the flame front is smaller. A tapered ground electrode increases flame front expansion and reduces the heat lost to the electrode.

Some ground electrodes have a U-groove machined into the side that faces the center electrode. The U-groove allows the flame front to fill the gap formed by the U. This ball of fire develops a larger and hotter flame front, leading to a more complete combustion.

One brand of spark plug has a V-shaped ground electrode. This style of electrode does not block the flame front and allows it to travel upward through the V notch into the combustion chamber. These spark plugs may be equipped with three separate points of platinum, one at each end of the V and the other at the center electrode.

There are also different center electrode designs. These variations are based on the diameter and shape of the electrode. A small diameter center electrode requires less firing voltage and tends to have a longer service life. Some center electrodes are tapered.

Some center electrodes have a V groove machined in them to force the spark to the outer edge of the ground electrode, placing it closer to the air-fuel mixture. This allows for quicker ignition of the air-fuel mixture. V-grooved center electrodes also require lower firing voltages.

On some spark plugs, the center electrode does not extend from the insulator and the spark is generated across the end of the plug. With this design, the ground electrode does not block the flame front. This arrangement is called a surface gap and is intended to prevent carbon fouling, timing drift, and misfiring.

Ignition Cables

Spark plug cables, or ignition cables, make up the secondary wiring. These cables carry the high voltage from the distributor or the multiple coils to the spark plugs. The cables are not solid wire; instead they contain carbon fiber cores that act as resistors in the secondary circuit **(Figure 26–17)**. They cut down on radio and television interference, increase

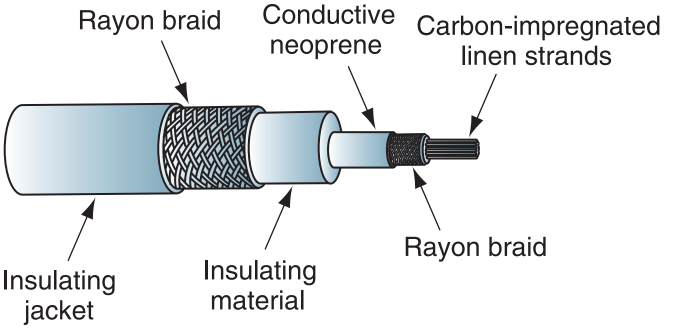


FIGURE 26–17 Spark plug cable construction.

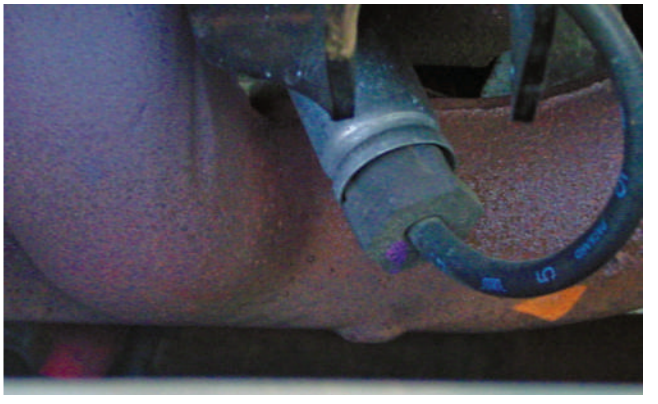


FIGURE 26–18 Spark plug boot heat shield.

firing voltages, and reduce spark plug wear by decreasing current. Insulated boots on the ends of the cables strengthen the connections as well as prevent dust and water infiltration and voltage loss.

Some ignition cables are called *variable pitch* resistor cables. These cables rely on tightly wound and loosely wound copper wire around a layer of ferrite magnetic material wrapped over a fiberglass strand core. This construction creates the necessary resistance with a fraction of the impedance found in solid carbon core-type wire sets.

Some engines have spark plug cable heat shields **(Figure 26–18)** fitted onto the boots at the cylinder head. These shields surround each spark plug boot and spark plug. They protect the spark plug boot from damage due to the extreme heat generated by the nearby exhaust manifold.

Triggering and Switching Devices

Triggering and switching devices are used to ensure the spark occurs at the correct time. A triggering device is simply a device that monitors the movement of the engine's crankshaft and pistons. A switching device is what controls current flow through the primary winding. When the triggering device sends a

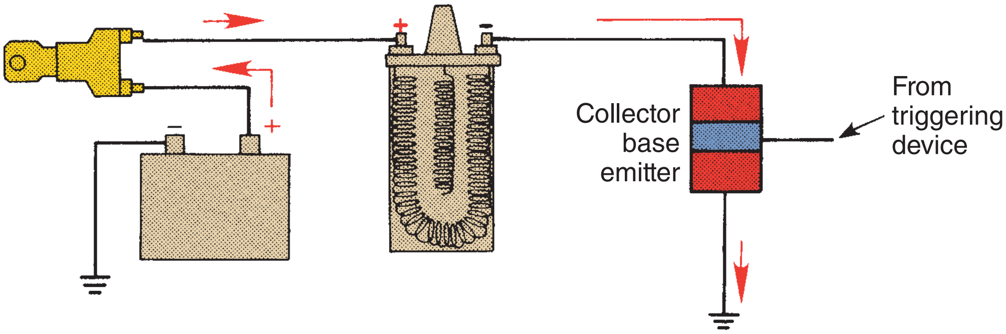


FIGURE 26–19 When the triggering device supplies a small amount of current to the transistor's base, the primary coil circuit is closed and current flows.

signal to the switching device that the piston of a particular cylinder is on the compression stroke, the switching device stops current flow to the primary winding. This interruption of current flow happens when the PCM decides it is best to fire the spark plug.

Electronic switching components are normally located in an ignition control module, which may be part of the vehicle's PCM. On older vehicles, the ignition module may be built into the distributor or mounted in the engine compartment.

The ignition module advances or retards the ignition timing in response to engine conditions. Early systems had little control of timing and used mechanical or vacuum devices to alter timing. Today's computer-controlled systems have full control and can adjust ignition timing in response to the input signals from a variety of sensors and the programs in the computer.

Most electronically controlled systems use an NPN transistor to control the primary ignition circuit, which ultimately controls the firing of the spark plugs. The transistor's emitter is connected to ground. The collector is connected to the negative terminal of the coil. When the triggering device supplies a small current to the base of the transistor, current flows through the primary winding of the coil. When the current to the base is interrupted, the current to the coil is also interrupted. An example of how this works is shown in **Figure 26–19**, which is a simplified diagram of an electronic ignition system.

Engine Position Sensors

The time when the primary circuit must be opened and closed is related to the position of the pistons and the crankshaft. Therefore, the position of the crankshaft is used to control the flow of current to the base of the switching transistor.

A number of different types of sensors are used to monitor the position of the crankshaft and control the flow of current to the base of the transistor. These engine position sensors and generators serve as triggering devices and include magnetic pulse generators, metal detection sensors, Hall-effect sensors, magnetoresistive sensors, and photoelectric (optical) sensors.

These sensors can be located inside the distributor or mounted on the outside of the engine to monitor crankshaft position (CKP). In many cases, the input from a CKP is supplemented by inputs from camshaft position (CMP) sensors. On nearly all late-model engines, the CKP and CMP are magnetic pulse generators, magnetoresistive sensors, or Hall-effect switches.

GO TO Chapter 25 for a detailed discussion of crankshaft and camshaft position sensors.

Magnetic Pulse Generator

Basically, a magnetic pulse generator or inductance sensor consists of two parts: a trigger wheel and a pickup coil. The trigger wheel may also be called a reluctor, pulse ring, armature, or timing core. The pickup coil, which consists of a length of wire wound around a permanent magnet, may also be called a stator, sensor, or pole piece. Depending on the type of ignition system used, the timing disc may be mounted on the distributor shaft, at the rear of the crankshaft, or behind the crankshaft vibration damper **(Figure 26–20)**.

The magnetic pulse or PM generator operates on the principles of electromagnetism. A voltage is induced in a conductor when a magnetic field passes over the conductor or when the conductor moves over a magnetic field. The magnetic field is provided by a magnet in the pickup unit, and the rotating trigger wheel provides the required movement through the magnetic field to induce voltage.

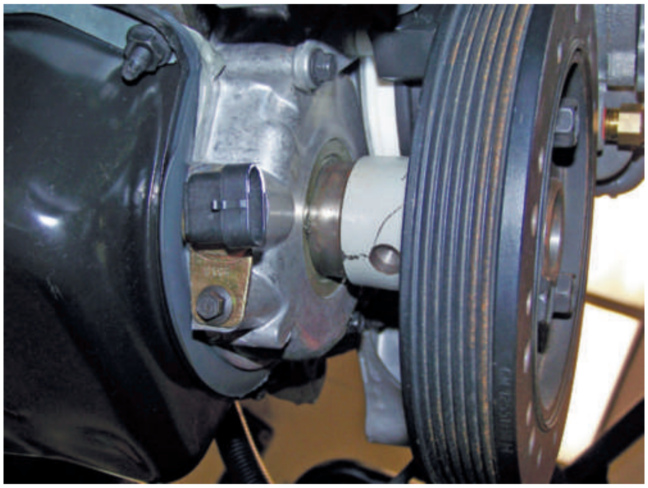


FIGURE 26–20 Location of a typical crankshaft position (CKP) sensor.

As the trigger wheel rotates past the pickup coil, a weak AC voltage signal is induced in the pickup coil. This signal is sent to the ignition module. In early ignition systems, the change in polarity was used as a signal to prepare the ignition coil for another spark plug firing.

When a tooth is aligned to the pickup coil, the magnetic field is not expanding or contracting. There is no change in the magnetic field and at that point zero voltage is induced in the pickup coil. The zero voltage signal from the coil is called the timing or "sync" pulse and is used by the PCM as the basis for timing the events in the ignition system. The timing pulses correspond with the position of each piston within their cylinder.

GO TO Chapter 25 for a detailed discussion of magnetic pulse generators and Hall-effect sensors.

Hall-Effect Sensor

The Hall-effect sensor or switch is the most commonly used engine position (CKP) sensor. A Hall-effect sensor produces an accurate voltage signal throughout the entire speed range of an engine. It also produces a square wave signal that is more compatible with computers. In an ignition system, the shutter blades are mounted on the distributor shaft **(Figure 26–21)**, flywheel, crankshaft pulley, or cam gear so the sensor can generate a position signal as the crankshaft rotates. A Hall-effect sensor may be normally on or off depending on the system and its circuitry. When a normally off sensor is used,

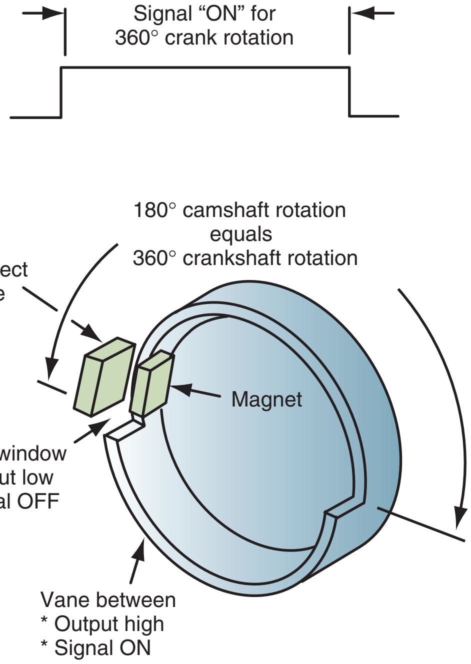


FIGURE 26–21 Operation of a Hall-effect switch.

there is maximum voltage output from the sensor when the magnetic field is blocked by the shutter. The opposite is true for normally on sensors. They have a voltage output when the magnetic field is not blocked.

A typical Hall-effect sensor has three wires connected to it. One wire is the reference voltage wire. The PCM supplies a reference voltage of 5 to 12 volts, depending on the system. The second wire delivers the output signal from the sensor to the PCM, and the third wire provides a ground for the sensor.

The signal from a Hall-effect CKP is also used to match fuel injector timing with the engine's firing order on engines equipped with sequential fuel injection. Hall-effect switches are also used as camshaft position (CMP) sensors. When the engine is being started, the PCM receives a signal from the CKP, but the spark plugs will not fire until the PCM receives a reference pulse from the CMP. After the engine starts, the PCM no longer relies on the CMP for ignition sequencing. However, if the CMP is bad, the engine will not restart. If the CKP goes bad, the engine will not start or run.

Magnetoresistive Sensor

Magnetoresistive (MR) sensors look similar to magnetic pulse generators but operate like Hall-effect and produce a digital square wave signal. An MR sensor uses a permanent magnet and two magnetic

reluctance pickups spaced on either side of the magnet. As a reluctor wheel passes the sensor, the magnetic field changes and is sensed by the two pickups. The detection of the change in the field takes place at slightly different times by the two sensors and results in the output of a signal.

Like a Hall-effect, the MR sensor has three wires but instead of requiring a voltage source to operate, the MR sensor generates a switching 5-volt signal.

Photoelectric Sensor

Some distributor ignition systems relied on photoelectric sensors **(Figure 26–22)** to monitor engine position. These sensors are also called optical sensors. They consisted of an LED, a light-sensitive phototransistor (photo cell), and a slotted disc called an interrupter. As the interrupter rotated between the LED and the photo cell, a square wave voltage signal was generated in the photo cell.

Photoelectric sensors may combine both the CKP and CMP sensors together, using one interrupter ring and two sets of LEDs and photo cells. The CKP uses 360 slots in the interrupter, one for each degree of crankshaft rotation. The CMP uses the number of slots equal to the number of cylinders of the engine. The slot for cylinder number one is larger to differentiate it from the others.

Timing Retard and Advance

One of the most important duties of an ignition system is to provide the spark at the correct time. On late-model engines, this is the job of the PCM. The PCM uses data from input sensors such as the CKP, engine coolant sensor, mass airflow sensor, and others to determine ignition timing. On earlier ignition systems, this was accomplished at the distributor through mechanical and vacuum-responsive devices. Mechanical advance responded to engine speed and vacuum advance responded to engine load.

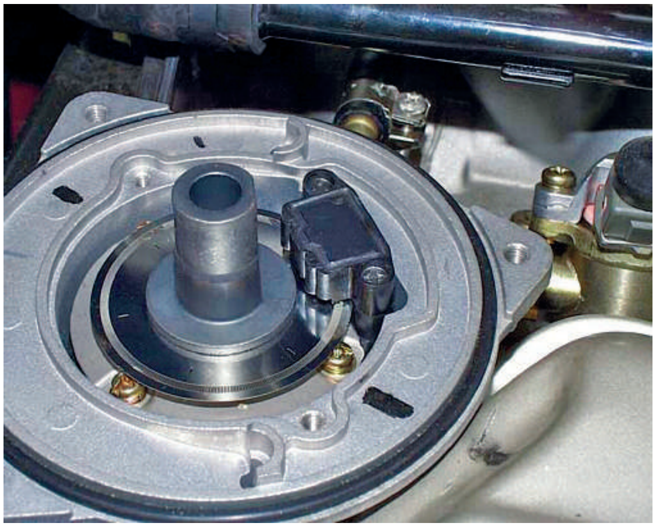


FIGURE 26–22 A distributor with an optical-type pickup.

Distributor Ignition System Operation

The primary circuit of a DI system is controlled by a triggering device and a switching device located inside the distributor or external to it. Although these systems are no longer used by auto makers, there are many of them still on the road and they need service.

Distributor

The reluctor, or trigger wheel, and distributor shaft assembly are attached to a drive gear that is driven by the engine's camshaft. The distributor shaft turns at the same speed as the camshaft, which rotates at one-half the speed of the crankshaft.

Through the years there have been many different designs of DI systems. All operate in basically the same way: A position sensor sends a signal to an ignition control module. The module controls current flow through the coil and opens the secondary circuit to release the spark.

Computer-Controlled DI Systems After the manufacturers eliminated the mechanical and vacuum advance mechanisms on their distributors, the ECM or PCM controlled ignition timing. This allowed for more precise control of ignition timing and provided improved combustion. The PCM adjusted the ignition timing according to engine speed, engine load, coolant temperature, throttle position, and intake manifold pressure. These systems varied with application and used a variety of triggering devices.

Electronic Ignition Systems

Modern engines are not equipped with a distributor; rather they have electronic ignitions. In the past, the term *electronic ignition* was designated to those ignition systems that used electronic controls. Today, electronic ignitions are those that do not use a distributor. As distributors were phased out, manufacturers used a waste spark system, where a coil fired

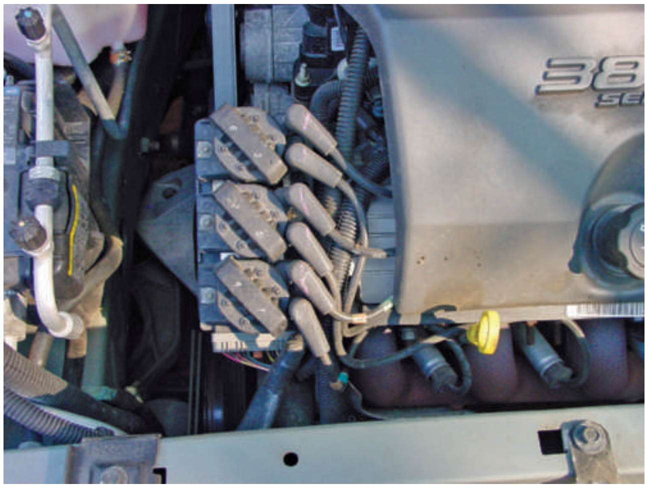


FIGURE 26–23 A coil pack for a double-ended or waste spark ignition system.

two cylinders at the same time **(Figure 26–23)**. Modern vehicles use coil-per-cylinder systems. Most waste spark systems use an ignition module to control firing order while the PCM determines spark timing. Coil-per-cylinder systems typically use the PCM as the ignition module, which controls firing order and timing. A crank sensor is used to trigger the ignition system.

There are many advantages of a distributorless ignition system over one that uses a distributor. Here are some of the more important ones:

- No moving parts and therefore requires little maintenance.
- It is possible to control the ignition of individual cylinders to meet specific needs.
- Increased available time for coil saturation.
- Increased time between firings, which allows the coil to cool more.

Double-Ended Coil or Waste Spark Systems

Double-ended or waste spark ignition systems use one ignition coil for two spark plugs **(Figure 26–24)**. Both ends of the coil's secondary side are directly connected to a spark plug, which means that two plugs are ignited at the same time; one is fired on the compression stroke of one cylinder and the other is fired on the exhaust stroke of the companion cylinder.

A four-cylinder engine has two ignition coils, a six-cylinder has three, and an eight-cylinder has four. The computer, ignition module, and various sensors combine to control spark timing.

The computer collects and processes information to determine the ideal amount of spark advance for the operating conditions. The ignition module uses crank/cam sensor data to control the timing of the primary circuit in the coils **(Figure 26–25)**. Remember that there is more than one coil in a distributorless ignition system. The ignition module synchronizes the coils' firing sequence in relation to crankshaft position and firing order of the engine. Therefore, the ignition module takes the place of the distributor.

Primary current is controlled by transistors in the control module. There is one switching transistor for each ignition coil in the system. The transistors complete the ground circuit for the primary, thereby allowing for a dwell period. When primary current flow is interrupted, secondary voltage is induced in the coil and the coil's spark plug(s) fire. The timing and sequencing of ignition coil action is determined by the control module and input from a triggering device.

The control module is also responsible for limiting the dwell time. In EI systems there is time between plug firings to fully saturate the coil.

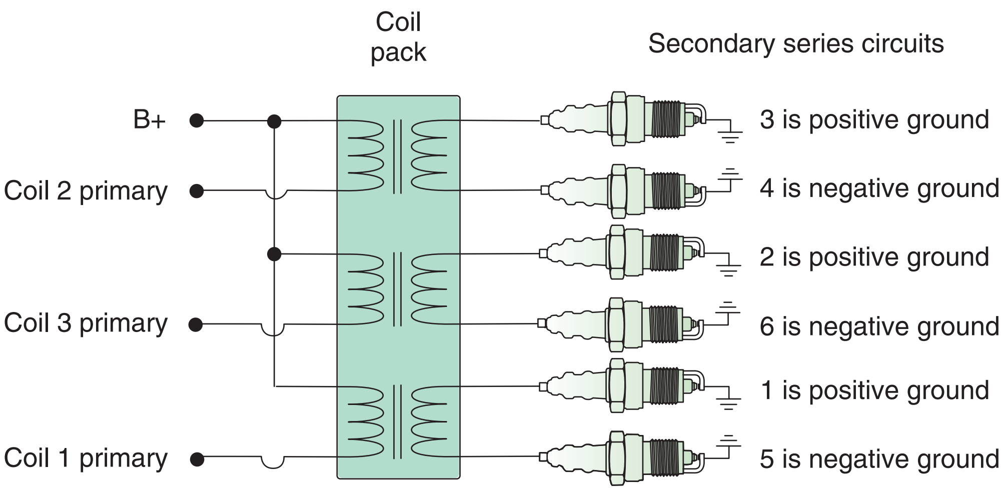


FIGURE 26–24 Polarity of the spark plugs in an EI system.

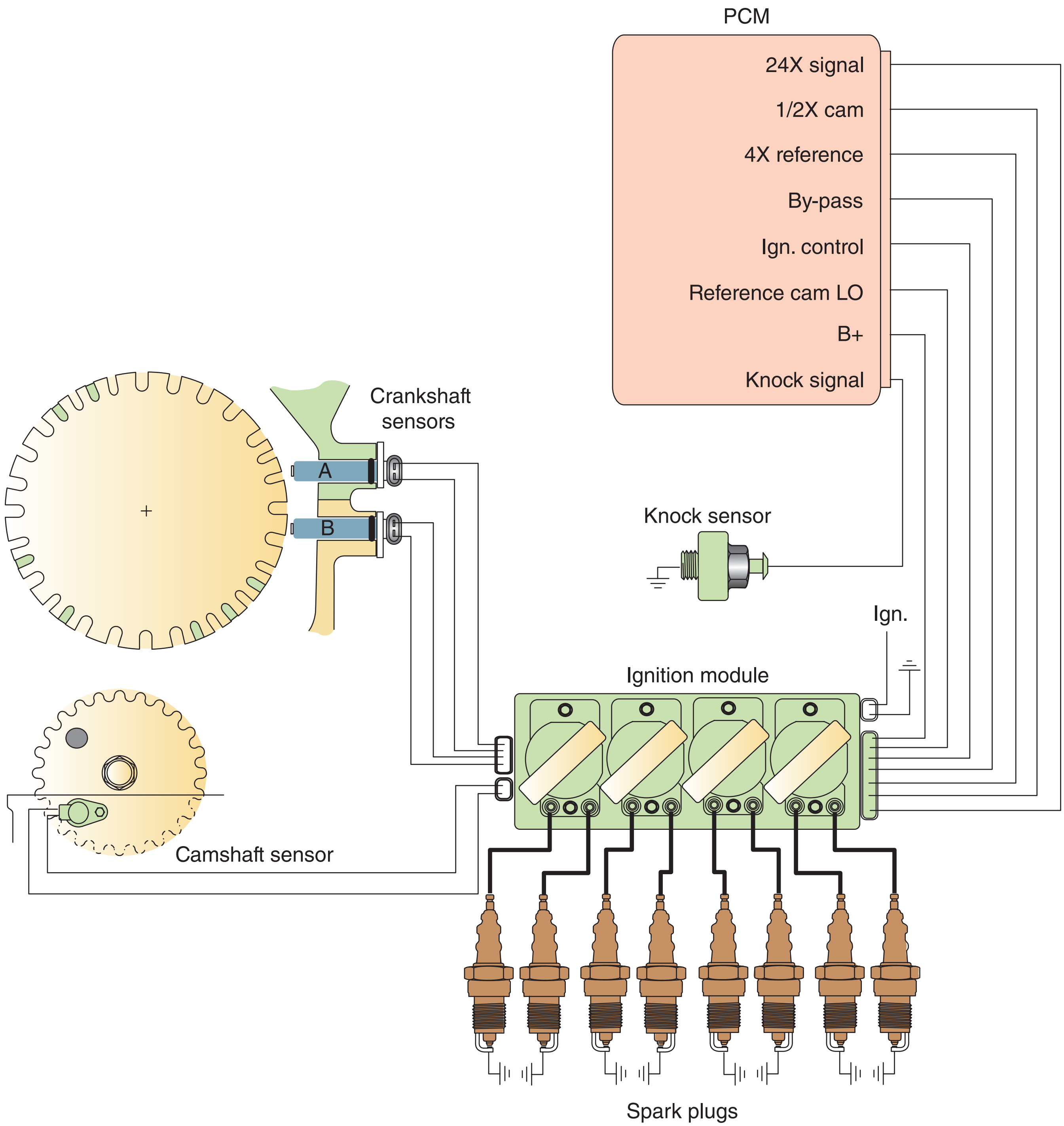


FIGURE 26–25 An electronic ignition (EI) system for an eight-cylinder engine.

Achieving maximum current flow through the coil is great if the system needs the high voltage that may be available. However, if the high voltage is not needed, the high current is not needed and the heat it produces is not desired. Therefore, the control module is programmed to only allow total coil saturation when the very high voltage is needed or the need for it is anticipated.

The ignition module also adjusts spark timing below 400 rpm (for starting) and when the vehicle's control computer by-pass circuit becomes open or grounded. Depending on the exact EI system, the ignition coils can be serviced as a complete unit or separately. The coil assembly is typically called a **coil pack** and is comprised of two or more individual coils.

Waste Spark Double-ended coil systems are based on the **waste spark** method of spark distribution. Both ends of the ignition coil's secondary winding are connected to a spark plug. Therefore, one coil is connected in series with two spark plugs. The two spark plugs belong to cylinders whose pistons rise and fall together, called companion cylinders. With this arrangement, one cylinder of each pair is on its compression stroke and the other is on its exhaust stroke when the spark plugs are fired. Typically, cylinder pairings are:

- Four-cylinder engines: 1 & 4 and 2 & 3
- V6 engines: 1 & 4, 2 & 5, and 3 & 6
- Inline six cylinders: 1 & 6, 2 & 5, and 4 & 3
- V8 engines: 1 & 4, 3 & 8, 6 & 7, and 2 & 5 or 1 & 6, 3 & 5, 4 & 7, and 2 & 8

(The pairings on V6s and V8s will vary as manufacturers vary how they number the cylinders.)

Due to the way the secondary coils are wired, when the induced voltage cuts across the primary and secondary windings of the coil, one plug fires in the normal direction—positive center electrode to negative side electrode—and the other plug fires just the reverse side to center electrode. Both plugs fire simultaneously, completing the series circuit. Each plug always fires the same way on both the exhaust and compression strokes.

The coil is able to overcome the increased voltage requirements caused by reversed polarity and still fire two plugs simultaneously because each coil is capable of producing up to 100,000 volts. There is very little resistance across the plug gap on exhaust, so the plug requires very little voltage to fire, thereby providing its mate (the plug that is on compression) with plenty of available voltage. If you think about a series circuit with two unequal resistors, the majority of the voltage will be dropped by the larger value resistor while less voltage will be used by the lower value resistor. The waste spark circuit operates in the same way; the lower resistance across the waste spark plug gap drops less of the available voltage, leaving voltage available for the other spark plug.

Some EI systems use the waste spark method of firing but only have one secondary wire coming off each ignition coil. In these systems, one spark plug is connected directly to the ignition coil and the companion spark plug is connected to the coil by a high-tension cable.

Coil-per-Cylinder Ignition

The operation of a coil-per-cylinder ignition system is basically the same as any other ignition system. By definition, these systems have an individual coil for each spark plug. There are two different designs of coil-per-cylinder systems used today: the **coil-over-plug (COP)** and the separate coil. COP systems rely on a single assembly of an ignition coil and spark plug **(Figure 26–26)**. In these systems, the spark plug is directly attached to the coil and there is no spark plug wire.


Courtesy of Visteon Corporation.

FIGURE 26–26 A coil-on-plug assembly.

The separate coil system is often called a coil-by-plug or coil-near-plug ignition system **(Figure 26–27)**. These systems have individual coils mounted near the plugs and use a short secondary plug wire to connect the coil to the plug. These systems are used when the location of the spark plug does not allow enough room to mount individual coils over the plugs, or when the plugs are too close to the exhaust manifold.

Having one coil for each spark plug allows for more time between each firing, which increases the life of the coil by allowing it to cool. In addition, it also allows for more saturation time, which increases the coil's voltage output at high engine speeds. The increased output makes the coils more effective with lean fuel mixtures, which require higher firing voltages.

Another advantage of using the coil-per-cylinder system is that the ignition timing at each cylinder can be individually changed for maximum performance and to respond to knock sensor signals. Other advantages of a coil-per-cylinder system are that all of the engine's spark plugs fire in the same direction and coil failure will affect only one cylinder.

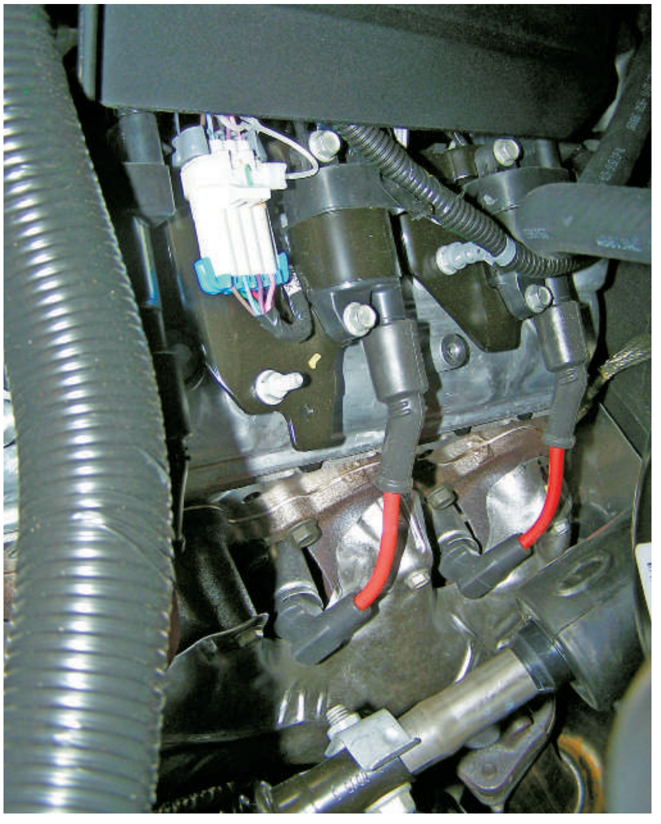


FIGURE 26–27 A coil-near-plug system.

Some manufacturers utilize a multi-fire or repetitive spark feature. Because each cylinder has its own coil, there is time to saturate and fire the coil several times per combustion event. Repetitive spark is often used at low engine rpm to improve idle quality and reduce exhaust emissions.

In a typical coil-per-cylinder system, a crankshaft position sensor provides a basic timing signal. This signal is sent to the PCM. The PCM is programmed with the firing order for the engine and determines which ignition coil should be turned on or off. Some engines require an additional timing signal from the camshaft position sensor. On some systems, there is also a coil capacitor for each bank of coils for radio noise suppression.

Coil-over-Plug (COP) Ignition The true difference between COP and other ignition systems is that each coil is mounted directly atop the spark plug **(Figure 26–28)**, so the voltage from the coil goes directly to the plug's electrodes without passing through a plug wire. This means there are no secondary wires to come loose, burn, leak current, break down, or replace. Eliminating plug wires also reduces radio frequency interference (RFI) and electromagnetic interference (EMI) that can interfere with computer systems. However, the absence of plug wires also means that the coils need to be removed and reconnected with adapters or plug wires to test for spark, connect a pickup for an ignition scope, or perform a manual cylinder power balance test.

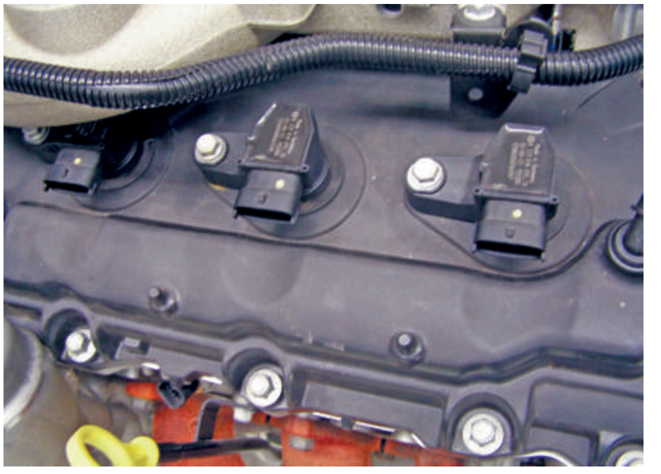


FIGURE 26–28 In a COP system, the coil is mounted directly above the spark plug.

Twin Spark Plug Systems

Most engines have one spark plug per cylinder, but some have two. One spark plug is normally located on the intake side of the combustion chamber and the other is at the exhaust side. When ignition takes place in two locations within the combustion chamber, more efficient combustion and cleaner emissions are possible. Two coil packs are used, one for the intake side and the other for the exhaust side. These systems are called dual or twin plug systems.

Some engines fire only one plug per cylinder during starting. The additional plug fires once the engine is running. During dual plug operation, the two coil packs are synchronized so the two plugs of each cylinder fire at the same time. Therefore, in a waste spark system, four spark plugs are fired at a time: two during the compression stroke of a cylinder and two during the exhaust stroke of another cylinder.

EI System Operation

From a general operating standpoint, most electronic ignition systems are similar. One difference in design is the number of ignition coils. COP systems have the same number of coils as the engine has cylinders. Waste spark systems have half the number of coils as there are cylinders. Perhaps the

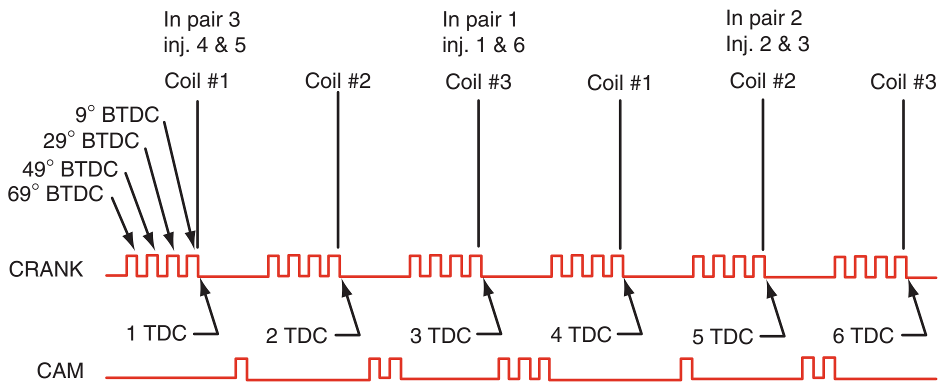


FIGURE 26–29 An example of crank and cam sensor signals.

biggest difference in system operation is based on the use of CKP and CMP sensors.

All systems have a CKP to monitor crankshaft position and engine speed. Some also monitor the relative position of each cylinder. The signals from a CMP sensor are used for cylinder identification and for verifying the correlation between the position of the crankshaft and the camshafts **(Figure 26–29)**. The design of the trigger wheels or rotors for these two sensors also varies. The design is primarily based on whether the sensor is a magnetic pulse (variable reluctance) or Hall-effect sensor. Both can be used for either sensor. Inputs from these sensors are critical to the operation of the fuel injection and ignition systems.

The layout and operation of these sensors are designed to provide fast engine starts and synchronization of the fuel injection and ignition systems with the position of the engine's individual pistons.

Hall-Effect Sensors

Many Hall-effect sensors rely on pulleys or harmonic balancers with interrupter rings or shutters. In many cases, the crankshaft pulley has half as many windows as the engine has cylinders. As the crankshaft rotates and the interrupter passes in and out of the Hall-effect switch, the switch turns the module reference voltage on and off. The signals are identical and the control module cannot distinguish which of these signals to assign to a particular coil. The signal from the cam sensor gives the module the information it needs to synchronize the crankshaft sensor signals with the position of the number one cylinder. From there the module can energize the coils according to the firing order of the engine. Once the engine has started, the camshaft signal serves no purpose for the ignition system. CMP signals are

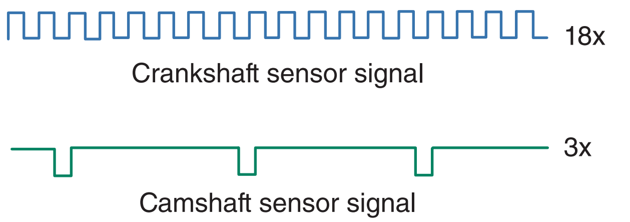


FIGURE 26–30 The relationship between crankshaft and camshaft signals on a GM 3.8L SFI engine.

used for proper fuel injection timing on sequential injection systems.

Many CMP sensors are Hall-effect sensors and produce a square wave signal **(Figure 26–30)**. The sensor may respond to a single slot on a camshaft pulley or the pulley will have several. One design has four narrow and wide slots on the trigger wheel. The PCM uses the narrow and wide signal patterns to identify camshaft position, or which cylinder is on its compression stroke and which is on the exhaust. The PCM can then calculate the correct timing and sequencing for the spark plugs and fuel injectors.

Magnetic Pulse Generators

Many late-model engines use magnetic pulse generators as CKP sensors. The trigger wheel, also called the reluctor, can be located behind the crankshaft pulley, inside the engine in the middle of the crankshaft, or at the flywheel. Again the design of the trigger wheel depends on the application and operation of the system.

In more basic systems, the trigger wheel is located behind the crankshaft pulley. If the engine is a six cylinder, there will be seven slots in the reluctor, six of which are spaced exactly 60 degrees apart and the seventh notch is located 10 degrees from the number six notch and is used to synchronize the

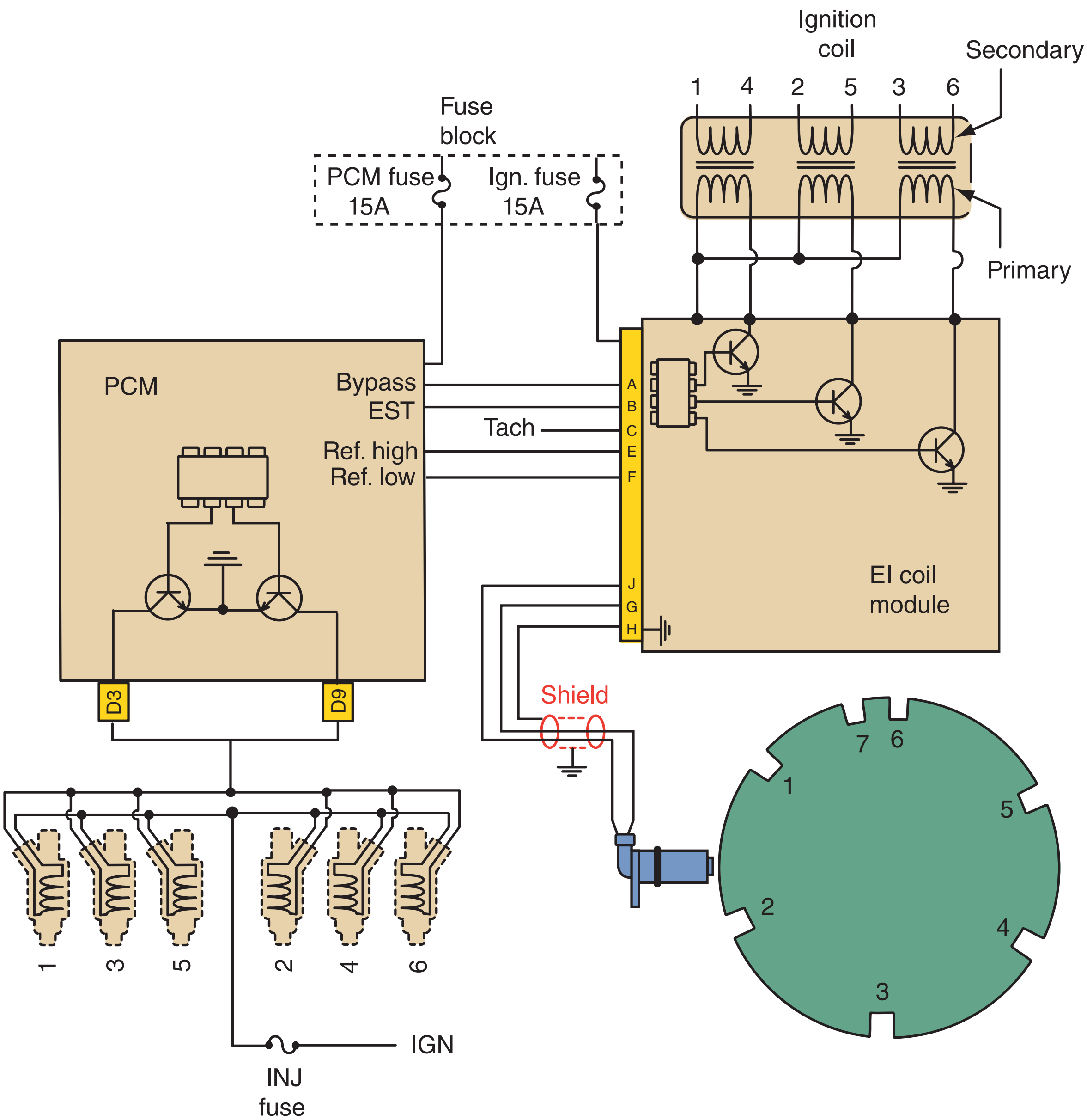


FIGURE 26–31 Schematic of an EI system with a magnetic pulse generator-type crankshaft sensor. Note the notches on the crankshaft timing wheel.

coil firing sequence in relation to crankshaft position **(Figure 26–31)**. The same triggering wheel can be and is used on four-cylinder engines. The computer only needs to be programmed to interpret the signals differently than for a six-cylinder engine.

The CKP sensor generates a small AC voltage each time one of the machined slots passes by. By counting the time between pulses, the ignition module picks out the unevenly spaced seventh slot and starts the calculation of the ignition coil sequencing. Similar systems are used with more slots or teeth machined into the reluctor. There is always at least one gap for cylinder identification purposes.

In many cases, the gap is used to identify the position of the crankshaft during engine cranking. A CMP sensor is used to determine what stroke the cylinders are on.

Magnetoresistive Sensors

This type of sensor is used as a CKP sensor and is usually mounted behind the crankshaft pulley or is bolted to the block. A toothed timing wheel may be mounted on the end of the crankshaft, integrated into the crankshaft, or located on the flywheel. MR sensors produce a digital square wave pattern that increases in frequency as engine speed increases.

Misfire Detection

A high data rate CKP sensor is used to detect engine misfires, required for OBD II, and the CMP is used to identify which cylinder is misfiring. Misfires are detected by variations in crankshaft rotational speed for each cylinder. An interesting feature of most misfire monitors is the ability of the PCM to distinguish an actual misfire from other things that may cause the engine's speed to fluctuate. Driving on a rough road can cause the vehicle's wheels to change rotational speed; this in turn will affect the rotational speed of the crankshaft. To determine whether the engine has misfired or the vehicle is merely driving on a poor surface, the PCM receives wheel speed data from the antilock brake system. A rough road will cause variances in wheel speed and the PCM looks at that data before concluding a misfire occurred.

Basic Timing

The PCM totally controls ignition timing and ignition timing is not adjustable. When the engine is cranked for starting, the PCM sets the timing at a fixed value. This value is used until the engine is running at a predetermined speed. Once that speed is met, the PCM looks at several inputs, including engine speed, load, throttle position, and engine coolant temperature, and makes adjustments accordingly. The PCM continues to rely on those inputs and its programmed strategy throughout operation. All PCMs have limits as to how far the timing can be retarded and advanced.

Timing Corrections The PCM adjusts ignition timing according to its programming and sensor inputs. There are times when the timing is adjusted or corrected to compensate for slight changes in the operating conditions or abnormal occurrences.

- *Load and RPM:* The two biggest factors in ignition timing are engine load and rpm. Timing will advance with engine speed up to a preset limit and rpm. As load increases, timing is retarded as crankshaft speed decreases.
- *Temperature:* Ignition timing is advanced when the coolant temperature is low. When the temperature is very high, the timing is retarded.
- *Engine Knock:* When a knock is detected, the PCM retards the timing in fixed steps until the knock disappears. When the knocking stops, the PCM stops retarding the timing and begins to advance the timing in fixed steps unless the knocking reoccurs.
- *Stabilizing Idle:* When the engine idle speed moves away from the desired idle speed, the PCM will adjust the timing to stabilize the engine speed. It is important to know that ignition timing changes are made only to correct minor idle problems. If the engine's speed is above the desired speed, the timing is retarded and when it is too low, the timing is advanced.
- *EGR Operation:* When the EGR valve opens, the timing is advanced. The amount of advance depends on intake air volume and engine speed.
- *Transition Correction:* When the vehicle is accelerated immediately after deceleration, the timing is temporarily advanced or retarded to smoothen the transition.
- *Torque Control:* To provide smooth shifting of an automatic transmission, the PCM will temporarily retard the ignition timing to reduce the engine's torque when the transmission is beginning to change gears.
- *Traction Control Correction:* When excessive wheel slippage occurs, the PCM will retard the timing to reduce the torque output from the engine. Once the slippage has been corrected, timing returns to normal.
- *E85 Fuel:* Modern flex-fuel vehicles, capable of using E85 ethanol blends, are able to detect the use of E85. When E85 is detected, engine operating parameters including ignition timing are changed to compensate for the difference in engine output and fuel consumption.

Caution! Since EI systems have considerably higher maximum secondary voltage compared to distributor-type ignition systems, greater electrical shocks are obtained from EI systems. Although such shocks may not be directly harmful to the human body, they may cause you to jump or react suddenly, which could result in personal injury. For example, when you jump suddenly as a result of an EI electrical shock, you may hit your head on the vehicle hood or push your hand into a rotating cooling fan.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2008	**Make:** Ford	**Model:** Focus	**Mileage:** 132,148	**RO:** 18604
Concern:	Car towed in, crank no-start. Customer states it died while driving.			
The technician confirms the engine cranks but does not start. Using a scan tool he checks for DTCs and finds a P0351–ignition coil primary/secondary circuit malfunction, a P0300–random cylinder misfire, a P0301–cylinder 1 misfire, and a P0303–cylinder 3 misfire. Thinking the no-start may be ignition related, he checks for spark from all four coils; none of which spark. Examining a wiring diagram he finds all four coils are powered by the same fuse. After locating the fuse he finds it is blown.				
Cause:	Found P0351, P0300, P0301, and P0303 stored and fuse 29 (ignition coils) blown. Replaced fuse, cranked engine and fuse blew again. Disconnected number 1 coil, replaced fuse and engine started. Found number 1 coil shorted internally. Spark plugs look original.			
Correction:	Replaced number 1 coil and spark plugs, cleared DTCs. No misfires present, engine operating normally.			

KEY TERMS

Air gap
Coil-over-plug (COP)
Coil pack
Direct ignition system (DIS)
Dwell
Heat range
Inductive reluctance
Misfiring
Primary circuit
Reach
Reactance
Secondary circuit
Waste spark

SUMMARY

- The ignition system supplies high voltage to the spark plugs to ignite the air-fuel mixture in the combustion chambers.
- The ignition system has two interconnected electrical circuits: a primary circuit and a secondary circuit.
- The primary circuit supplies low voltage to the primary winding of the ignition coil. This creates a magnetic field in the coil.
- A switching device interrupts primary current flow, collapsing the magnetic field and creating a high-voltage surge in the ignition coil secondary winding.
- The switching device used in electronically controlled systems is an NPN transistor.
- The secondary circuit carries high-voltage surges to the spark plugs. On some systems, the circuit runs from the ignition coil, through a distributor, to the spark plugs.
- Ignition timing is directly related to the position of the crankshaft. Magnetic pulse generators and Hall-effect sensors are the most widely used engine position sensors. They generate an electrical signal at certain times during crankshaft rotation. This signal triggers the electronic switching device to control ignition timing.
- Today's engines are equipped with an EI system for which there are primarily two different designs: double-ended coil and coil-per-cylinder.
- In computer-controlled ignitions, the computer receives input from numerous sensors. Based on this data, the computer determines the optimum firing time and signals an ignition module to activate the secondary circuit at the precise time needed.
- In some systems, the camshaft sensor signal informs the computer when to sequence the coils and fuel injectors.
- The crankshaft sensor signal provides engine speed and crankshaft position information to the computer.
- Some EI systems have a combined crankshaft and SYNC sensor at the front of the crankshaft.

REVIEW QUESTIONS

Short Answer

1. Explain how voltage is induced in a permanent magnet pickup coil as the reluctor approaches alignment with the pickup coil.
2. Explain why dwell time is important to ignition system operation.
3. Name the engine operating conditions that most affect ignition timing requirements.
4. Explain how the plugs fire in a two-plug-per-coil DIS system.
5. Why is high voltage needed to establish a spark across the gap of a spark plug?
6. List the advantages of having one ignition coil per cylinder.
7. Modern ignition cables contain fiber cores that act as a ___ in the secondary circuit to cut down on radio and television interference and reduce spark plug wear.
8. Explain the components and operation of a Hall-effect sensor.

True or False

1. *True or False?* The spark plug wire is eliminated in all coil-per-cylinder ignition systems to reduce maintenance and the chances of EMI and RFI.
2. *True or False?* A spark plug with two ground electrodes will provide two separate sparks when fired.

Multiple Choice

1. What happens when the low-voltage current flow in the coil primary winding is interrupted by the switching device?
   a. The magnetic field collapses.
   b. A high-voltage is induced in the coil secondary winding.
   c. Both A and B.
   d. Neither A nor B.
2. Which of the following is a function of all ignition systems?
   a. To generate sufficient voltage to force a spark across the spark plug gap
   b. To time the arrival of the spark to coincide with the movement of the engine's pistons
   c. To vary the spark arrival time based on varying operating conditions
   d. All of the above
3. Reach, heat range, and air gap are all characteristics that affect the performance of which ignition system component?
   a. Ignition coils
   b. Ignition cables
   c. Spark plugs
   d. Ignition modules
4. The magnetic field surrounding the coil in a magnetic pulse generator moves when the ___.
   a. Reluctor tooth approaches the coil
   b. Reluctor tooth begins to move away from the pickup coil pole
   c. Reluctor is aligned with the pickup coil pole
   d. Both A and B
5. Which of the following electronic switching devices has a reluctor with wide shutters rather than teeth?
   a. Magnetic pulse generator
   b. Optical sensor
   c. Hall-effect sensor
   d. All of the above

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that a magnetoresistive sensor is equipped with a permanent magnet. Technician B says that a Hall-effect switch is equipped with a permanent magnet. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. While discussing ignition systems: Technician A says that an ignition system must supply high-voltage surges to the spark plugs. Technician B says that the system must maintain the spark long enough to burn all of the air-fuel mixture in the cylinder. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

3. While discussing ignition timing requirements: Technician A says that more advanced timing is desired when the engine is under a heavy load. Technician B says that more advanced timing is desired when the engine is running at low engine speeds. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. While discussing secondary voltage: Technician A says that the normal required secondary voltage is higher at idle speed than at wide-open throttle conditions. Technician B says that the maximum available secondary voltage must always exceed the normally required secondary voltage. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Technician A says that an ignition system must generate sufficient voltage to force a spark across the spark plug gap. Technician B says that the ignition system must time the arrival of the spark to coincide with the movement of the engine's pistons and vary it according to the operating conditions of the engine. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. In EI systems using one ignition coil for every two cylinders: Technician A says that two plugs fire at the same time with the same voltage used by each spark plug. Technician B says that one plug fires in the normal direction (center to side electrode) and the other in reversed polarity (side to center). Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. While discussing EI systems: Technician A says that all systems rely on CKP and CMP signals to synchronize the ignition system with piston movement. Technician B says that CKP and CMP signals are used to synchronize the operation of the ignition and fuel injection systems with piston position. Who is correct?
   a. Technician A
   b. Both A and B
   c. Technician B
   d. Neither A nor B
8. While discussing EI systems: Technician A says that when the engine is being cranked, the PCM relies only on the signals from the ECT to determine initial ignition timing. Technician B says that when an engine is initially started and is running at a predetermined speed, the PCM looks at several inputs, including engine speed, load, throttle position, and engine coolant temperature, and makes adjustments accordingly. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. Technician A says the switching device controls the flow of current through the coil primary winding. Technician B says that when the switching device stops supplying current to the coil primary winding, it is time to fire the spark plug. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While discussing spark plugs: Technician A says that too narrow of a spark plug gap can cause a rough idle and premature wear of the electrodes. Technician B says that a spark plug with the wrong reach can cause preignition. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER 27

IGNITION SYSTEM DIAGNOSIS AND SERVICE

This chapter concentrates on testing ignition systems and their individual components. It must be stressed, however, that there are many variations in the ignition systems used by auto manufacturers. The tests covered in this chapter are those generally used as basic troubleshooting procedures. Exact test procedures and the ideal troubleshooting sequence will vary among vehicle makers and individual models. Always consult the vehicle's service information when performing ignition system service.

Two important precautions should be taken during all ignition system tests:

1. Turn the ignition switch off before disconnecting any system wiring.
2. Do not touch any exposed connections while the engine is cranking or running.

OBJECTIVES

- Perform a no-start diagnosis and determine the cause of the condition.
- Determine the cause of an engine misfire.
- Perform a visual inspection of ignition system components, primary wiring, and secondary wiring to locate obvious trouble areas.
- Describe what an oscilloscope is, its scales and operating modes, and how it is used in ignition system troubleshooting.
- Test the components of the primary and secondary ignition circuits.
- Test individual ignition components using test equipment such as a voltmeter, ohmmeter, and testlight.
- Service and install spark plugs.
- Describe the effects of incorrect ignition timing.
- Diagnose engine misfiring on EI-equipped engines.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2007	**Make:** GMC	**Model:** Yukon	**Mileage:** 142,698	**RO:** 18825
Concern:	Check engine light is on and engine makes rattle sound on acceleration.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

Misfires

When something prevents complete combustion, the result is a misfire or incomplete combustion. Misfires can cause lack of power, poor gas mileage, excessive exhaust emissions, and a rough running engine. Misfires **(Figure 27–1)** are not always caused by the ignition system; other systems also can cause them. A spark plug misfires when it has a weak spark or does not fire at all. Misfires can be caused by a fouled spark plug, a bad coil, problems in the primary or secondary ignition circuit, or an incorrect plug gap.

Abnormal Combustion

Incomplete combustion is not the only abnormal condition engines may experience; they may also experience detonation. Detonation is usually caused by excessively advanced ignition timing, engine overheating, excessively lean mixtures, or the use of low-octane gasoline. Detonation can cause physical damage to the pistons, valves, bearings, and spark plugs.

Preignition can cause pinging or spark knocking. Any hot spot within the combustion chamber can cause preignition. Common causes of preignition are incandescent carbon deposits in the combustion chamber, a faulty cooling system, too hot of a spark plug, poor engine lubrication, and cross firing. Preignition usually leads to detonation; preignition and detonation are two separate events.

General Ignition System Diagnosis

The ignition system should be tested whenever you know or suspect there is no spark, not enough spark, or when the spark is not being delivered at the correct time to the cylinders.

Common vs. Noncommon Problems

In most cases, ignition problems can be divided into two types: common and noncommon. Common problems are those that affect all cylinders, and noncommon problems are those that affect one or more cylinders but not all. Common ignition components include the parts of the primary circuit and the secondary circuit up to the distributor's rotor in DI systems. Noncommon parts are the individual spark plug terminals inside the distributor cap, spark plug wires, and the spark plugs. With EI systems, the individual coils are noncommon parts.

The best indicator of a noncommon problem is the reading on a vacuum gauge **(Figure 27–2)**. If a vacuum gauge is connected to a four-cylinder engine at idle and the needle of the gauge is within the normal vacuum range for three-fourths of the time and drops one-fourth of the time, this indicates that three of the cylinders are working normally while the fourth is not. The cause of the problem is noncommon. If that cylinder is sealed and all cylinders are receiving the correct amount of air and fuel, the problem must

FIGURE 27–1 The PCM will store a DTC when it detects a misfire.

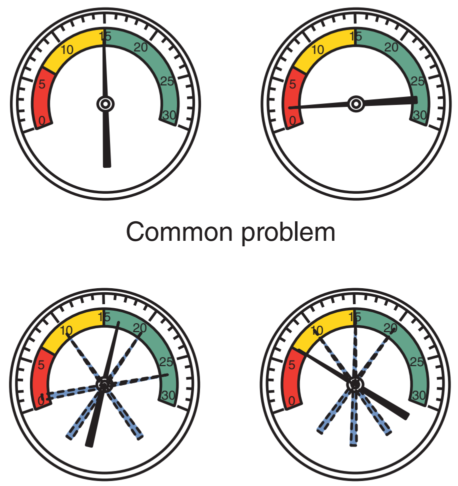


FIGURE 27–2 The reaction of a vacuum gauge when there is a common or noncommon problem.

be in the ignition system. The problem is in the noncommon parts of the ignition system.

Determining if the ignition problem is common or noncommon is a good way to start troubleshooting the ignition system. By dividing the ignition system into common and noncommon parts, you will test only those parts that could cause the problem.

Generally when an engine runs unevenly, the cause is a noncommon problem. If the engine does not start, the cause is probably a common one. EI systems, especially coil-per-cylinder systems, make troubleshooting a little easier. The PCM or ignition module may be the only part that is common to all cylinders. The coils and all of the secondary circuits are common to only one or two cylinders. For example, if a coil in a waste fire system is bad, two cylinders will be affected and not the entire engine.

Ignition System Inspection

Begin all diagnosis by gathering as much information as possible from the customer. Then conduct a careful visual inspection. The system should be checked for obvious problems. Although no-start problems and incorrect ignition timing are caused by the primary circuit, the secondary circuit can be the cause of driveability problems and should be carefully checked. In addition to the ignition system, inspect all related electrical connectors or fuses, vacuum lines, air intake system, and cooling system. Also check available service information that may relate to the symptoms.

Symptoms commonly caused by ignition system problems include (keep in mind that the ignition system is not the only thing that can cause these):

- *Hard starting*—The engine requires an excessive amount of time to start.
- *Rough idle*—The engine idles poorly and may stall.
- *Engine stalling*—The engine quits unexpectedly. It may occur right after engine startup, while idling, or during deceleration.
- *Hesitation*—The engine does not immediately respond to opening of the throttle.
- *Stumble*—The engine temporarily loses power during acceleration.
- *Poor acceleration*—The vehicle accelerates slower than expected.
- *Surge*—The engine's speed fluctuates with a constant throttle during idle, steady cruise, acceleration, or deceleration.
- *Bucking*—The vehicle jerks shortly after acceleration or deceleration.
- *Knocking (pinging)*—The engine makes a sharp metallic noise during acceleration.
- *Backfire and afterfire*—Backfire is a loud pop coming from the intake system, usually during rapid throttle opening. Afterfire is a popping noise that occurs in the exhaust system, usually during quick deceleration.

Scan Tools

Today's ignition systems are part of the engine control system. Part of the visual inspection should include a check of the MIL. If it is operating correctly and a fault is emissions related, the lamp will remain on after the engine has started. If the MIL is flashing with the engine running, this indicates a catalyst-damaging misfire is occurring. Within the OBD II diagnostic trouble code structure, DTCs P0300 through P0399 are specific to the ignition system and misfires. DTCs related to specific components and systems are addressed in the appropriate sections in this chapter. Also check all TSBs related to the vehicle. Look for bulletins that recommend reflashing the PCM. Sometimes the EEPROM needs to be reprogrammed due to changes made in the strategy or calibrations after the vehicle was produced.

GO TO Chapter 22 for flashing procedures.

DTCs and scan tool data should be retrieved during the initial diagnostic routine **(Figure 27–3)**. This includes KOEO, KOER, and continuous self-test DTCs. If the scan tool is unable to communicate with the system, follow the tests prescribed by the manufacturer to correct that problem. Also make sure to record any and all freeze frame data associated with the DTCs. Review the code setting conditions and follow the pinpoint tests to identify what set the code. Often these will lead to the exact cause of the problem; other times you will need to do further testing. If more than one DTC was set, refer to the vehicle's wiring diagram to identify parts and circuits that may be common to those codes. If DTCs are retrieved, you will need to determine if they are

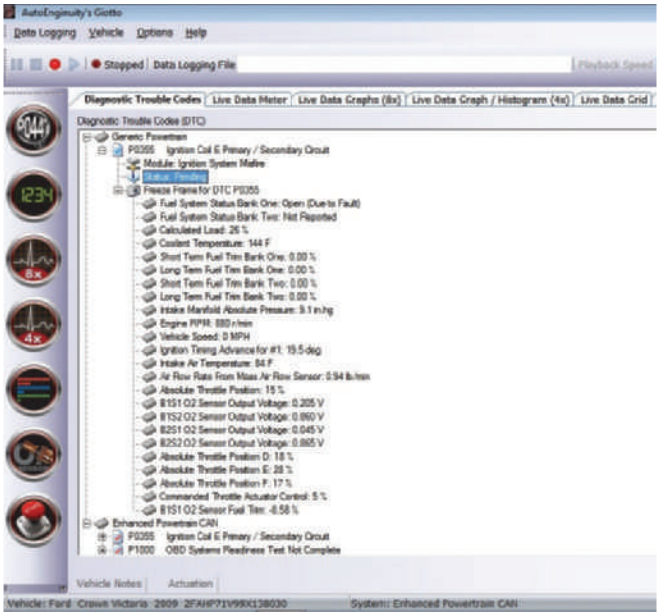


FIGURE 27-3 A sample of the information about a DTC displayed on a scan tool.

related to the concern. You may need to correct the problems that are causing the trouble codes before moving on. Fixing the cause of the codes may correct the ignition problem.

If no DTCs were retrieved, look at the system's serial data. First identify the appropriate PIDs. The PID test mode allows access to PCM information, including input signals, outputs, calculated values, and the status of the system and monitors. While observing serial data, look at the inputs. Identify any signals that are outside the normal range. Do the same with the outputs. Many systems and scan tools display misfire counts, a misfire monitor, or cylinder contribution test. The data show which cylinders have misfire histories and if any are currently experiencing misfires **(Figure 27–4)**. Mode 6 data can also be helpful. This mode displays the test values stored at the time a particular monitor was completed **(Figure 27–5)**. Depending on the vehicle, Mode $06 data may also provide information specific for cylinder misfires.

If no codes were retrieved and all appears to be normal on the data stream, diagnosis should be based on symptoms and detailed testing of the ignition system.

SHOP TALK

Keep in mind that the PCM may assume that the input signals are correct while it controls an output device. This means incorrect inputs can cause an output to appear out of range because the PCM is driving it outside the normal range. Check the input signals before checking the outputs.

Primary Circuit

Primary ignition system wiring should be checked for tight connections. Electronic circuits operate on very low voltage. Voltage drops caused by corrosion

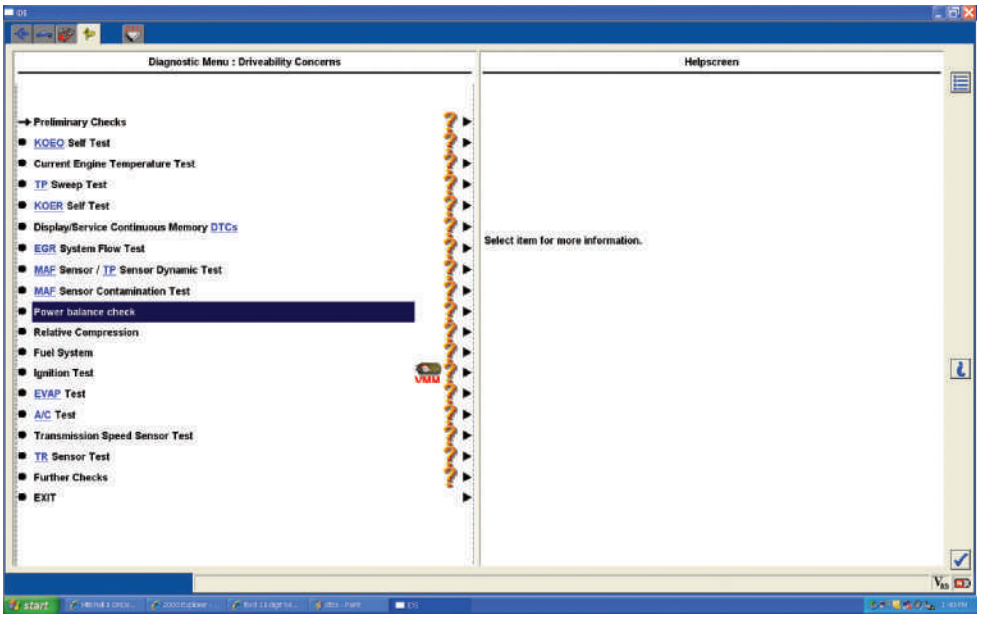


FIGURE 27-4 Diagnostic tests available on the Ford IDS scan tool.

J1979 MISFIRE MODE $06 DATA			
Monitor ID	**Test ID**	**Description for CAN**	**Increments**
A1	$80	Total engine misfire and catalyst damage misfire rate	%
A1	$81	Total engine misfire and emission threshold misfire rate	%
A1	$82	Highest catalyst damage misfire and catalyst damage threshold misfire rate	%
A1	$83	Highest emission threshold misfire and emission threshold misfire rate	%
A1	$84	Inferred catalyst mid-bed temperature	°C
A2-AD	$0B	Misfire counts for last 10 drive cycles	events
A2-AD	$0C	Misfire counts for last/current drive cycle	events
A2-AD	$80	Cylinder "X" misfire rate and catalyst damage misfire rate	%
A2-AD	$81	Cylinder "X" misfire rate and emission threshold misfire rate	%

FIGURE 27-5 Mode $06 data from the misfire monitor.

or dirt can cause running problems. Missing or broken tab locks on wire terminals are often the cause of intermittent ignition problems due to vibration or thermal related failure.

Test the integrity of a suspect connection by tapping, tugging, and wiggling the wires while the engine is running **(Figure 27–6)**. Be gentle. The object is to re-create an ignition-interruption, not to cause permanent circuit damage. With the engine and key off, separate the suspect connectors and check them for dirt and corrosion. Clean the connectors according to the manufacturer's recommendations.

On older systems, do not overlook the ignition switch as a source of intermittent ignition problems. A loose mounting rivet or poor connection can result in erratic spark output. To check the switch, gently wiggle the ignition key and connecting wires with the engine running. If the ignition cuts out or dies, the problem is located.

FIGURE 27-6 Check primary connections for damage.

Carefully inspect the wires and belts for the charging system. Also, check the charging voltage at the battery. The efficiency of an ignition system depends on the voltage it receives. If battery or charging system voltage is low, the input to the primary side of the coil will also be low.

Moisture can cause a short to ground or reduce the amount of voltage available to the spark plugs. This can cause poor performance or a no-start condition. Carefully check the ignition system for signs of moisture.

Ground Circuits

Ground straps are often neglected, or worse, left disconnected after routine service. With the increased use of plastics in today's vehicles, ground straps may mistakenly be reconnected to a nonmetallic surface. The result of any of these problems is that the current that was to flow through the disconnected or improperly grounded strap is forced to find an alternate path to ground. Sometimes the current attempts to back up through another circuit. This may cause the circuit to operate erratically or fail altogether. The current may also be forced through other components, such as wheel bearings or shift and clutch cables that are not meant to handle current flow, causing them to wear prematurely or become seized in their housing.

Examples of bad ground-circuit-induced ignition failures include burned ignition modules resulting from missing or loose coil ground straps and intermittent ignition operation resulting from a poor ground at the control module. Poor ground can be identified by conducting voltage drop tests and by monitoring the circuit with a lab scope.

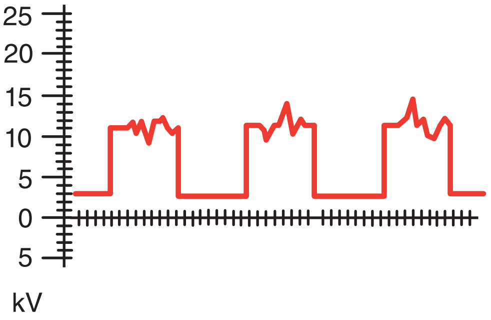


FIGURE 27–7 A voltage trace with ignition system noise due to a bad ground. Notice that the trace does not reach zero.

When conducting a voltage drop test, remember that the circuit must be turned on and have current flowing through it. If the circuit is tested without current flow, the circuit will show zero voltage drop, which would indicate that it is good regardless of the amount of resistance present.

The same is also true when checking a ground with the lab scope. Make sure the circuit is on. If the ground is good, the trace on the scope should be at 0 volts and be flat. If the ground is bad, some voltage will be indicated and the trace will not be flat.

Often a bad sensor ground will cause the same symptoms as a faulty sensor. Before condemning a sensor, check its ground with a lab scope. **(Figure 27–7)** shows the output of a good Hall-effect switch with a bad ground.

Electromagnetic Interference

Electromagnetic interference (EMI) can cause problems with the vehicle's computer. EMI is produced when electromagnetic radio waves of sufficient amplitude escape from a wire or conductor. Unfortunately, an automobile's spark plug wires, ignition coil, and AC generator coils all possess the ability to generate these radio waves. EMI can alter signals from sensors and to actuators. The result may be an intermittent driveability problem that may appear to be caused by many different systems.

To minimize the effects of EMI, check to make sure that sensor wires running to the computer are routed away from potential EMI sources. Rerouting a wire by no more than an inch or two may keep EMI from falsely triggering or interfering with computer operation.

SERVICE TIP

When checking the ignition system with a lab scope, gently tap and wiggle the components while observing the trace. This may identify the source of an intermittent problem.

Connecting a lab scope to voltage and ground wires can identify EMI problems. Common problems such as poor spark plug wire insulation will allow EMI.

Sensors

A voltage pulse from a crankshaft position sensor **(Figure 27–8)** activates the transistor in the control module. In most ignition systems, this sensor is either a magnetic pulse generator or Hall-effect sensor. These sensors are mounted either on the distributor shaft or the crankshaft.

Under unusual circumstances, the nonmagnetic reluctor can become magnetized and upset the pickup coil's voltage signal to the control module. Use a steel feeler gauge to check for signs of magnetic attraction and replace the reluctor if the test is positive. On some systems, the gap between the pickup and the reluctor must be checked and adjusted to manufacturer's specifications. To do this, use a properly sized nonmagnetic feeler gauge to check the air gap between the coil and reluctor. Adjust the gap if it is out of specification.

Hall-effect sensor problems are similar to those of magnetic pulse generators. This sensor produces a voltage when it is exposed to a magnetic field. The Hall-effect assembly is made up of a permanent magnet located a short distance away from the sensor. Attached to the distributor shaft or crankshaft pulley is a shutter wheel. When the shutter is between the sensor and the magnet, the magnetic field is interrupted and voltage immediately drops to zero. This drop in voltage is the signal to the ignition module. When the shutter leaves the gap between the magnet and the sensor, the sensor produces voltage again.

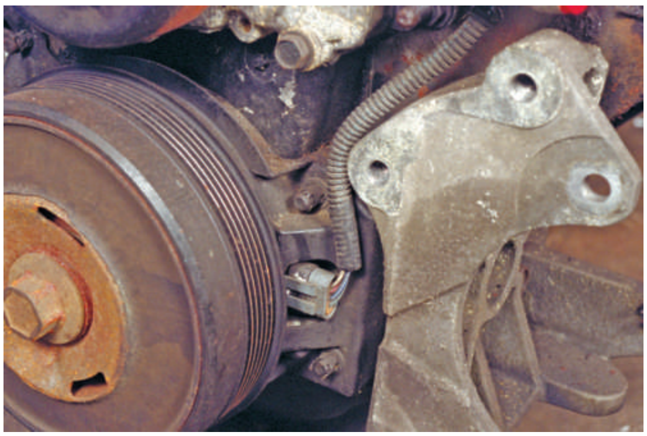


FIGURE 27–8 The wiring to the crankshaft sensor should be carefully inspected.

Control Modules

Electronic ignitions use transistors as switches. These transistors are contained inside the control module that can be mounted to or in the distributor, remotely mounted to a surface inside the engine compartment, mounted below the ignition coil pack **(Figure 27–9)**, or be integral to the PCM. Control modules should be tightly mounted to clean surfaces. A loose mount can cause intermittent misfires or no-start conditions. Often the module is grounded through its mounting. A loose mounting also can cause heat buildup that can damage and destroy the transistors and other electronic components inside the module. Some manufacturers recommend the use of special heat-conductive silicone grease between the control unit and its mounting. This helps conduct heat away from the module, reducing the chance of heat-related failure. During the visual inspection, check all electrical connections to the module. They must be clean and tight.

Secondary Circuit

Spark plug (ignition) and coil cables should be pushed tightly into the distributor cap and coil and onto spark plugs. Inspect all secondary cables for cracks and worn insulation, which cause high-voltage leaks. Inspect all of the boots on the ends of the secondary wires for cracks and hard, brittle conditions. Replace the wires and boots if they show evidence of these conditions. Inspect the terminals inside of the boots. Often corrosion and signs of arcing are found inside the boots. This is often caused by poor contact between the terminals which results in arcing between the terminals. Most manufacturers recommend spark plug wire replacement only in complete sets.

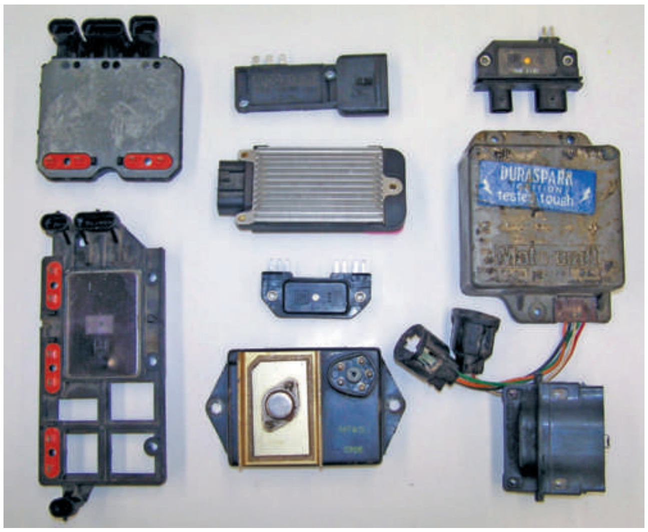


FIGURE 27–9 When the ignition module is not part of the PCM, it can have many different shapes and designs.

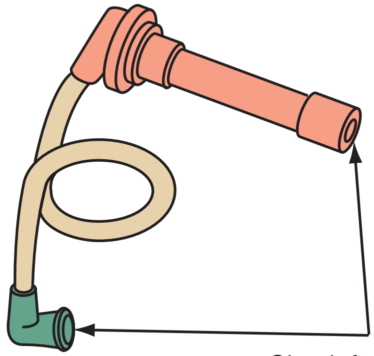


FIGURE 27–10 Carefully inspect the secondary cables.

The secondary coil cable should also be inspected **(Figure 27–10)**. When checking this cable, check the ignition coil. The coil should be inspected for cracks or any evidence of arcing or leakage in the coil tower.

Secondary cables must be connected according to the firing order. Refer to the manufacturer's service information to determine the correct firing order and cylinder numbering.

White or grayish powdery deposits on secondary cables at the point where they cross or near metal parts indicate that the cables' insulation is faulty. The deposits occur because the high voltage in the cable has burned the dust collected on the cable. Such faulty insulation may produce a spark that sometimes can be heard and seen in the dark. An occasional glow around the spark plug cables, known as a corona effect, is not harmful but indicates that the cable should be replaced.

Many OHC engines locate the spark plugs at the top of the combustion chamber. This requires the spark plug cables to pass through the valve cover to the plug. Inspect the spark plug end of the cables for oil. The seals surrounding the plug passage can leak, which allows oil to leak onto the plug wire boots. The oil then breaks down the boots and arcing can occur.

Spark plug cables from consecutively firing cylinders should cross rather than run parallel to one another. Spark plug cables running parallel to one another can induce firing voltages in one another and cause the spark plugs to fire at the wrong time.

On distributorless or electronic ignition (EI) systems, visually inspect the secondary wiring connections at the individual coil modules. Make sure all

of the spark plug wires are securely fastened to the coil and the spark plug. If a plug wire is loose, inspect the terminal for signs of burning. The coils should be inspected for cracks or any evidence of leakage in the coil tower. Check for evidence of terminal resistance. A loose or damaged wire or bad plug can lead to carbon tracking of the coil. If this condition exists, the coil must be replaced.

On COP systems, carefully check the tubes that fit around the terminal of the spark plugs **(Figure 27–11)**. If the tube is cracked, voltage can leak out, jump to the cylinder head, and cause a misfire **(Figure 27–12)**. Also, make sure the coil assembly fits snugly over the spark plug and is securely mounted.

Distributor Cap and Rotor

The distributor cap should be properly seated on its base. All clips or screws should be tightened securely.

The distributor cap and rotor should be removed for visual inspection **(Figure 27–13)**. Physical or electrical damage is easily recognizable. Electrical damage from high voltage can include corroded or burned metal terminals and carbon tracking inside distributor caps. Carbon tracking is the formation of a line of carbonized dust between distributor cap terminals or between a terminal and the distributor housing. Carbon tracking indicates that high-voltage electricity has found a low-resistance conductive path over or through the plastic. The result is a misfire or a cylinder that fires at the wrong time. Check the outer cap towers and metal terminals for defects. Cracked plastic requires replacement of the unit. Damaged or carbon-tracked distributor caps or rotors should be replaced.

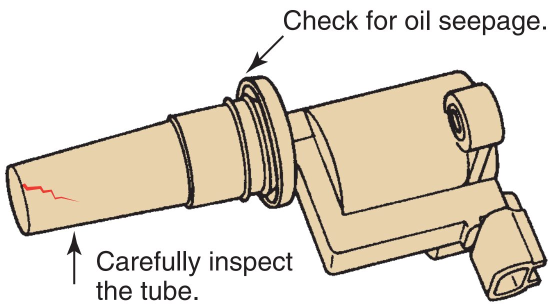


FIGURE 27–11 The plastic assembly for COP assembly should be carefully inspected.

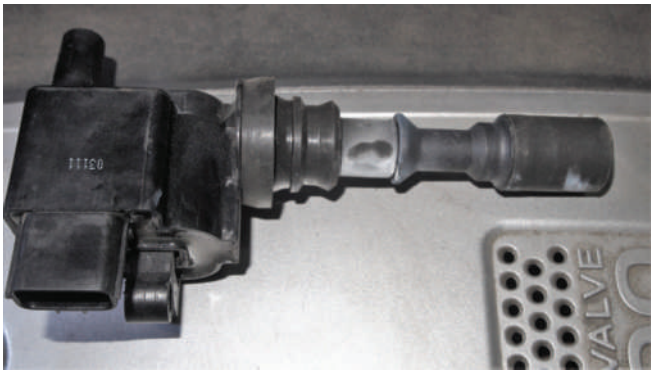


FIGURE 27–12 This COP assembly was leaking voltage and arcing to the engine.

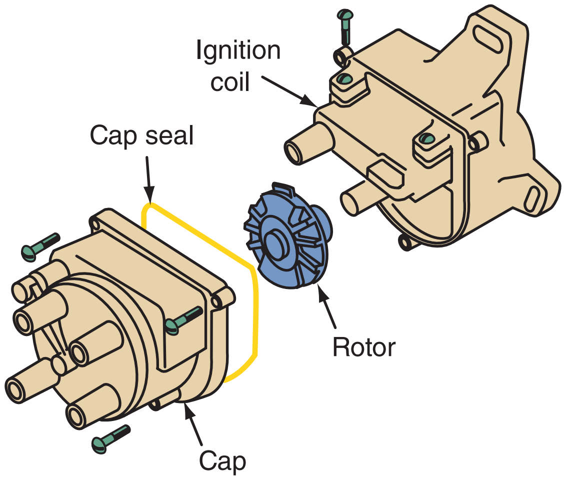


FIGURE 27–13 Inspect the distributor cap and rotor.

The rotor should be inspected carefully for discoloration and other damage. Inspect the top and bottom of the rotor carefully for grayish, whitish, or rainbow-hued spots. Such discoloration indicates that the rotor has lost its insulating qualities. High voltage is being conducted to ground through the plastic. This can cause a no-start condition as the spark jumps to ground inside the cap.

If the distributor cap or rotor has a mild buildup of dirt or corrosion, it should be cleaned. If it cannot be cleaned up, it should be replaced. Small round brushes are available to clean cap terminals. Wipe the cap and rotor with a clean shop towel, but avoid cleaning them in solvent or blowing them off with compressed air, which may contain moisture and may result in high-voltage leaks.

Check the distributor cap and housing vents. Make sure they are not blocked or clogged. If they are, the internal ignition module will overheat. It is good practice to check these vents whenever a module is replaced.

No-Start Diagnosis

When an engine will not start, the cause is most likely a common circuit or component. If the cause is in the ignition system, simple tests can identify if the problem is in the primary or secondary circuit. Begin by cranking the engine and listening to it as it turns over. If the engine sounds like it is spinning faster

SHOP TALK

Checking the operation of the fuel injection system when there is a no-start condition can also check the primary ignition. Connect a noid light to an injector harness **(Figure 27–14)**. If the injectors pulse while the engine is cranked, the triggering unit for the primary ignition circuit should be okay. The injection system uses the same signals to pulse the injectors.

than normal, the problem may be a broken or jumped timing belt or chain. If the cranking speed is normal and there is no attempt to start, the ignition may be at fault. If the engine acts as if it is trying to start, the problem may be in the fuel system.

If the problem is caused by an ignition fault, follow this procedure to determine the exact cause of the problem. Often manufacturers include a detailed troubleshooting tree in their service information to help identify the cause of the no-start condition.

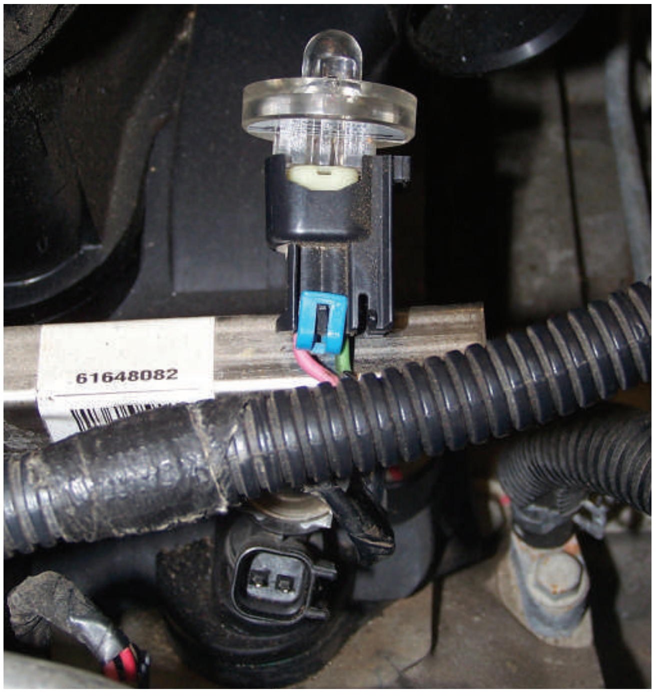


FIGURE 27–14 Use a noid light at the injectors when there is a no-start condition. If the injectors pulse while the engine is cranked, the triggering unit for the primary ignition circuit should be okay.

PROCEDURE

Basic No-Start Diagnosis

STEP 1 Connect a test spark plug to the spark plug wire and ground the spark plug case.

STEP 2 Crank the engine and observe the spark plug. If there is a bright, snapping, blue spark, the ignition is working properly.

STEP 3 If the test spark plug does not fire, check for coil output at the coil terminal.

STEP 4 If there is no spark, connect a testlight or DMM from the negative side of the coil to ground. Turn on the ignition switch. In most cases, the testlight should light. If the testlight is "off," there is an open circuit in the coil primary winding or in the circuit from the ignition switch to the coil battery terminal.

STEP 5 With the testlight or DMM still connected, crank the engine. If the light flashes, the primary circuit is okay and the problem is a bad coil.

STEP 6 If the light does not flash, check the voltage from the ignition switch to the positive side of the coil. If there is no voltage, the problem is in that circuit or the switch. If there is voltage at the positive side of the coil, the problem is the pickup unit or the control module.

STEP 7 Keep in mind that on some vehicles, the PCM will not send power to the coil until it receives a CKP signal. A magnetic pulse generator can be checked with an ohmmeter, DMM, or scope. A Hall-effect sensor should be checked with a DMM or scope. Compare your findings to specifications. A quick check for CKP operation is to connect a scan tool, crank the engine and observe the engine data. If engine rpm PID shows cranking speed, the CKP is working.

STEP 8 If the pickup unit is good, suspect the ignition module. Make sure all wiring to and from the module are good.

SHOP TALK

When using a test spark plug, make sure you use the correct one for the system. There are two different types: low-voltage and high-voltage test plugs. Low-voltage plugs will fire if around 25 kV is applied to them. High-voltage plugs need 35 kV. If you use a high-voltage plug on a low-voltage system, it may not spark, leading you to believe that there is an ignition problem when there may not be. To determine which test plug to use, look at the specifications of the ignition system.

No-Start Diagnosis of EI Systems

When an engine with an EI system has a no-start problem, begin diagnosis by connecting a scan tool. Check for DTCs and make sure the PCM shows rpm when cranking the engine. Without an rpm reference, the PCM cannot trigger the ignition coils or fuel injectors.

There are many ignition-related DTCs that may be set by the PCM when there is a no-start condition. Always retrieve the codes and follow their pinpoint tests when diagnosing an EI system. A stored P0335 indicates a problem with the CKP circuit, which can cause a no-start condition. Follow the manufacturer's diagnostic information to determine the cause of the fault. If the PCM set no codes, follow this procedure to identify the cause of a no-start problem. Keep in mind that it is very unlikely that a no-start concern is caused by a noncommon circuit or component, such as an ignition coil.

Courtesy of Snap-on Tools (www.snapon.com).

FIGURE 27–15 A test spark plug for high-voltage ignition systems.

PROCEDURE

No-Start Diagnosis for EI Systems

STEP 1 Connect a test spark plug **(Figure 27–15)** to the spark plug wire and ground the spark plug case.

STEP 2 Crank the engine and observe the spark plug. If there is a bright, snapping, blue spark, the ignition is working properly.

STEP 3 If the spark is weak, check the power at each coil. With the ignition switch on, the voltmeter should read battery voltage. If the voltage is less than that, check the system's wiring diagram to determine what is included in the coil's power feed circuit. If there is no spark, check the CKP sensor input to the PCM.

STEP 4 If the CKP signal is good, check the power and ground circuits for the PCM.

STEP 5 If battery voltage is present, check the voltage drop across each of the components and wires to identify the location of an open or high resistance.

STEP 6 If none is found, check the crankshaft and camshaft position sensors. Both of these sensor circuits can be checked with a voltmeter, ohmmeter, or DSO. If the sensors are receiving the correct amount of voltage and have good low-resistance ground circuits, their output should be a digital or a pulsing voltage signal while the engine is cranking. Compare their resistance readings to specifications. If any readings are abnormal, the circuit needs to be repaired or the sensor needs to be replaced.

SHOP TALK

When using a DMM to check a digital crankshaft or camshaft sensor, crank the engine for a very short time and observe the meter. The reading should cycle from around 0 volts to 9–12 volts. Because digital meters do not react instantly, it is difficult to see the changes if the engine is cranked continually.

If your diagnosis leads to the ignition system, perform a visual inspection of the ignition system. Check for good primary connections. Inspect the coils and all related wiring. Check the CKP and CMP sensors and their wiring for damage. If these sensors fail or if there is resistance in the connections, the engine may not start.

Diagnosing with an Engine Analyzer

It is impossible to accurately troubleshoot any ignition system without performing various electrical tests. An engine analyzer houses most of the necessary test equipment to do a complete engine performance analysis, but is not used as often as it once was. On older systems, using an engine analyzer is a good way to determine if the driveability problem is caused by the ignition system.

Cylinder Performance Test

During the cylinder performance test (also called the power balance test), the analyzer momentarily stops the ignition system from firing one cylinder at a time. To perform this test, the analyzer is connected to the primary ignition at the coil's negative terminal. During this brief time, the rpm drop is recorded. When a cylinder is not contributing to engine power due to low compression or some other problem, there will be very little rpm drop when that cylinder stops firing. If a cylinder was misfiring prior to the test, the cylinder will have high HC emissions. Therefore, when this cylinder stops firing during the test, there will not be much of a change in HC emissions. A cylinder with low compression or a problem that causes incomplete combustion will not have much rpm drop or HC change during the cylinder performance test **(Figure 27–16)**.

FIGURE 27–16 Cylinder performance test results showing one bad cylinder.

Ignition Performance Tests

Ignition performance tests on most engine analyzers include primary circuit tests, secondary kilovolt (kV) tests, acceleration test, scope patterns, and cylinder miss recall. Some secondary kV tests include a snap kV test in which the analyzer directs the technician to accelerate the engine rapidly. When this action is taken, the firing kV should increase evenly on each cylinder. Some analyzers display the burn time for each cylinder with the secondary kV tests. The burn time is measured in milliseconds (ms).

The secondary kV display from an EI system includes average kV for each cylinder on the compression stroke and average kV for the matching cylinder that fires at the same time on the exhaust stroke. The burn time is also included on the secondary kV display from an EI system **(Figure 27–17)**.

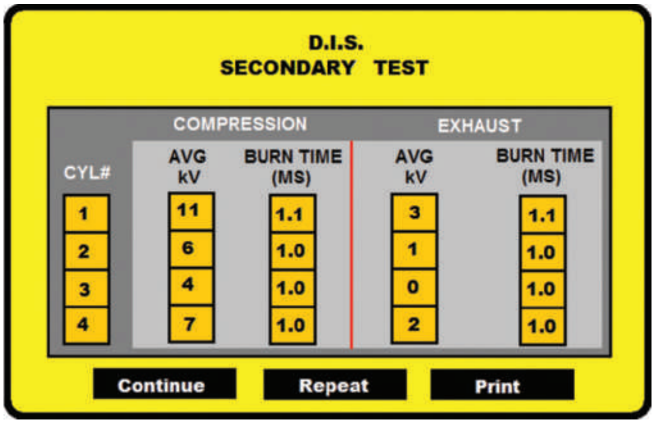


FIGURE 27–17 Secondary kV display on an EI system.

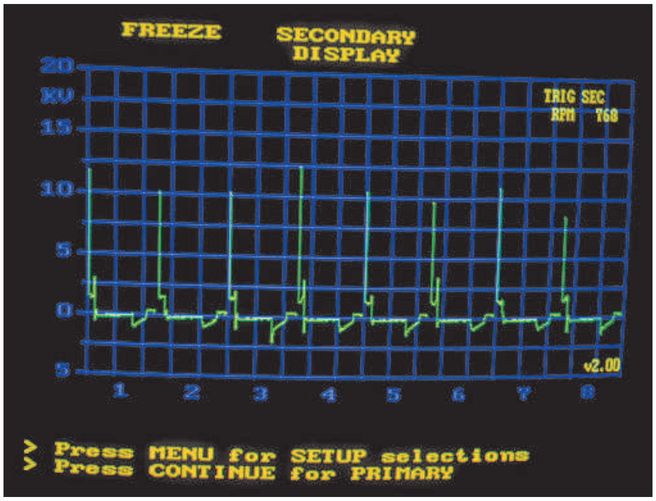


FIGURE 27-18 The secondary pattern for an eight-cylinder engine.

Scope Patterns

An oscilloscope or "scope" converts the electrical activity of the ignition system into a visual image showing voltage changes over a given period. This information is displayed on a screen in the form of a continuous voltage line called a pattern or trace **(Figure 27–18)**. By studying the pattern, a technician can see what the ignition system is doing.

Always follow the instructions for the analyzer when connecting the test leads and operating the scope. Scopes typically have at least four leads for distributor ignitions: a primary pickup that connects to the negative terminal of the ignition coil, a ground lead that connects to a good ground, a secondary pickup that clamps around the coil's high-tension wire, and a trigger pickup that clamps around the spark plug wire of the number 1 cylinder.

Connecting the scope to a DIS system requires adapters **(Figure 27–19)** or additional test leads. The leads are connected to the individual spark plug wires **(Figure 27–20)**. On some scopes, the companion cylinders of a waste spark system are viewed at the same time while others will display all of the cylinders for comparison. Adapters must also be used to monitor the secondary circuit on COP systems **(Figure 27–21)**. These adapters also allow for cylinder-to-cylinder comparisons.

Scales A typical scope screen has two vertical voltage scales: one on the left and one on the right. The scale on the left is divided into increments of 1 kV (1,000 volts) and ranges from 0 to 25 kV. This scale is useful for testing secondary voltage. The scale on the right side is divided into increments of 2 kV and has a range of 0 to 50 kV. This scale is primarily used for testing secondary voltage.

The screen also has a horizontal time scale located at the bottom. The time may be expressed as percent of dwell or in milliseconds. The percent of

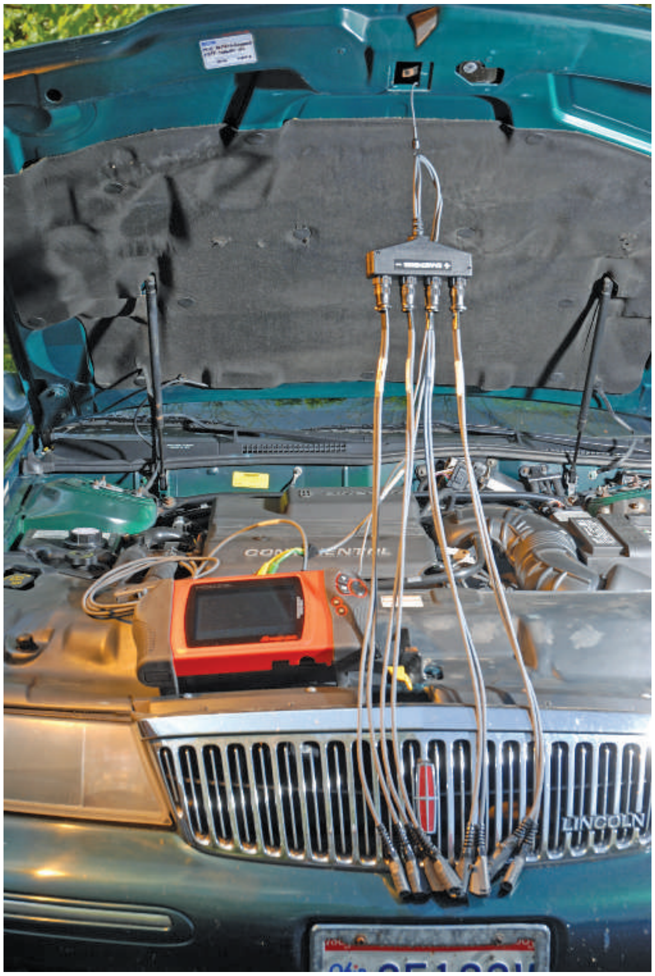


FIGURE 27-19 Leads for connecting to an EI system.

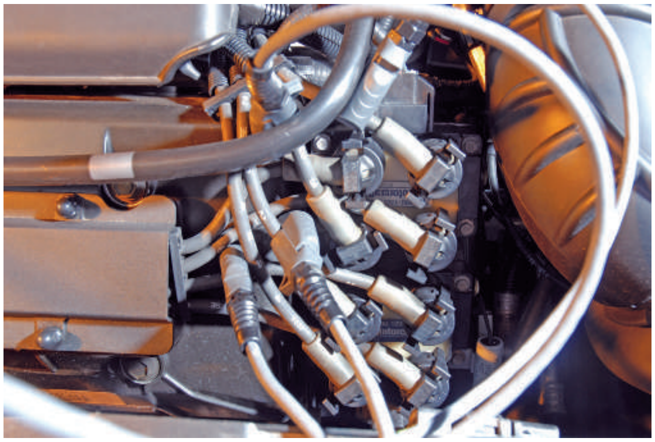


FIGURE 27-20 The tester's leads are connected to the individual spark plug wires.

FIGURE 27–21 A COP test adapter.

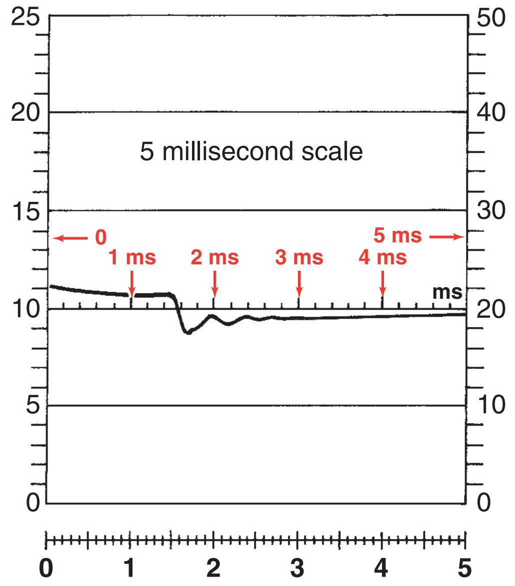


FIGURE 27–22 A 5-millisecond pattern showing spark duration.

dwell scale is divided into increments of 2 percentage points and ranges from 0 percent to 100 percent. This represents one complete ignition cycle. The millisecond scale is typically broken down into units of 0 to 5 ms or 0 to 25 ms. The 5 ms scale is often used to measure the duration of the spark **(Figure 27–22)**. The complete firing pattern is normally displayed in 25 ms. A scope displays changes in voltage over time from left to right.

Understanding Single Cylinder Patterns A typical ignition waveform can represent the secondary or primary circuit. The primary pattern **(Figure 27–23)** is used when secondary circuit connections are not possible, to observe a particular cylinder, or when there are timing problems. The main sections of a secondary waveform include the following **(Figure 27–24)**:

- *Firing Line Section.* The height of the firing line represents the voltage needed to overcome the resistance in the secondary circuit and to initiate a spark across the gap of the spark plug. Typically, around 10,000 volts are required. .
- *Spark Line.* Once the resistance in the secondary is overcome, the spark jumps the plug gap, establishing current flow. The time the spark actually lasts is represented by the **spark line**. The spark line continues until the voltage from the coil drops below the level needed to keep current flowing across the gap.
- *Intermediate Section.* After the spark line is the intermediate section or coil-condenser zone. It shows the remaining coil voltage as it dissipates or drops to zero. Remember, once the spark has ended, there is still voltage in the ignition coil. This voltage must leave the coil before the coil

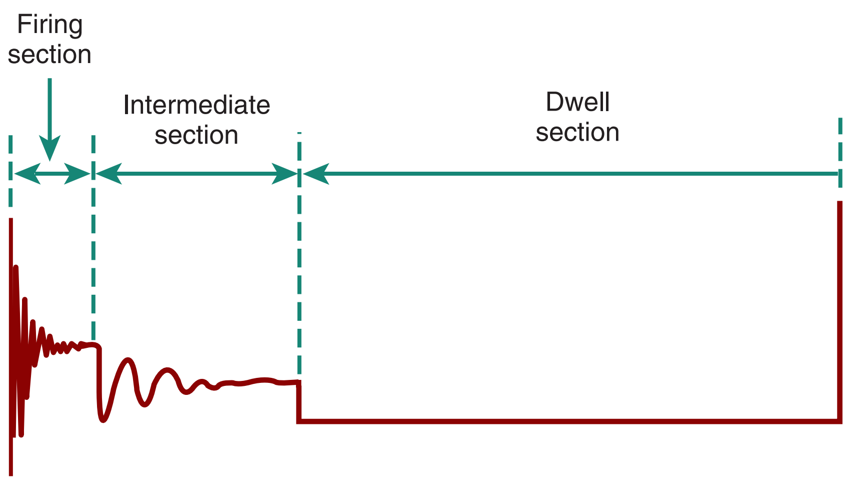


FIGURE 27–23 A typical primary pattern.

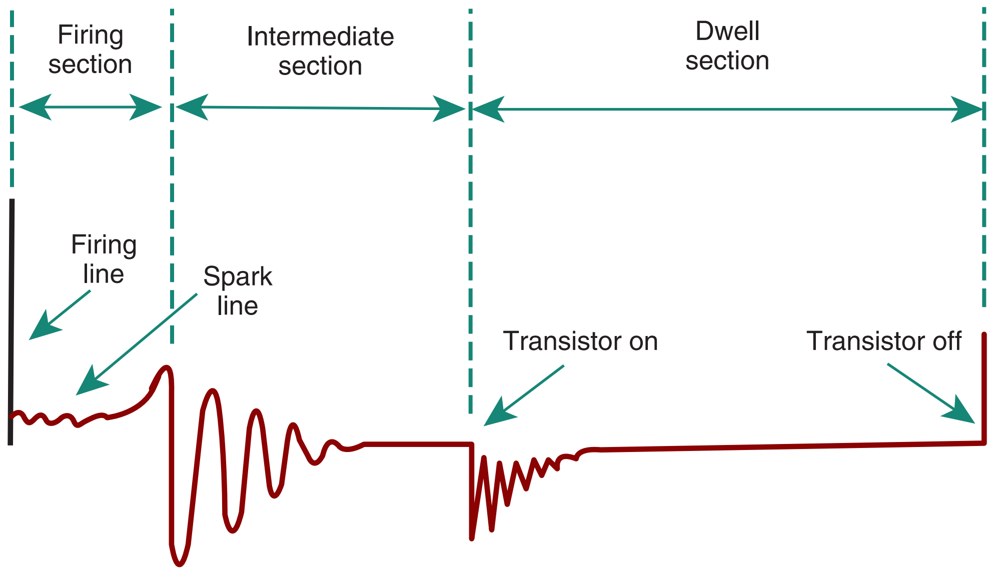


FIGURE 27–24 A typical secondary pattern.

can be prepared for another cylinder firing. The voltage moves back and forth within the primary circuit until it drops to zero. Notice that the voltage traces in this section steadily drop until the coil's voltage is zero.

- *Dwell Section.* The next section of the waveform appears as a slight downward turn followed by several small oscillations. The downward curve occurs just as current begins to flow through the coil's primary winding. The oscillations that follow indicate the beginning of the magnetic field buildup in the coil. This curve marks the beginning of a period known as the dwell. The end of the dwell zone occurs when the primary current is turned off by the switching device. The trace turns sharply upward at the end of the dwell. Turning off primary current flow collapses the magnetic field around the coil and generates another high-voltage surge for the next cylinder in the firing order. The length of the dwell section represents the amount of time that current is flowing through the primary.

Older DI systems used a fixed dwell period. The number of dwell degrees remained the same during all engine speeds. So if the engine has 30 degrees of dwell at idle, it should have 30 degrees of dwell at 2,000 rpm. A fixed dwell of 30 degrees at 2,000 rpm gives the ignition coil only one-fourth the saturation time, in milliseconds, that it has at 500 rpm.

Most control modules provide a variable dwell; dwell time changes with engine speed. At idle and low rpm speeds, a short dwell provides enough time for complete ignition coil saturation **(Figure 27–25A)**. As engine speed increases, the control module lengthens the dwell degree **(Figure 27–25B)**. This, of course, increases the available time for coil saturation.

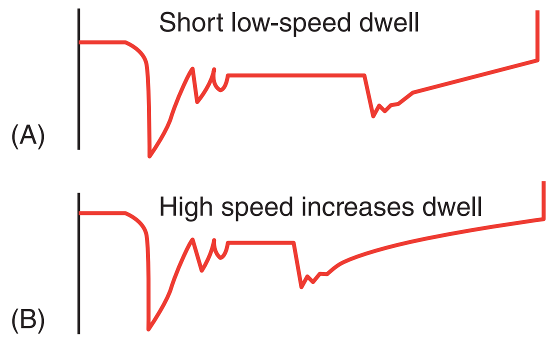


FIGURE 27–25 An example of a variable dwell ignition system. Low-speed dwell (A) and high-speed dwell (B).

The point at which the control module cuts back from high to low current appears as a small blip or oscillation during the dwell section of the pattern **(Figure 27–26)**. At high engine speeds, this blip may be missing. In an attempt to keep the coil saturated, the module may not stop sending high current to the coil. Further testing of the coil is needed to pinpoint the cause of the missing blip.

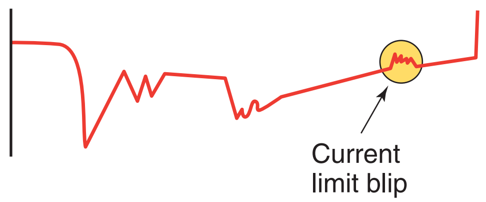


FIGURE 27–26 A pattern showing an ignition system limiting current during dwell.

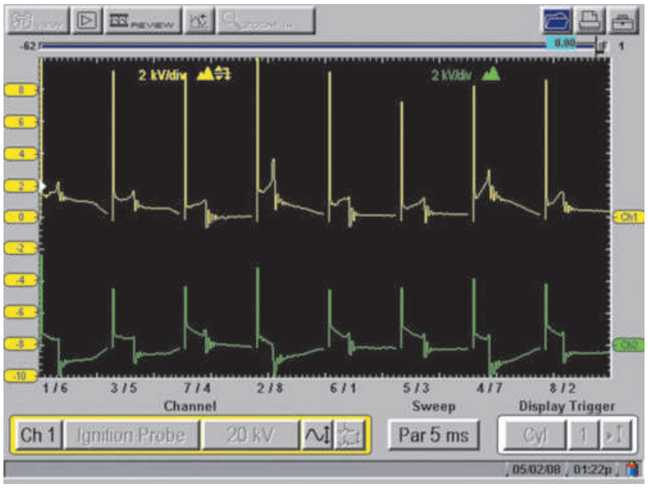


FIGURE 27–27 Typical parade (display) patterns for the primary and secondary circuits.

Pattern Display Modes The scope can display waveforms in several ways. When the display pattern is selected, the scope displays all the cylinders in a row from left to right as shown in **Figure 27–27**. The cylinders are arranged according to the engine's firing order. The pattern begins with the spark line of cylinder #1 and ends with the firing line for cylinder #1. This display pattern is commonly used to compare the voltage peaks for each cylinder.

Another display mode is the **raster pattern (Figure 27–28)**. A raster pattern stacks the waveforms of the cylinders one above the other. Cylinder #1 is displayed at the bottom of the screen and the rest of the cylinders are arranged above it according to the engine's firing order. In a raster pattern, the waveform for each cylinder begins with the spark line and ends with the firing line.

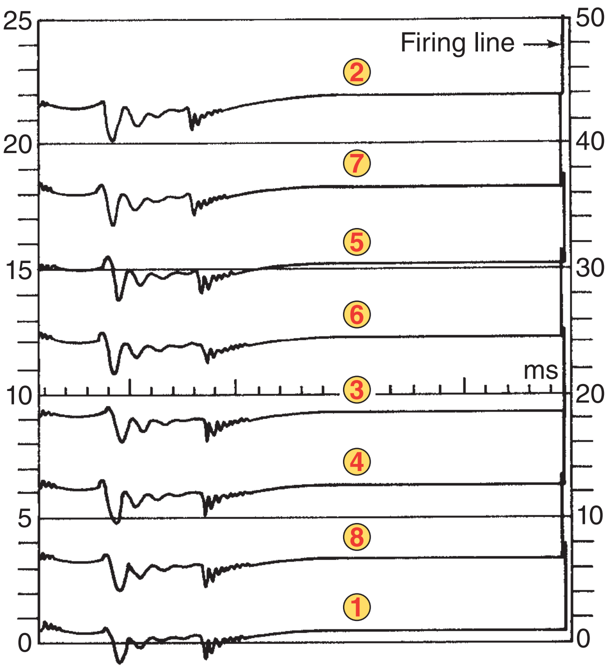


FIGURE 27–28 A secondary raster pattern.

SHOP TALK

Often a DSO is only capable of displaying one cylinder at a time. To look at the rest of the signals, the input pickup must be moved to the other cylinders one at a time. This means it is not possible to view a parade, raster, superimposed pattern.

A **superimposed pattern** displays all of the patterns one on top of the other. Like the raster pattern, the superimposed voltage patterns are displayed the full width of the screen, beginning with the spark line and ending with the firing line. A superimposed pattern is used to identify variations of one cylinder's pattern from the others.

Spark Plug Firing Voltage In a secondary pattern, the height of the firing line is affected by anything that adds resistance to the secondary circuit. This includes the condition of the spark plugs or the secondary circuit, engine temperature, fuel mixture, and compression pressures. The normal height of a firing line, with the engine at idle, should be between 7 and 13 kV with no more than a 3 kV variation between cylinders. If one or more firing lines are too low or too high, the cause is something that is common to only those cylinders. If the firing lines are all too high or too low, the problem is something that is common to all cylinders. **Table 27–1** covers most of the things that could cause abnormal firing lines.

High resistance in the secondary circuit also produces a spark line that is higher in voltage and has a steep slope with shorter firing durations. A good spark line should be relatively flat and measure 2 to 4 kV in height.

The voltage required to fire a spark plug increases when the engine is under load. The voltage increase is moderate and uniform if the spark plugs are in good condition and properly gapped. To test the spark plugs under load, note the height of the firing lines at idle speed. Then quickly open and release the throttle (snap accelerate) and note the rise in the firing lines while checking the voltages for uniformity. A normal rise should be between 3 and 4 kV. If the rise is not equal on all cylinders or if the rise is too low or too high, the spark plugs are probably faulty. Also, watch the decrease in their height as the throttle is closed.

TABLE 27-1 FIRING LINE DIAGNOSIS

Condition	Probable Cause	Remedy
Firing voltage lines the same, but abnormally high	1. Retarded ignition timing 2. Fuel mixture too lean 3. High resistance in coil wire 4. Corrosion in coil tower terminal 5. Corrosion in distributor coil terminal	1. Reset ignition timing 2. Check fuel pressure, fuel trims, MAF sensor, check for vacuum leak 3. Replace coil wire 4. Clean or replace coil 5. Clean or replace distributor cap
Firing voltage lines the same, but abnormally low	1. Fuel mixture too rich 2. Breaks in coil wire causing arcing 3. Cracked coil tower causing arcing 4. Low coil output 5. Low engine compression	1. Check fuel pressure, fuel trims, MAF sensor, ECT sensor, check for plugged air filter 2. Replace coil wire 3. Replace coil 4. Replace coil 5. Determine cause and repair
One or more, but not all, firing voltage lines higher than the others	1. Idle mixture not balanced 2. EGR valve stuck open 3. High resistance in spark plug wire 4. Cracked or broken spark plug insulator 5. Intake vacuum leak 6. Defective spark plugs 7. Corroded spark plug terminals	1. Readjust idle mixture 2. Inspect or replace EGR valve 3. Replace spark plug wires 4. Replace spark plugs 5. Repair leak 6. Replace spark plugs 7. Replace spark plugs
One or more, but not all, firing voltage lines lower	1. Curb idle mixture not balanced 2. Breaks in plug wires causing arcing 3. Cracked coil tower causing arcing 4. Low compression 5. Defective or fouled spark plugs	1. Readjust idle mixture 2. Replace spark plug wires 3. Replace coil 4. Determine cause and repair 5. Replace spark plugs
Cylinders not firing	1. Cracked distributor cap terminals 2. Shorted spark plug wire 3. Mechanical problem in engine 4. Defective spark plugs 5. Spark plugs fouled	1. Replace distributor cap 2. Determine cause of short and replace wire 3. Determine problem and correct 4. Replace spark plugs 5. Replace spark plugs

If the cylinders do not uniformly drop, there is high resistance in the circuits that were different.

Spark Duration The amount of time that the spark plug is actually firing is called spark duration. **Spark duration** is represented by the length of the spark line and is measured in milliseconds. Most engines have a spark duration of approximately 1.5 milliseconds. Short spark durations cannot provide complete combustion and can cause increased emissions levels and a loss of power. If the spark duration is too long, the spark plug electrodes might wear prematurely. When the ignition pattern has a long spark line, it normally follows a short firing line, which may indicate a fouled spark plug, low compression, or a spark plug with a narrow gap.

The spark line should be at a right angle to the firing line. It should also be relatively flat but show some small ripples. These ripples result from the turbulence inside the combustion chamber. The slope of the spark line gives a picture of air-fuel ratio.

SHOP TALK

The spark line may appear as if the secondary path is complete, but the spark plug may not be firing. This can be caused by problems that allow the voltage to jump before it reaches the spark plug. If the spark line is totally flat, longer than 2 ms, and less than 500 volts, there is a good chance that the plug is not firing.

Coil Condition The coil/condenser section shows the voltage reserve in the coil. The reserve can be determined by looking at the height of the oscillations. The heights should uniformly decrease to a zero value. If the waveform does not have normal oscillations in its intermediate section, check for a possible short in the coil by testing the resistance of the primary and secondary windings.

The available voltage output from a coil can also be checked with the coil output test. Following are steps to safely perform a coil output test:

1. Install a test plug in the coil wire or a plug wire if there is no coil wire.
2. Set the scope on display with a voltage range of 50 kV.
3. Crank the engine and note the height of the firing line. The firing line should exceed 35 kV. Lower-than-specified voltages may indicate lower-than-normal available voltage in the primary circuit. The control module may have developed high internal resistance. The coil or coil cable may also be faulty.

Primary Circuit Checks The primary ignition pattern shows the action of the primary circuit. To be able to spot abnormal sections of a primary waveform, you must know what causes each change of voltage and time in a normal primary waveform. Although the true cycle of the primary circuit begins and ends when the switching transistor is turned on, the displayed pattern begins right after the transistor is turned off. At this moment in time, the magnetic field around the windings collapses and a spark plug is fired.

Looking at the primary pattern shown in **Figure 27–29**, the trace at the left represents the collapsing of the primary winding after the primary current flow is interrupted. The height of these oscillations depends on the current that was flowing through the winding right before it was stopped. High primary circuit resistance will reduce the maximum amount of current that can flow through the winding. Reduced current flow through the winding will reduce the amount of voltage that can be induced when the field collapses.

During the collapsing of the primary winding, the spark plug is firing. The primary circuit's trace shows

SHOP TALK

Always carefully check the primary circuit; a 1-volt loss in the primary circuit can reduce secondary output by up to 10,000 volts.

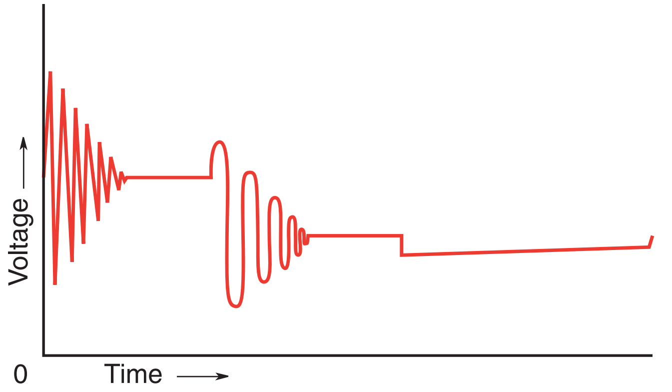
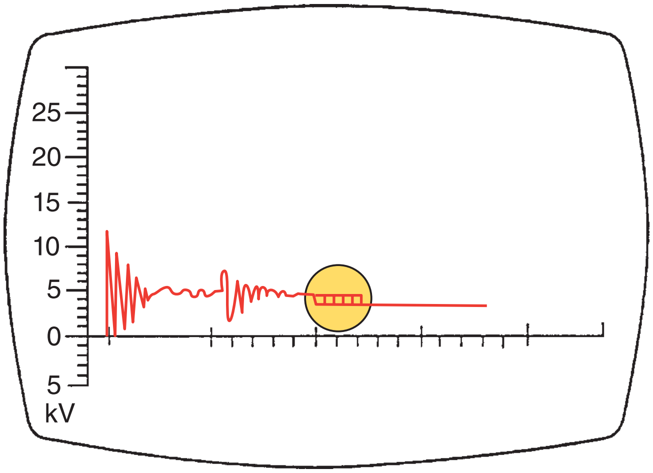


FIGURE 27–29 A typical primary pattern.

sharp oscillations of decreasing voltages. The overall shape of this group of oscillations should be conical and should last until the spark plug stops firing.

After the firing of the plug, some electrical energy remains in the coil. This energy must be released prior to the next dwell cycle. The next set of oscillations shows the dissipation of this voltage. These oscillations should be smooth and become gradually smaller until the 0-volt line is reached. At that point there is no voltage left and the coil is ready for the next dwell cycle.

Immediately following this is the transistor "on" signal. This is when current begins to flow through the primary circuit. It is the beginning of dwell. When the transistor turns on, there should be a clean and sharp turn in the trace. A clean change indicates that the circuit was instantly turned on. If there is any sloping or noise at this part of the signal, something is preventing the circuit from being instantly turned on. When looking at a superimposed primary pattern, any variation between cylinders will show up as a blurred or noisy transistor "on" signal **(Figure 27–30)**.



Courtesy of SPX Service Solutions.

FIGURE 27–30 A superimposed primary pattern showing cylinders with different transistor "on" times.

If there are erratic voltage spikes at the transistor "on" signal, the ignition module may be faulty, the distributor shaft bushings may be worn, or the armature is not securely fit to the distributor shaft. The problem is preventing dwell from beginning smoothly and causing the engine to have a rough idle, intermittent miss, and/or higher-than-normal HC emission levels.

During dwell, the trace should be relatively flat. However, many ignition systems have features that change current flow during dwell. By reducing the amount of current, the amount of voltage induced in the secondary is also reduced.

Diagnosing with a DSO or GMM

Commonly used diagnostic tools include scan tools, lab scopes, DMMs, and GMMs. These may contain libraries of information that serve as references for diagnostics, such as the basic operation of a component or system, test procedures, identification of pins in a connector, location of the component or connector, specifications, and diagnostic tips, some have a database of known-good waveforms.

Each model of these testers has unique operating procedures and those procedures must be followed to achieve accurate results. What follows are some general guidelines for using these tools to diagnose an ignition system.

After vehicle identification information is entered, the test mode is selected. This mode allows you to test individual components. The tool will display how to properly connect the tool to the component. There will also be the option of displaying the test results in a variety of ways: digital, digital graphs or waveforms, analog graphs or waveforms, or a combination of these.

Using the DSO or GMM

The graphing meter function is much like using a scope, except that it also displays digital MIN/MAX readings with the trace. Many have a four-channel capability, which means you can look at the signals from four different sensors and/or outputs at the same time. This mode also allows a technician to observe any glitches or noise that may affect operation.

To aid in diagnosing intermittent problems, screens can be frozen, saved, and printed for review later. The tool can typically be connected to the vehicle, and then the vehicle is taken for a road test. Intermittent problems can be observed and the data around those problems can be stored in the meter's memory for review after the road test.

In most cases, additional leads must be attached to the lab scope or GMM to read additional channels. These are color-coded and the color of the display matches the color of the lead. That lead is attached to the point where the desired signal will be monitored. A ground lead must also be attached. The color-coding throughout allows for easy identification of what is being monitored **(Figure 27–31)**. The lab scope may allow a look at DC volts, low amps, ignition secondary voltages, vacuum, and pressure.

The readings or waveforms for the component or system monitored can be looked at individually or at the same time. In most cases, Channel 1 will always be displayed. If the tool is capable of two or more channels, these can be selected individually. However, on many GMMs, Channels 1 and 2 are always displayed and the additional channels must be selected.

Certain settings and controls are critical to recording a worthwhile waveform, including the following:

- *Scale*—Used to measure the events of one or more waveforms.
- *Filter*—Minimizes and cleans up waveforms from unwanted noise in order to look at voltages.
- *Threshold*—Changes the reference point for the waveform and is only used when measuring frequency, duty cycle, dwell, and pulse width. This may be manually or automatically set.
- *Peak Detect*—Used to capture spikes and glitches in signals. When it is off, the tool collects just enough data to form a waveform. When it is on, the tool collects more data than is needed. This is why it allows you to capture a glitch or noise.

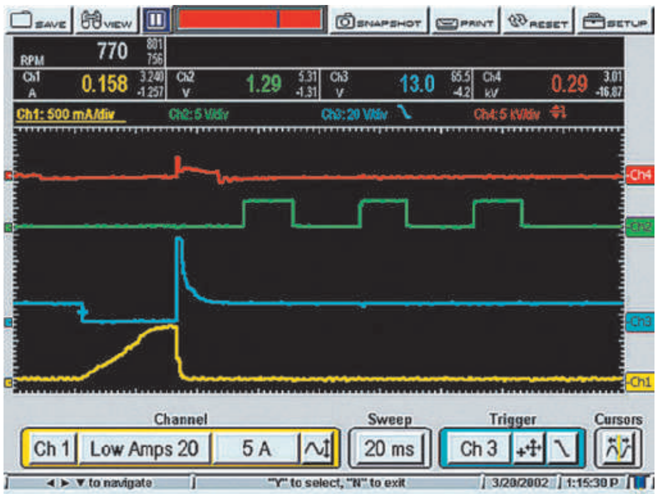


FIGURE 27–31 Waveforms on four different channels: CH1 in yellow, CH2 in blue, CH3 in green, and CH4 in red.

- *Time Scale (Sweep)*—Sets the amount of time data will be displayed; more data can be observed with a faster sweep. Also, the usefulness of peak detect is increased with a longer sweep. However, long sweeps have a slow sample rate and when observing ignition systems, the firing line may not appear.
- *Voltage Scale (Sensitivity)*—Adjusts how sensitive the scope will be to voltage changes. The lower the setting, the more sensitive the ignition scope will be to detecting cylinder firing.
- *Trigger*—Sets the criteria that should be recognized to start the display of data.
- *Trigger Slope*—Sets the direction that the waveform must be moving toward to start the waveform.
- *Trigger Level*—Used to place the trigger point along the horizontal or vertical axis of the display.

Testing the Ignition System

Prior to testing an ignition system, the diagnostic tool must be programed to match the type of ignition system found on the vehicle; this includes ignition type, number of cylinders, firing order, polarity of the spark plugs, and the source of the engine speed reference. Each type of ignition system also requires different adapters and different setup procedures.

All ignition scopes must have a way to monitor the secondary and to monitor the switching of the primary circuit. The primary circuit is monitored with a reference or engine speed pickup. This pickup is placed around the number 1 spark plug wire on all systems. On DIS systems, the tool must be programed with the number of cylinders, cylinder firing order, and plug polarities. On coil-per-cylinder systems, the tool must know the number of cylinders and the firing order.

SHOP TALK

It is important that the correct adapters and leads be used when using most testers. These are designed for specific purposes and if the wrong ones are used, inaccurate measurements will result. For example, there are many different coil-over-plug (COP) adapters because there are many different designs of COP systems. Also, adapters allow for connection to a waste spark system that allows a view of the total system.

It may take a few seconds for the tool to synchronize itself with the ignition system. Also, on some tools connected to waste spark systems, the firing of the plugs that are on the compression stroke will only appear on Channel 1 and those that occur on the exhaust stroke will appear on Channel 2.

All events of the ignition system will appear in the waveform, as they were in the waveform shown on an ignition scope. This means the interpretation of the patterns is the same regardless of what is displaying it.

The primary difference between an ignition scope and a DSO or GMM is that the latter can display the MIN/MAX values for firing kV, spark kV, and spark duration for each cylinder. On an ignition scope, those values must be visually observed.

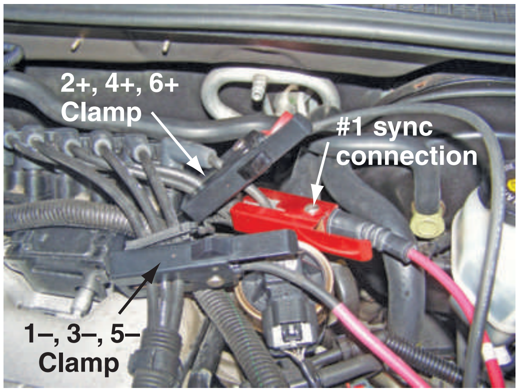
Both the power and waste spark of an EI system can be observed and compared for each coil. **Photo Sequence 25** shows the procedure for connecting a scope to a DIS and how to interpret the results. Keep in mind that if one plug in a DIS system is fouled, it will affect the other plug in the circuit. Observing the activity of both will identify the problem plug.

Ignition Timing

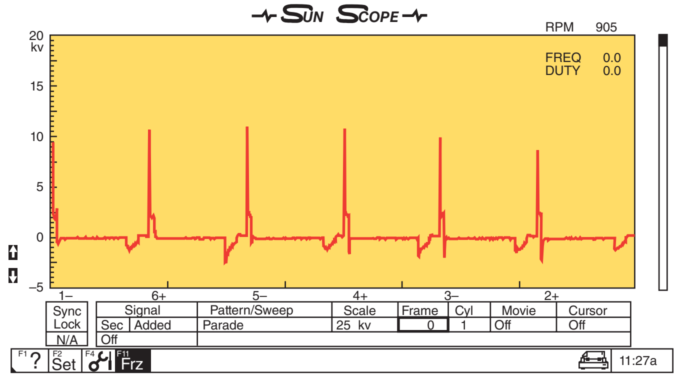
The primary circuit controls the secondary circuit. Therefore, it controls ignition timing. Most primary circuit problems in a computer-controlled ignition system result in starting problems or poor performance due to incorrect timing.

If engine performance is poor, the cause of the problem can be many things. There can be a problem with the engine such as poor compression, incorrect valve timing, overheating, and so on. The air-fuel mixture or the ignition timing is incorrect. When the ignition timing is not correct, many tests will point to the problem. Incorrect ignition timing will cause incomplete combustion at one or all engine speeds. Incomplete combustion will cause excessive O_2 in the exhaust. This will cause the PCM to try to correct the apparent lean mixture **(Figure 27–32)**. Incorrect timing is not a lean condition, but the PCM cannot tell that the timing is wrong. It only knows there is too much O_2 in the exhaust. Under this condition the waveform from the O_2 sensor will be lean biased.

Using a Scope to Test a Distributorless Ignition System

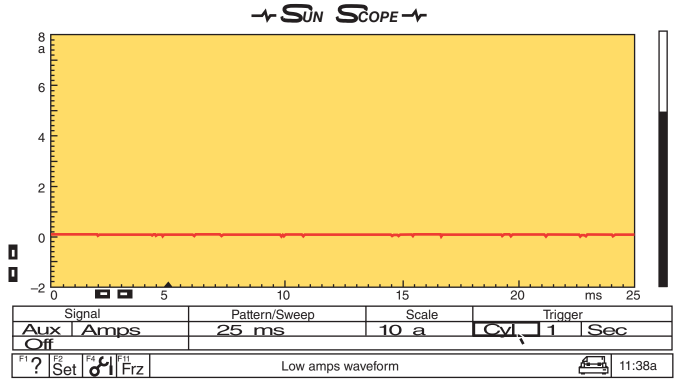


P25-1 To observe the activity of an EI system on a scope, special adapters are required.



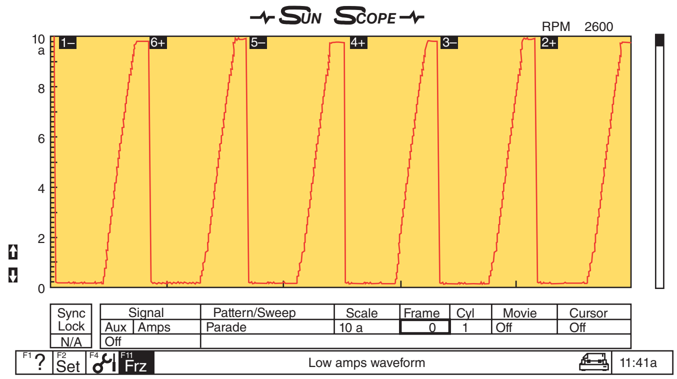
P25-2 A secondary pattern for the system. Note the waveform for three of the cylinders (6+, 4+, and 2+) that fire positively and the remaining three (1–, 3–, and 5–) that fire negatively.

P25-3 To look at the primary circuit, connect a low-amp probe to the scope. Make sure it is compatible with the scope.



P25-4 The baseline on the scope for amperage must be set to zero before the probe is connected to the system.

P25-5 Install the probe around the ignition feed at the ignition module.



P25-6 Once the amp probe is synchronized to the firing order, primary patterns for all cylinders will appear. The slope on the front edge of the waveform shows the time it took for coil saturation. The flat tops of the waveform result from the module limiting the current to the coil.

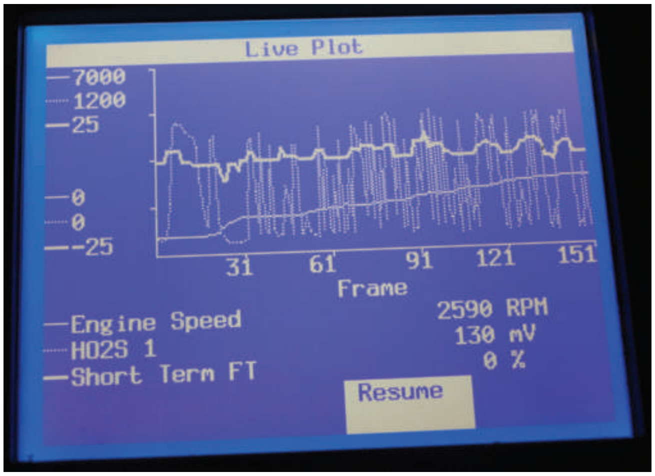


FIGURE 27–32 This screen capture shows how fuel trim responds to a lean O_2 reading.

SHOP TALK

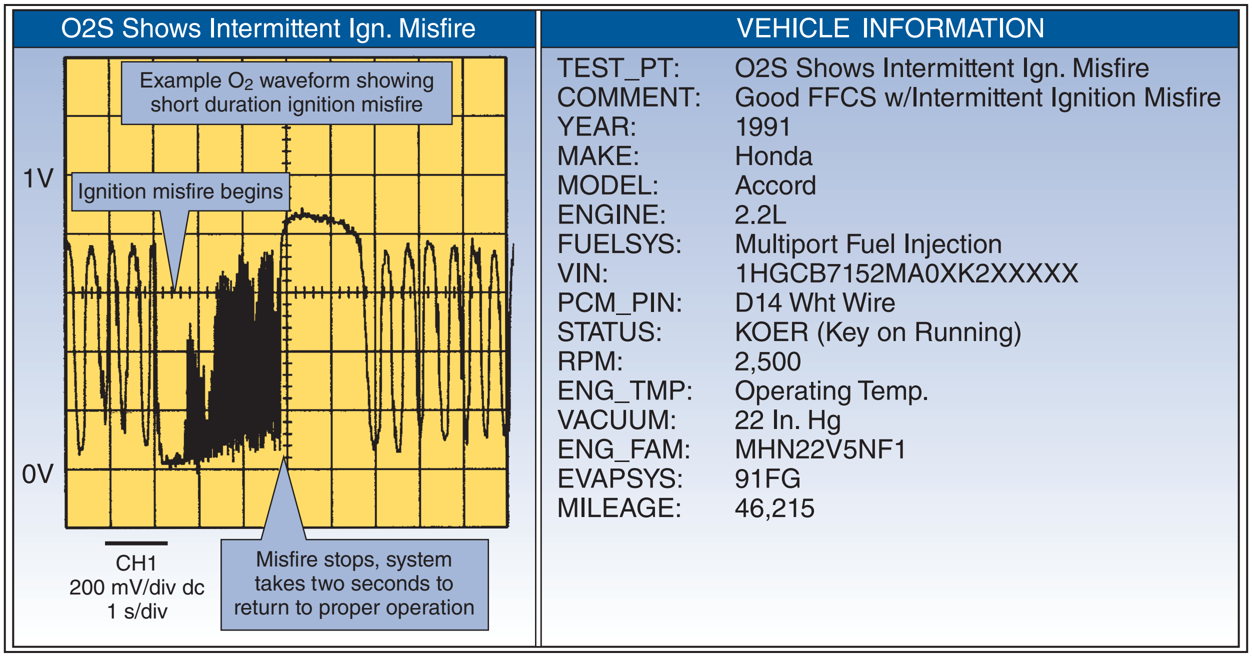
Observing the waveform of an O_2 sensor can help in the diagnosis of engine performance problems. **Figure 27–33** shows how ignition problems affect the signal from the O_2 sensor. Keep in mind that during complete combustion, nearly all of the O_2 in the combustion chamber is combined with the fuel. This means there will be little O_2 in the exhaust. As combustion becomes more incomplete, the levels of O_2 increase.

Excessive O_2 in the exhaust will also show up on an exhaust gas analyzer. With incorrect timing you should also see higher-than-normal amounts of HC. Keep in mind that it takes approximately 7 seconds for the exhaust to be analyzed. If you slowly accelerate the engine and see the HC and O_2 levels on the exhaust gas analyzer rise, the condition that existed 7 seconds earlier was the cause of the rise in emissions levels. To make this easier to track, make sure you hold the engine at each test speed for at least 7 seconds. This way you will be able to observe the rise (or fall) of the emissions levels at that particular speed.

Incorrect ignition timing will also affect manifold vacuum readings and ignition system waveforms on a scope. When anything indicates a problem with the primary ignition circuit, the suspected parts should be tested. Symptoms of overly advanced timing include pinging or engine knock. Insufficient advance or retarded timing at higher engine speeds could cause hesitation and poor fuel economy.

Setting Ignition Timing

Only engines equipped with a distributor may need to have their ignition timing set or adjusted. On these systems, the correct base timing is critical for the proper operation of the engine. Because the computer bases its control to the base timing setting, all other ignition timing settings will also be wrong. On DI systems, the base timing is adjustable. On others, if the base timing is wrong, the ignition module, distributor, or PCM may need to be replaced.



Courtesy of Progressive Diagnostics—wavelife AutoPro.

FIGURE 27–33 An O_2 sensor signal caused by an ignition problem.

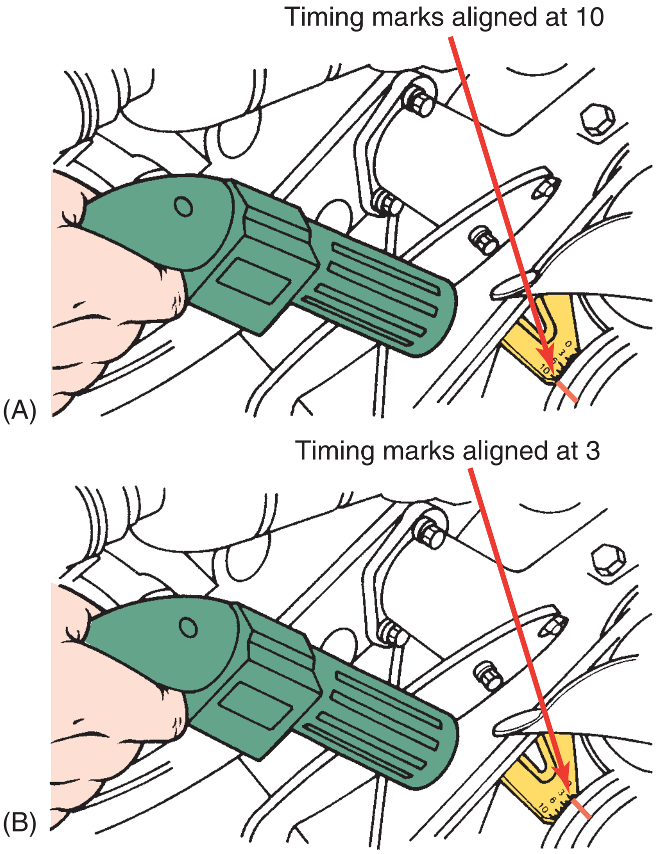


FIGURE 27–34 (A) Timing marks illuminated by a timing light at 10 degrees BTDC and (B) timing marks at 3 degrees BTDC.

To check the ignition timing, a timing light is aimed at the ignition timing marks. The timing marks are usually located on the crankshaft pulley or the flywheel. A stationary pointer, line, or notch is positioned above the rotating timing marks. The timing marks are lines on the crankshaft pulley **(Figure 27–34)** or flywheel that represent various positions of the piston as it relates to TDC. When piston 1 is at TDC, the timing line or notch will line up with the zero reference mark on the timing plate. Usually an engine is timed so that the number 1 spark plug fires several degrees BTDC. The timing light flashes every time the number 1 spark plug fires. When pointed at the timing marks, the strobe of the light will freeze the spinning timing marks as it passes the timing scale. The ignition timing is checked by observing the degrees of crankshaft rotation (BTDC or ATDC) when the spark plug fires.

After you have a base timing reading, compare it to the specifications. As an example, if the specification calls for 10 degrees before TDC and your reading was 3 degrees before TDC, the timing is retarded 7 degrees. This means the timing must be advanced by 7 degrees. To do this, rotate the distributor until the timing marks align at 10 degrees. Then retighten the distributor holddown bolt.

Diagnosing Primary Circuit Components

The primary circuit has the responsibility of controlling the action of the secondary and, in many cases, is the cause of starting problems. The components in the primary ignition circuit vary with manufacturer and design. It is important to identify the component of the circuit and the appropriate test methods. Always work systematically through a circuit, testing each wire, connector, and component. Do not jump from one component to another. Always compare the readings with specifications given by the manufacturer.

Ignition Switch

On many older systems, the ignition switch supplies voltage to the ignition control module and/or the ignition coil. Often an ignition system has two wires connected to the run terminal of the ignition switch. One is connected to the module. The other is connected to the primary side of the coil. The start terminal of the switch is also wired to the module. On newer systems, the ECM often supplies power to the coil primary terminal once the ignition is turned on or the engine is cranked.

You can check for voltage using either a 12-volt testlight or a DMM. To use a testlight, turn the ignition key off and disconnect the wire connector at the module. Turn the key to the run position and probe the power wire connection to check for voltage. Also check for voltage at the battery terminal of the ignition coil using the testlight.

Next, turn the key to the start position and check for voltage at the module and the battery terminal of the ignition coil. If voltage is present, the switch and its circuit are okay.

To make the same test using a DMM, turn the ignition switch to the off position and backprobe, with the meter's positive lead, the power feed wire at the module. Connect the meter's negative to a good ground. Turn the ignition to the run or start position as needed, and measure the voltage. The reading should be at least 90 percent of battery voltage.

Ignition Coil Resistance

Ignition coils, like all parts that contain electrical windings, can be checked with an ohmmeter. In an ignition coil, there are two separate windings and

each has a different resistance value. This is due to the wire size and the number of windings. Always refer to the specifications prior to testing a coil. If a measurement is not within specifications, the coil or coil assembly should be replaced. It is important to remember that a resistance test can confirm if a part is faulty but should not be relied on to prove a part is good. This is because measuring the resistance of the coil windings is a static test, without the coil being under any load or stress. The winding may test good this way but fail in operation as current flows through the winding and heat is generated.

To check the primary windings, set the ohmmeter to the auto-range mode and connect the meter across to the primary coil (BAT and TACH or + and –) terminals **(Figure 27–35)**. Coil primary resistance is typically low, a couple of ohms or less. An infinite ohmmeter reading indicates an open winding. Higher-than-normal readings indicate the presence of excessive resistance. If the measurement is less than the specified resistance, the windings are shorted.

To check the secondary winding, connect the meter between the coil's secondary terminal and the positive (BAT) terminal of the coil **(Figure 27–36)**. Secondary resistance is usually in the thousands or tens of thousands of ohms. A meter reading below the specified resistance indicates a shorted secondary winding. An infinite meter reading indicates that the winding is open. Higher-than-normal readings indicate the presence of excessive resistance.

The secondary windings of a waste spark ignition coil are not checked in the same way as other coils. Each coil has two secondary terminals. The coil is checked by connecting the meter across the two secondary terminals **(Figure 27–37)**. As with other coils, compare the readings to specifications. COP coils are checked in the same way as other coils.

Although ohmmeter measurements are a good indication of the condition of a coil, they do not

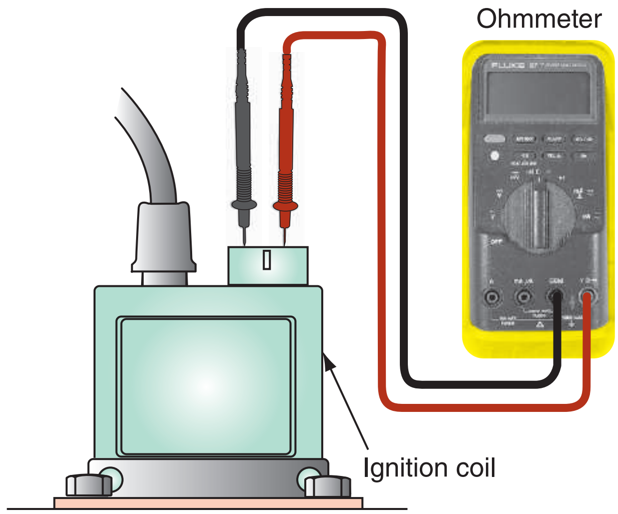


FIGURE 27–35 An ohmmeter connected to primary coil terminals.

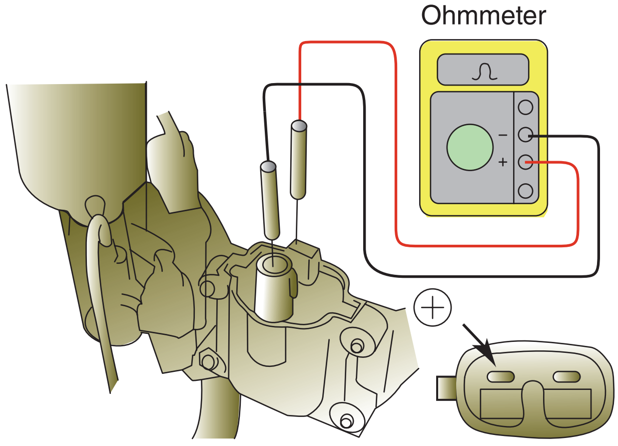


FIGURE 27–36 An ohmmeter connected from one primary terminal to the coil tower to test secondary winding.

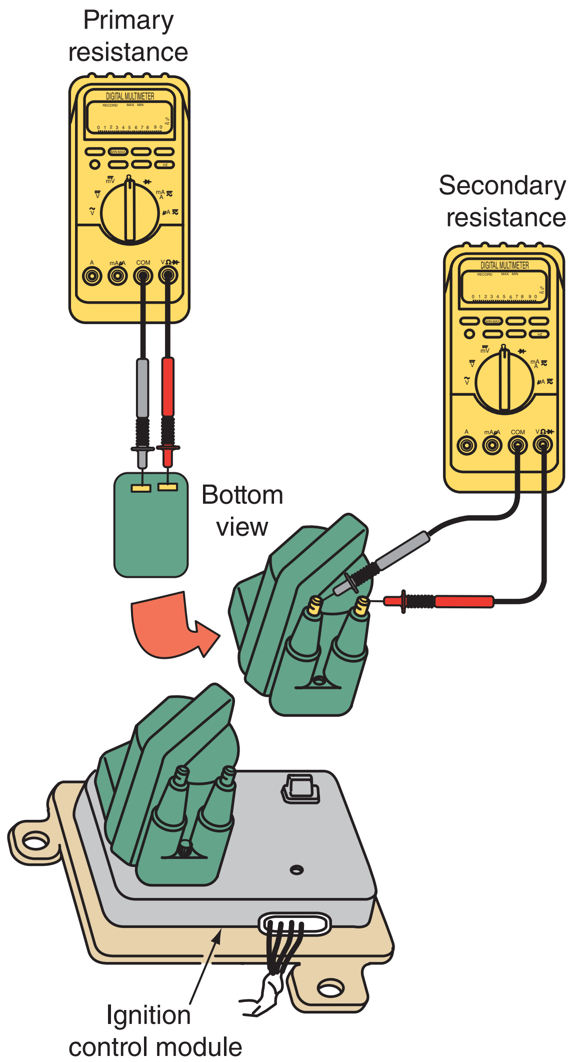


FIGURE 27–37 Meter connections for testing the resistance of a double-ended ignition coil.

check for defects such as poor insulation around the windings, which causes high-voltage leaks. Therefore, an accurate indication of coil condition is the coil voltage output test with a test spark plug connected from the coil secondary wire to ground as explained in the no-start diagnosis.

High-Voltage Diodes Some secondary ignition coil windings contain a high-voltage diode. Normally when the coil has one, the manufacturer does not recommend testing the resistance of the secondary winding. The coil's output can be measured but this test should only be done after the primary windings have been checked.

Crankshaft/Camshaft Sensors

Although ignition timing on most EI systems is not adjustable, the air gaps at the crankshaft and camshaft sensors will affect the operation of the ignition system. On some engines, this gap is adjustable and on others it is an indication that the sensor should be replaced. If there is no provision for adjusting the gap and the gap is incorrect, the sensor should be replaced.

When checking the gap, make sure there are no signs of damage to the rotating vane assembly. Measure the gap with a nonmagnetic feeler gauge. Compare your findings to specifications. If the gap is not correct, the sensor should be replaced or the gap adjusted.

The sensors can also be checked with an ohmmeter. Connect the negative lead to the ground terminal at the sensor and measure the resistance between that terminal and the others one at a time. The resistance should be within the specified range; if not, replace the sensor.

Also, the action of the sensors can be monitored with an AC voltmeter or a lab scope connected across the sensor terminals to check the sensor signal while the engine is cranking. Meter readings below the specified value indicate a shorted sensor winding, whereas infinite meter readings prove that the sensor winding is open. On a lab scope, the pattern should be smooth, and all peaks, with the exception of the sync pulse, should be at the same height **(Figure 27–38)**.

SHOP TALK

While observing the wave patterns of a CKP, remember that the pattern can be altered by engine misfiring **(Figure 27–39)**.

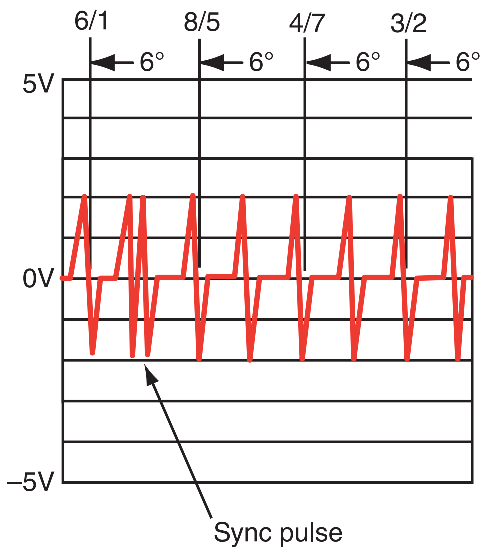


FIGURE 27–38 A waveform for a nine-slot trigger wheel for the crankshaft sensor.

On some engines, the crankshaft sensor is mounted inside the engine. These sensors are continuously splashed with engine oil. Often these sensors fail because engine oil enters the sensor and shorts out the winding.

A quick check of the condition of the permanent magnet in a sensor can be made by placing a flat steel tool (such as the blade of a feeler gauge set) near the sensor. It should be attracted to the sensor if the sensor's magnet is okay.

If a crankshaft or camshaft sensor needs to be replaced, always clean the sensor tip and install a new spacer (if so equipped) on the sensor's tip. New sensors typically have a spacer already installed on the sensor **(Figure 27–40)**. Install the sensor until the spacer lightly touches the sensor ring and tighten the sensor mounting bolt.

Pickup Coils

It is important that all wires and connectors between the trigger sensor and ignition module and module to the PCM be visually checked as well as checked for excessive resistance with an ohmmeter.

To test magnetic pulse and metal detection pickup coils inside a distributor or used as a CKP or CMP with an ohmmeter, connect the ohmmeter from one of the pickup leads to ground to test for a short to ground. If there is a short to ground, the ohmmeter will have a reading of less than specifications. Most pickup coils have 150 to 900 ohms resistance, but always refer to the manufacturer's specifications. If the pickup coil is open, the ohmmeter will display an infinite reading. When the pickup coil is

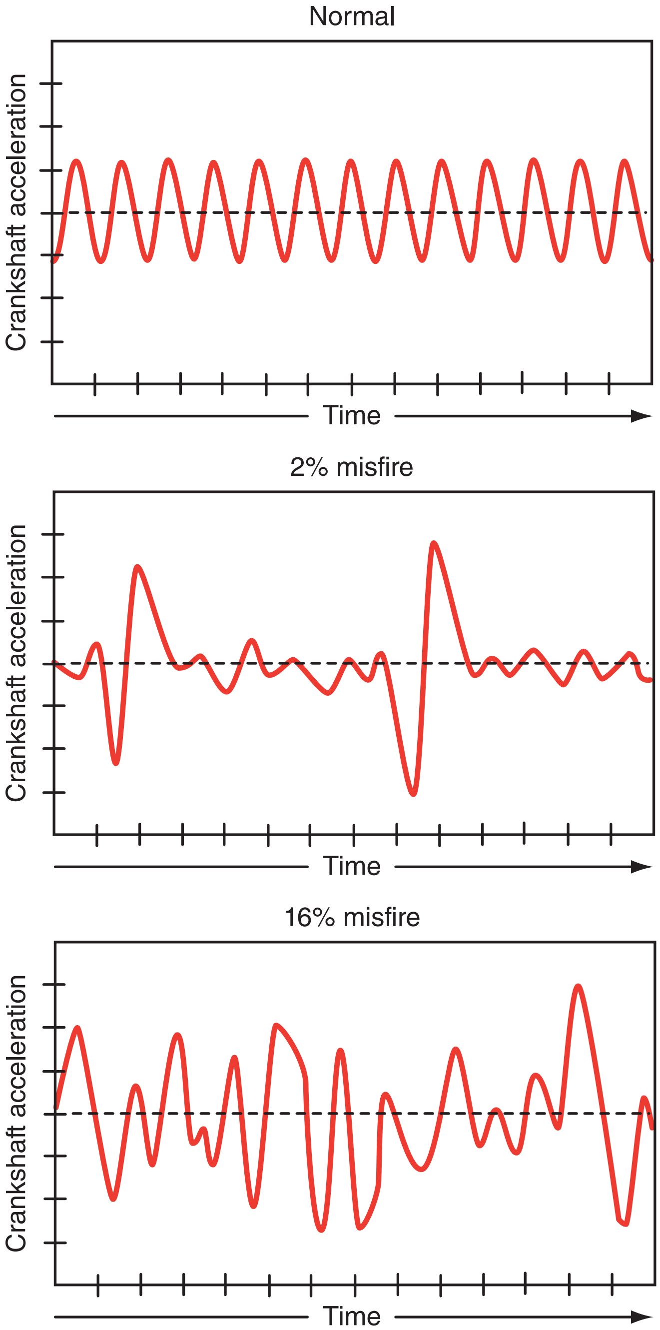


FIGURE 27-39 The reaction of a CKP's waveform to misfires.

shorted, the ohmmeter will display a reading lower than specifications.

While the ohmmeter leads are connected, pull on the pickup leads and watch for an erratic reading, indicating an intermittent open in the pickup leads.

Often the gap between the pickup coil and reluctor is adjustable. The gap should be measured with a nonmagnetic feeler gauge placed between the reluctor high points and the pickup coil. If adjustment is required, loosen the pickup and move it until the specified air gap is obtained. Retighten the pickup coil bolts to the specified torque. Some pickup coils are riveted to the pickup plate. A pickup gap adjustment is not required for these pickup coils.

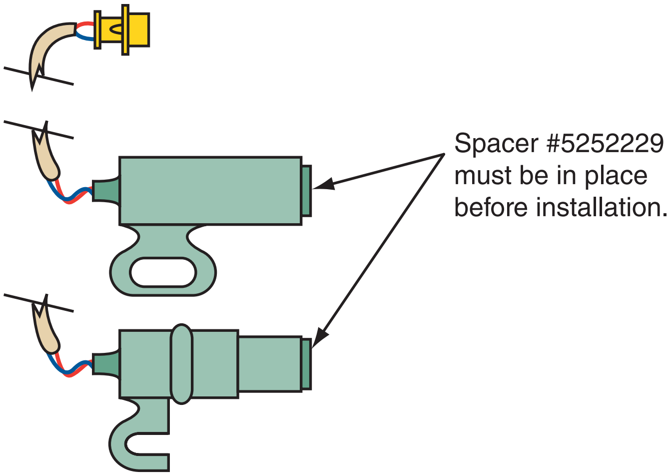


FIGURE 27-40 Some new CKP sensors rely on a paper spacer to set the sensor's gap to specifications.

Voltmeter Checks If the resistance is within specifications, the circuit should be checked with a voltmeter. Disconnect the sensor or backprobe the terminals at the connector. Set the meter to measure AC volts and connect the meter leads to the sensor. Crank the engine and note the voltage. A varying AC voltage should be displayed. At cranking speeds the sensor should produce at least 200 mVAC.

Hall-Effect Sensors

With the voltmeter hooked up, insert a steel feeler gauge or knife blade between the Hall layer and magnet. If the sensor is good, the voltmeter should read within 0.5 volt of battery voltage when the feeler gauge or knife blade is inserted and touching the magnet. When the feeler gauge or blade is removed, the voltage should read less than 0.5 volt.

In the following tests, the distributor connector is connected to the unit and the connector backprobed. With the ignition switch on, a voltmeter should be connected from the voltage input wire to ground. The specified voltage should appear on the meter. The ground wire should be tested with the ignition switch on and a voltmeter connected from the ground wire to a ground connection near the distributor. With this meter connection, the meter indicates the voltage drop across the ground wire, which should not exceed 0.2 volt.

Connect a digital voltmeter from the pickup signal wire to ground. If the voltmeter reading does not

fluctuate while cranking the engine, the pickup is defective. However, if the voltmeter reading fluctuates from nearly 0 volts to between 9 and 12 volts, that indicates a satisfactory pickup. During this test, the voltmeter reading may not be accurate because of the short duration of the voltage signal. If the Hall-effect pickup signal is satisfactory and the 12-volt test lamp did not flutter during the no-start test, the ignition module is probably defective.

Using a Logic Probe

The primary can also be checked with a logic probe. There are three lights on a logic probe. The red light illuminates when the probe senses more than 10 volts. When there is a good ground, the green light turns on. The yellow light flashes whenever the voltage changes. This light is used to monitor a pulsing signal, such as one produced by a digital sensor like a Hall-effect switch.

To check the primary circuit with a logic probe, turn the ignition on. Touch the probe to both (positive and negative) primary terminals at the coil. The red light should come on at both terminals **(Figure 27–41)**, indicating that at least 10 volts are available to the coil and that there is continuity through the coil. If the red light does not come on when the positive side of the coil is probed, check the power feed circuit to the coil. If the light comes on at the positive terminal but not at the negative, the coil has excessive resistance or is open.

Now move the probe to the negative terminal of the coil and crank the engine. The red and green lights should alternately flash, indicating that over 10 volts are available to the coil while cranking and that the circuit is switching to ground. If the lights do not

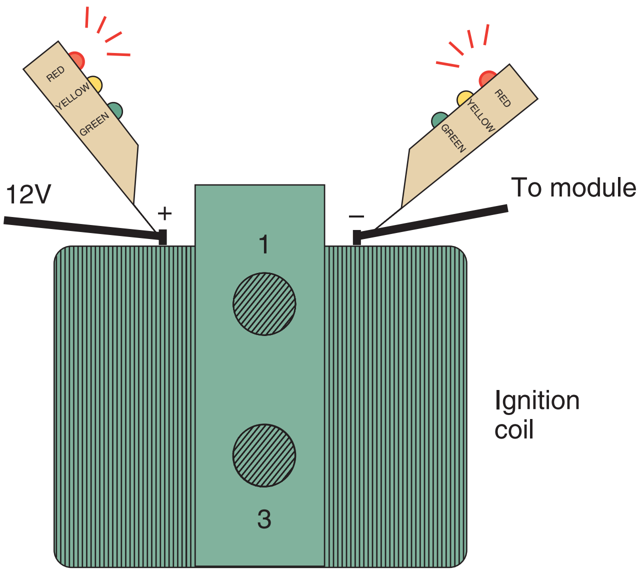


FIGURE 27–41 The red light on a logic probe should turn on when touched to both sides of the primary winding.

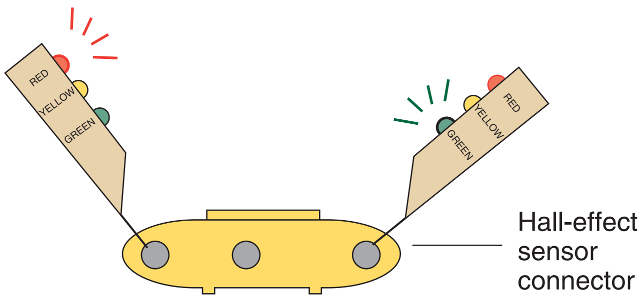


FIGURE 27–42 One end terminal of a Hall-effect sensor connector should cause the red light to come on; the other end terminal should cause the green light to come on.

come on, check the ignition power feed circuit from the starter. If the red light comes on but the green light does not, check the crankshaft or camshaft sensor. If these are working properly, the ignition module is probably defective.

A Hall-effect switch is also easily checked with a logic probe. If the switch has three wires, probe the outer two wires with the ignition on **(Figure 27–42)**. The red light should come on when one of the wires is probed, and the green light should come on when the other wire is probed. If the red light does not turn on at either wire, check the power feed circuit to the sensor. If the green light does not come on, check the sensor's ground circuit.

Backprobe the center wire and crank the engine. All three lights should flash as the engine is cranked. The red light will come on when the sensor's output is above 10 volts. As this signal drops below 4 volts, the green light should come on. The yellow light will flash each time the voltage changes from high to low. If the logic probe's lights do not respond in this way, check the wiring at the sensor. If the wiring is okay, replace the sensor.

Using a Lab Scope

If the crankshaft sensor is a Hall-effect switch, square waves should be seen on the scope. All pulses should normally be identical in spacing, shape, and amplitude. Note that some systems use a different size shutter to designate cylinder 1. This will cause the waveform to display one square wave that is different than the others. By using a dual-trace lab scope, the relationship between the crankshaft sensor and the ignition module can be observed. During starting, the module will provide a fixed amount of timing advance according to its program and the cranking speed of the engine. By observing the crankshaft sensor output and the ignition module, this advance can be observed **(Figure 27–43)**. The engine will not start if the ignition module does not provide for a fixed amount of timing advance.

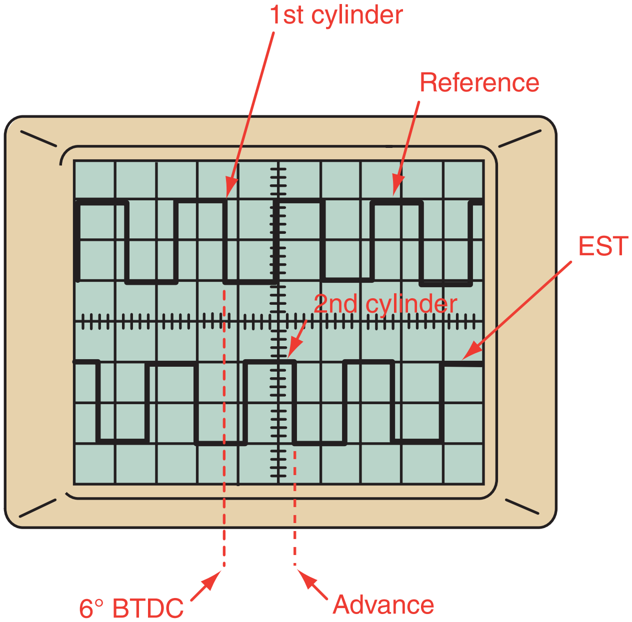


FIGURE 27-43 Electronic spark timing (EST) and crankshaft sensor signals compared on a dual-trace scope.

Knock Sensors

Most systems have knock sensors that retard timing when the engine is experiencing ping or knocking. A quick check of a knock sensor is made by watching ignition timing while the engine is running and the engine block is tapped with the handle of a screwdriver. The noise should cause a change in timing.

Control Module

The most effective way to test a control module is to use an ignition module tester. This tester evaluates and determines if the module is operating within a given set of parameters. It does this by simulating normal operating conditions while looking for faults in the module's components. If a module tester is not available, check out all other system components before condemning the control module. Test for power and ground to the module as well as the signal from the CKP sensor. It is possible that a weak signal from the CKP may not trigger the module, resulting in the module not triggering the coil.

Secondary Circuit Tests and Service

A coil secondary winding and spark plug are found in all ignition systems. DI, distributorless, and coil-near-cylinder systems also have spark plug wires. DI systems also have a distributor cap and rotor and sometimes a lead for the ignition coil.

Distributor Cap and Rotor

Because there is an air gap between the rotor and the distributor cap, electrical arcing takes place between the two. This causes a deterioration of the rotor tip and the distributor cap terminals. This added resistance could cause cylinder misfires.

When installing a new cap or rotor, it is always wise to replace both at the same time. Make sure both are fully seated before attempting to start the engine. Also remember that the spark plug wires need to be arranged on the cap according to the firing order **(Figure 27–44)**.

Waste Spark Systems

Standard test procedures using an oscilloscope, an ohmmeter, and a timing light can be used to diagnose problems in distributorless ignition systems **(Figure 27–45)**. Keep in mind, however, that

FIGURE 27-44 Before installing the spark plug wires to the distributor cap, identify the terminal for cylinder number 1 and then follow the engine's firing order.

FIGURE 27-45 A distributorless ignition system.

problems involving one cylinder may also occur in its companion cylinder that fires off the same coil. Follow the testing procedures given in the service information. Specific DTCs are designed to help troubleshoot ignition problems in these systems. The diagnostic procedure for EI systems varies depending on the vehicle make and model year.

There is a separate primary circuit for each coil. If one coil does not work properly, it may be caused by something common or not common to the other coils. Regardless of the system's design, there are common components in all electronic ignitions: an ignition module, crankshaft and/or camshaft sensors, ignition coils, a secondary circuit, and spark plugs. Most of these components are common to only the spark plug or spark plugs to which they are connected. The components that are common to all cylinders (such as the camshaft sensor) will, most often, be the cause of no-start problems. The other components will cause misfire problems.

Testing the secondary circuit of a DIS system is just like testing the secondary of any other type of ignition system. The spark plug wires and spark plugs should be tested to ensure that they have the appropriate amount of resistance. Because the resistance in the secondary dictates the amount of voltage the spark plug will fire with, it is important that secondary resistance be within the desired range.

A quick way to examine the secondary circuit is with an ignition scope. On the scope, the firing line and the spark plug indicate the resistance of the secondary. While observing the firing line, remember that the height of the line increases with an increase in resistance. The length of the spark line decreases as the firing line goes higher. This means that high resistance will cause excessively high firing voltages and reduced spark times.

When checking a DIS system with a scope, remember that in waste spark systems half of the plugs fire with reverse polarity. This means half of the firing lines will be higher than the other firing lines. Normally, reverse firing requires 30 percent more voltage than normal firing.

Excessive resistance is not the only condition that will affect the firing of a spark plug. Spark plug wires and the spark plug itself can allow the high voltage to leak and establish current through another metal object instead of the electrodes of the spark plug. When this happens, the spark plug does not fire and combustion does not take place within the cylinder.

Also keep in mind that the secondary circuit is completed through the metal of the engine. If the spark plugs are not properly torqued into the cylinder heads, the threads of the spark plug may not make good contact and the circuit may offer resistance. Always tighten spark plugs to their specified torque. Make sure not to cross-thread them.

Manufacturers may recommend the use of an antiseize compound on spark plug threads. This compound must be applied in the correct amounts and at the correct place. Too little compound will cause gaps in the contact between the spark plug threads and the spark plug bores. Too much may allow the spark to jump to a buildup rather than the spark plug electrode.

Coil-over-Plug Systems

Remember, an individual coil problem will cause misfiring in only one cylinder. Ignition coils are tested with an ohmmeter in much the same way as other ignition coils. If the resistance is out of specifications, the coil should be replaced. Intermittent coil problems can be caused by corrosion at the electrical connectors to the coil. The action of the secondary can also be monitored on a lab scope **(Figure 27–46)**.

Codes retrieved from the PCM will indicate whether the misfire is a general one or an individual cylinder. Because a COP ignition problem will affect only one cylinder, the general misfire code (P0300) is probably caused by a fuel delivery problem or a vacuum leak.

DTCs that indicate a misfire at an individual cylinder (P0301, P0302, P0303, etc.) are typically caused by a dirty or defective fuel injector, a fouled spark plug, a bad coil, or an engine mechanical problem.

FIGURE 27–46 The scope pattern for a COP system with one faulty cylinder.

If the misfire is caused by a fuel injector problem, a fuel injector code (P0201, P0202, P0203, etc.) will also be retrieved; these identify the affected cylinder.

If a crankshaft position sensor is bad, there will no timing reference and this can prevent the engine from starting or have a hard time starting. A defective CKP may set a P0335 or P0336. Problems with the sensor connection and wiring may also cause these DTCs to set.

Each ignition coil has a driver circuit in the PCM that controls primary current flow. If there is a bad driver circuit, that spark plug will not fire. Also, keep in mind that an engine may start with a faulty camshaft sensor but it may only run in the fail-safe or limp-in mode because the fuel injectors cannot be synchronized without the camshaft signal. Faults in the coil primary or secondary circuits or a faulty coil may cause a DTC ranging from P0351 to P0362 to set.

Coil-near-plug systems can be checked with a scope or graphing meter in the same way as other ignition systems. The pickup for secondary signals is installed over the spark plug wire. However, COP systems require special adapters to connect the scope or analyzer to the ignition system. Some low-amperage current probes can also be used to monitor the activity of an individual coil in a COP system. Also, make sure to check the spark plug wires **(Figure 27–47)**.

Spark Plugs

All of the ignition system is designed to do no more than supply the voltage necessary to cause a spark across the gap of a spark plug. This simple event is what starts the combustion process. Needless to say, a healthy spark plug is extremely important to the combustion process. Spark plug replacement is part of the preventive maintenance program for all vehicles. The recommended replacement interval depends on a number of factors but ranges from 20,000 to 100,000 miles (32,000 to 160,000 km).

Warning! When removing the cable boots from the spark plugs, do not pull on the cables. Instead, grasp the boot and gently twist it off.

Using a spark plug socket and ratchet, loosen each plug a couple of turns. A spark plug socket should be used because it has an internal rubber bushing to prevent plug insulator breakage. Spark plug sockets can have either a $^{3}/_{8}$- or ½-inch drive, and most have an external hex so that they can be turned using an open-end or box wrench.

Once the plugs are loose, use compressed air to blow dirt away from the base of the plugs. Then remove the plugs, making sure their gaskets have also been removed (if applicable). When the spark plugs are removed **(Figure 27–48)**, they should be set in order so the spark plug from each cylinder can be examined.

Check the threads in the cylinder head for damage. Normally you can do this by feel as you remove a spark plug. If the plug does not turn smoothly after it is loose, the threads may be damaged. Often the threads can be cleaned up with a spark plug thread chaser. Also, check the threads on the spark plug. Look for damage or metal embedded in the threads, as these are sure signs of problems. If the cylinder head is aluminum, it may be necessary to install a threaded insert into the spark plug bore.

When working on certain Ford V8s with the extended reach spark plugs, special procedures are

FIGURE 27–47 A coil-near-plug ignition system.

FIGURE 27–48 Use a spark plug socket to remove the plugs.

often required to remove the spark plugs. Due to the design of the plug, the extended shell often breaks off in the cylinder head. A special tool is needed to remove the shell. Follow the Ford service information regarding servicing the spark plugs in 4.6L, 5.4L, and 6.8L 3V engines.

Inspecting Spark Plugs

Once the spark plugs have been removed, it is important to "read" them. In other words, inspect them closely, noting in particular any deposits on the plugs and the degree of electrode erosion. A normal-firing spark plug will have a minimum amount of deposits on it and will be colored light tan or gray **(Figure 27–49)**. However, there should be no evidence of electrode burning, and the increase of the air gap should be no more than 0.001 inch (0.0254 mm) for every 10,000 miles (16,000 km) of engine operation. A plug that exceeds this wear should be replaced and the cause of excessive wear corrected **(Figure 27–50)**. Worn or dirty spark plugs may work fine at idle or low speeds, but they frequently fail during heavy loads or higher engine speeds.

It is possible to diagnose a variety of engine conditions by examining the electrodes of the spark plugs. Ideally, all of the plugs from an engine should look alike. Whenever plugs from different cylinders look different, a problem exists in those cylinders. The following are examples of plug problems and how they should be dealt with.

Carbon Fouling This condition is the result of an excessively rich air-fuel mixture. It is characterized by a layer of dry, fluffy, black carbon deposits on the tip of the plug **(Figure 27–51)**. Carbon fouling, also called cold fouling, can also be caused by an ignition fault that causes the spark plug not to fire. If only one or two of the plugs show evidence of fouling, sticking valves are the likely cause. If the plug is cleaned, it can be used again. Correct the cause of the fouling before reinstalling or replacing the plugs.

Courtesy of Federal-Mogul Corporation.

FIGURE 27–49 Normal spark plug.

Courtesy of Federal-Mogul Corporation.

FIGURE 27–50 A worn spark plug.

Courtesy of Federal-Mogul Corporation.

FIGURE 27–51 A cold or carbon-fouled spark plug.

Wet Fouling When the tip of the plug is covered with oil, this condition is known as wet fouling **(Figure 27–52)**. The oil may be entering the combustion chamber through worn valve guides or valve guide seals. On high-mileage engines, check for worn rings

SHOP TALK

If carbon fouling is found on a vehicle that operates a great deal of the time at idle and low speeds, plug life can be lengthened by using hotter spark plugs.

FIGURE 27–52 A wet- or oil-fouled spark plug.

FIGURE 27–54 A spark plug with preignition damage.

or excessive cylinder wear. Before replacing the plugs, correct the problem.

Glazing Under high-speed conditions, the combustion chamber deposits can form a shiny, yellow **glaze** over the insulator. When it gets hot enough, the glaze acts as an electrical conductor, causing the current to follow the deposits and short out the plug. Because it is virtually impossible to remove glazed deposits, glazed plugs should be replaced.

Overheating This condition is characterized by white or light-gray blistering of the insulator. There may also be considerable electrode gap wear **(Figure 27–53)**. Overheating can result from using too hot a plug, over-advanced ignition timing, detonation, a malfunction in the cooling system, an overly lean air-fuel mixture, using fuel too low in octane, an improperly installed plug, or a heat-riser valve that is stuck closed. Overheated plugs must be replaced.

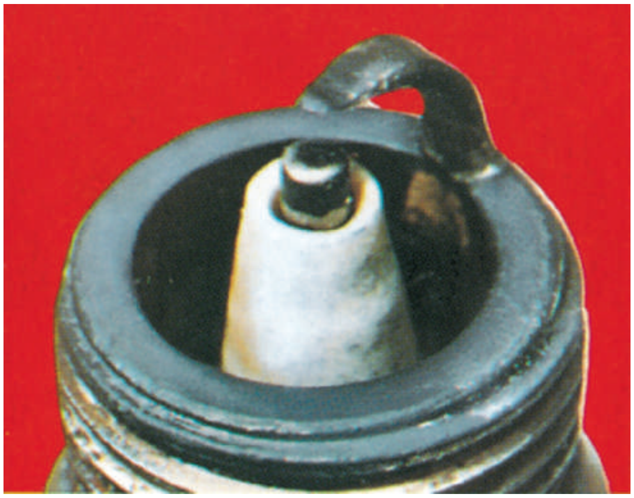


FIGURE 27–53 This spark plug shows signs of overheating.

Turbulence Burning When turbulence burning occurs, the insulator on one side of the plug wears away as the result of normal turbulence in the combustion chamber. As long as the plug life is normal, this condition is of little consequence. However, if the spark plug shows premature wear, overheating can be the problem.

Preignition damage is caused by excessive engine temperatures. Preignition damage is characterized by melting of the electrodes or chipping of the electrode tips **(Figure 27–54)**. Look for the general causes of engine overheating, including over-advanced ignition timing, a burned head gasket, and using fuel too low in octane. Other possibilities include loose plugs or using plugs of the improper heat range. Do not attempt to reuse plugs with preignition damage.

Regapping Spark Plugs

Both new and used spark plugs should have their air gaps set to manufacturer's specifications. Always use round wire gauges when checking and setting the gap **(Figure 27–55)**.

After the gap has been adjusted, make sure that the ground electrode is as horizontal as it can be.

Always check the air gap of a new spark plug before installing it. Never assume the gap is correct just because the plug is new. Do not try to reduce a plug's air gap by tapping the side electrode on a bench. Use a spark plug gapping tool to bend the ground electrode to its correct height. When doing this, be careful not to contact or put pressure on the center electrode. This is

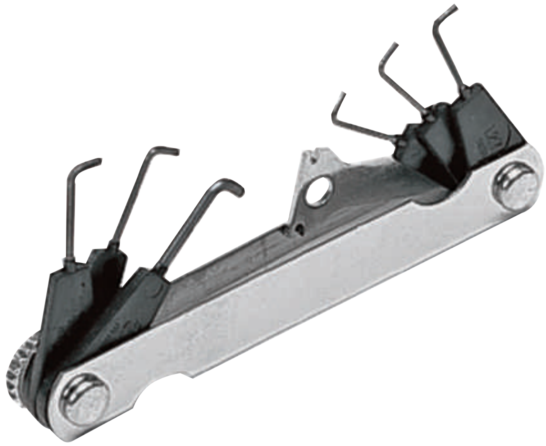


FIGURE 27–55 A round wire-type feeler gauge set.

especially critical with fine wire platinum and iridium plugs. Also while bending the ground electrode, try to keep it in alignment with the center electrode.

Some engines are equipped with spark plugs that have more than one ground electrode. The gap between the center electrode and each ground electrode should be checked **(Figure 27–56)**. If the gap between the center electrode and one of the ground electrodes is less than that of the others, spark will occur only at the smallest gap. This is also true of V-shaped ground electrodes. If one leg of the V is closer to the center electrode than the other, the spark will always occur across the shortest distance.

The gap of spark plugs with a surface gap and of some with more than one ground electrode cannot be adjusted with conventional tools, and most manufacturers recommend that the gap be left alone.

Secondary Ignition Wires

Inspect all the spark plug wires and the secondary coil wire for cracks and worn insulation, which cause high-voltage leaks. Inspect all the boots on the ends

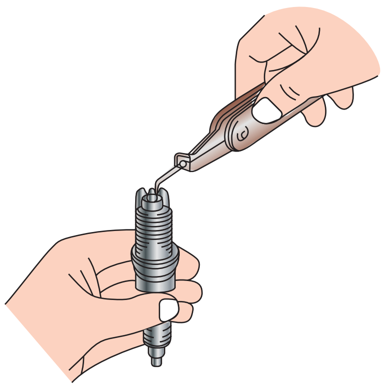


FIGURE 27–56 The gap between the center electrode and both ground electrodes should be checked and adjusted to specifications.

PROCEDURE

Spark Plug Installation

STEP 1 Wipe dirt and grease from the plug seats with a clean cloth.

STEP 2 Verify that the replacement spark plugs are the correct ones for the engine by matching the part number to its application **(Figure 27–57)**. Never assume that the plugs that were removed from the engine are the correct type.

STEP 3 Adjust the air gap, as needed.

STEP 4 Check the service information to see if antiseize compound should be applied to the plug's threads **(Figure 27–58)**.

STEP 5 Install the plugs and tighten them with your hand. If the plugs cannot be installed easily by hand, the threads in the cylinder head may need to be cleaned with a thread-chasing tap. Be especially careful not to cross-thread the plugs when working with aluminum heads.

STEP 6 Tighten the plugs with a torque wrench, following the vehicle manufacturer's specifications or the values shown in **Figure 27–59**.

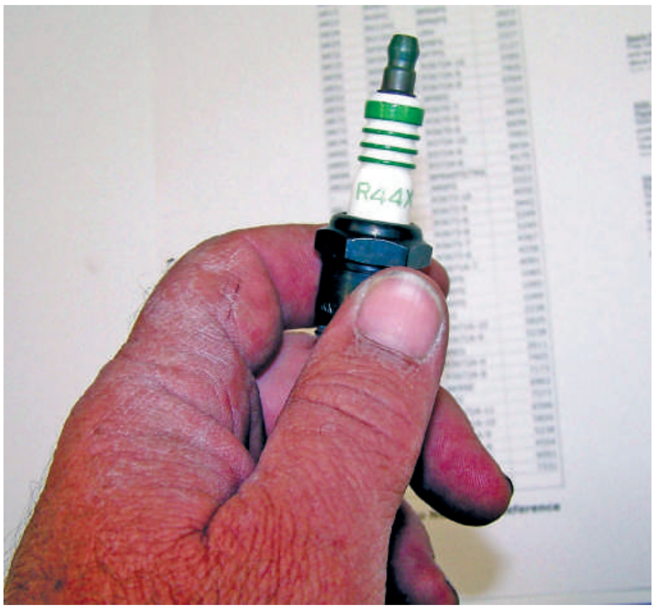


FIGURE 27–57 Make sure that the replacement spark plugs are the correct ones for the application.

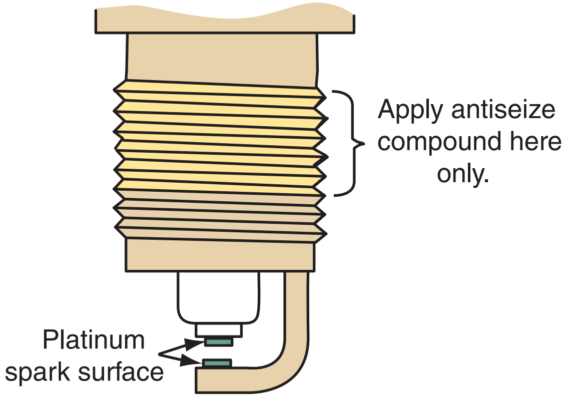


FIGURE 27–58 Proper placement of antiseize compound on the threads of a spark plug.

SHOP TALK

Many ignition systems use locking tabs to secure the spark plug cable to the ignition coil. To remove the cable from the coil, squeeze the locking tabs with needle-nose pliers or use a screwdriver to lift up the locking tab. When reconnecting the cables to the coil, make sure that the locking tabs are in place by pressing down on the center of the cable terminal.

of the plug wires and coil secondary wire for cracks and hard, brittle conditions.

Make sure that the secondary cables are secured tightly to the spark plugs and the ignition coil(s). Also check the cables for any damage or signs of arcing. Replace the wires and boots if they show evidence of these conditions. Most manufacturers recommend that spark plug wires be replaced as a complete set.

Resistance Checks The resistance of secondary cables can be checked with an ohmmeter. Do this by removing the cable and measuring across the cable. On DI systems, the spark plug wires may be left in the distributor cap when measuring resistance **(Figure 27–60)**. This will also check the cap-to-cable connections. Set the ohmmeter to the X1,000 scale and connect the ohmmeter leads from the end of a spark plug wire to the appropriate terminal inside the distributor cap.

If the ohmmeter reading is more than specified by the manufacturer, remove the wire from the cap and check the wire alone. If the wire has more resistance than specified, replace the wire. When the spark plug wire's resistance is satisfactory, check for corrosion at the cap terminal. Repeat the ohmmeter tests on each spark plug wire and the coil secondary wire.

Replacing Spark Plug Wires

When spark plug wires are being installed, make sure they are routed properly as indicated in the vehicle's service information. When removing the spark plug wires from a spark plug, grasp the spark plug boot tightly, and twist while pulling the cable from the end of the plug. When installing a spark plug wire, make sure the boot is firmly seated around the top of the plug, and then squeeze the boot to expel any air that may be trapped inside.

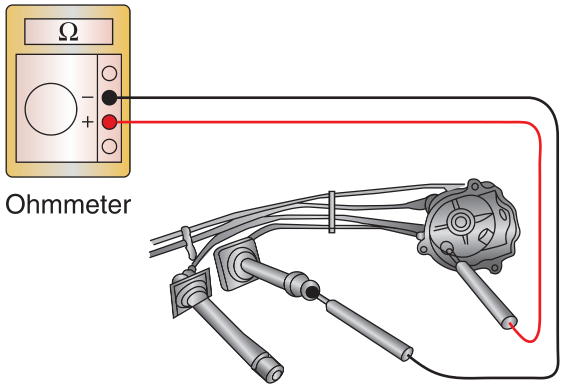


FIGURE 27–60 Check the resistance of each spark plug cable between both ends of the cable.

Spark Plug Type	Thread Diameter	Cast-Iron Head (lb-ft.)	Aluminum Head (lb-ft.)
Flat seat w/gasket	18 mm	25–33	25–33
Conical seat/no gasket	18mm	14–22	14–22
Flat seat w/gasket	14 mm	18–25	18–22
Flat seat w/gasket	12 mm	10–18	10–15
Conical seat/no gasket	14 mm	10–18	7–15

FIGURE 27–59 Typical spark plug torque specifications.

Two spark plug wires should not be placed side-by-side for a long span if these wires fire one after the other in the cylinder firing order. When two spark plug wires that fire one after the other are placed side-by-side for a long span, the magnetic field from the wire that is firing builds up and collapses across the other wire. This magnetic collapse may induce enough voltage to fire the other spark plug and wire when the piston in this cylinder is approaching TDC on the compression stroke. This action may cause detonation and reduced engine power.

Also make sure that the wires are secure in their looms and that the looms are properly placed **(Figure 27–61)**.

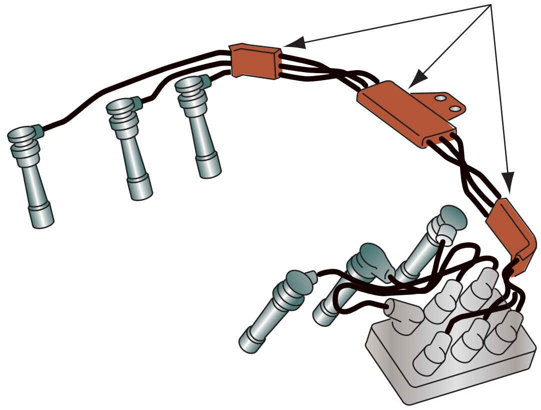


FIGURE 27–61 Make sure the wire separators are in place when reconnecting the spark plug wires.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2007	**Make:** GMC	**Model:** Yukon	**Mileage:** 142,698	**RO:** 18825
Concern:	Check engine light is on and engine makes rattle sound on acceleration.			
The technician confirms the noise on acceleration and that the MIL is on and checks for DTCs. He finds a P0332 stored in the PCM. Searching for TSBs he finds a bulletin specific to this code and problems with the knock sensors and their wiring.				
Cause:	Found P0332 stored and TSB for knock sensor and wiring damage due to water getting under the intake manifold. Removed intake and found corroded harness and sensors.			
Correction:	Replaced knock sensor, wiring harness, and sealed boots covering sensors. Installed updated intake gaskets. Advise customer to NOT wash engine.			

KEY TERMS

Glaze
Raster pattern
Spark duration
Spark line
Superimposed pattern

SUMMARY

- Secure wiring and connections are important to ignition systems. Loose connections, corrosion, and dirt can adversely affect performance.
- Wires, connections, and ignition components can be tested for intermittent failure by wiggling them or stress testing by applying heat, cold, or moisture.
- A scope provides a visual representation of voltage changes over time.
- Waveforms can be viewed in different modes and scales on a scope. Secondary and primary ignition circuits can be viewed.
- Ignition patterns can be broken down into three main sections or zones: firing section, intermediate section, and dwell section.
- The firing line and spark line display firing voltage and spark duration.
- The intermediate section shows coil voltage dissipation.
- The dwell section shows the activation of primary coil current flow and primary coil current switch off. The primary current off signal is also the firing line for the next cylinder in the firing order.
- Current limiting ignition systems saturate the ignition coil very quickly with high current flow and then cut back or limit current flow to maintain saturation. This system extends coil life.
- Precautions must always be taken to avoid open circuits during ignition system testing. A special test plug is used to limit coil output during testing. Always use the correct test plug for the system.
- Firing voltages are normally between 7 and 13 kV with no more than 3 kV variation between cylinders.

- High secondary circuit resistance produces a higher-than-normal firing line and shorter spark lines.
- Individual ignition components are commonly tested for excessive internal resistance using an ohmmeter. A voltmeter or scope can also be used to monitor their operating voltages.
- Proper spark plug gapping and installation are important to ignition system operation. Spark plug condition, such as cold fouling, wet fouling, and glazing, is often a good indication of other problems.
- Standard test procedures using an oscilloscope, GMM, and/or DMM can be used to diagnose problems in EI and DI systems.
- Often, if a crank or cam sensor fails, the engine will not start. These sensor circuits can be checked with a voltmeter. If the sensors are receiving the correct amount of voltage and have good low-resistance connections, their output should be a square wave or a pulsing analog signal while the engine is cranking.
- The resistance of COP ignition coils can be checked in the same way as conventional coils; however, different meter connections are required to test waste spark coils.

REVIEW QUESTIONS

Short Answer

1. Why is the procedure for checking the resistance of a waste spark ignition coil different from the procedures for checking other types of ignition coils?
2. Name the three types of trace pattern display modes used on an oscilloscope and give examples of when each mode is most useful.
3. List the common types of spark plug fouling and the typical problems each type of fouling indicates.
4. List at least two methods of checking the operation of Hall-effect sensors.
5. Describe the basic procedure for finding the cause of a no-start problem on an engine equipped with an EI system.
6. What is the typical procedure for checking the resistance of the primary winding in an ignition coil?
7. What does a slope in the spark line represent?
8. What happens if one of the ground electrodes of a spark plug with two or more electrodes is closer to the center electrode than the other?

True or False

1. *True or False?* The first test when checking a no-start condition is to check all input signals.
2. *True or False?* Coil secondary resistance is typically very low, less than 1 ohm.
3. *True or False?* On some engines, if the gap between the crankshaft sensor and its trigger wheel is outside specifications, the sensor should be replaced.

Multiple Choice

1. Richer air-fuel mixtures ___.
   a. decrease the electrical resistance inside the cylinder and decrease the required firing voltage
   b. increase the electrical resistance inside the cylinder and increase the required firing voltage
   c. increase the electrical resistance inside the cylinder and decrease the required firing voltage
   d. have no measurable effect on cylinder resistance
2. While checking a pickup coil with an ohmmeter, a lower-than-normal reading indicates that the pickup unit is ___.
   a. shorted
   b. open
   c. has high resistance
   d. none of the above
3. A CKP sensor can be checked with all of the following *except* a(n) ___.
   a. logic probe
   b. voltmeter
   c. ammeter
   d. lab scope
4. Which of the following will cause one or more, but not all, firing lines to be higher than normal?
   a. High resistance in the spark plug wire
   b. Faulty fuel injector
   c. Defective spark plug
   d. All of the above

ASE-STYLE REVIEW QUESTIONS

1. The firing lines on an oscilloscope pattern are all abnormally low. Technician A says that the problem is probably low coil output. Technician

B says that the problem could be an overly lean air-fuel mixture. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

2. While testing the coils in an EI system: Technician A says that an infinite reading means that the winding has zero resistance and is shorted. Technician B says that the primary windings in each coil should be checked for shorts to ground. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

3. While discussing no-start diagnosis with a test spark plug: Technician A says that if a testlight flutters at the coil tach terminal but the test spark plug does not fire when connected from the coil secondary wire to ground with the engine cranking, the ignition coil is defective. Technician B says that if a test spark plug connected to a terminal of a waste spark ignition coil fires when the engine is cranking but the engine does not run, a bad PCM is indicated. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

4. Technician A says that EMI can affect sensor signals. Technician B says that EMI can cause intermittent driveability problems. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

5. While discussing waste spark EI systems: Technician A says that a spark plug with too wide of a gap can affect the firing of its companion spark plug. Technician B says that improper spark plug torque can cause an engine misfire. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

6. While discussing how to test a Hall-effect crankshaft position sensor: Technician A says that a logic probe can be used. Technician B says that a DMM can be used. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

7. While discussing the possible causes for a no-start condition on an EI-equipped engine: Technician A says that a shorted crankshaft sensor may prevent the engine from starting. Technician B says that a faulty ignition coil may stop the engine from starting. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

8. While discussing the diagnosis of an electronic ignition (EI) system in which the crankshaft and camshaft sensor tests are satisfactory but a test spark plug connected from the spark plug wires to ground does not fire: Technician A says that the coil assembly may be defective. Technician B says that the PCM may be faulty. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

9. While discussing EI service and diagnosis: Technician A says that the crankshaft sensor may be rotated to adjust the basic ignition timing. Technician B says that the crankshaft sensor may be moved to adjust the clearance between the sensor and the rotating blades on some EI systems. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

10. While discussing engine misfire diagnosis: Technician A says that a defective EI coil may cause cylinder misfiring. Technician B says that a shorted CKP could cause a misfire. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

CHAPTER 28

GASOLINE, DIESEL, AND OTHER FUELS

This chapter takes a look at the fuels used to propel a vehicle. Although there are several types of fuels for automotive use, gasoline is the most commonly used and most readily available. However, there is much interest in finding suitable alternatives to gasoline; these are discussed in this chapter.

Regardless of the type of fuel used for combustion, efficiency depends on having the correct amount of air mixed with the correct amount of fuel. The ideal air-fuel or stoichiometric ratio for a gasoline engine is approximately 14.7 pounds of air mixed with 1 pound of gasoline. This provides a ratio of 14.7:1. Different fuels have different stoichiometric ratios. Because air is so much lighter than gasoline, it takes nearly 10,000 gallons of air mixed with 1 gallon of gasoline to achieve this air-fuel ratio. Lean ratios of 15 to 16:1 provide the best fuel economy. Rich mixtures have a

OBJECTIVES

- Describe the basic composition of gasoline.
- Explain why materials are added to gasoline to make it more efficient.
- Name the common substances used as oxygenates in gasoline and explain what they do.
- Describe how the quality of a fuel can be tested.
- Explain the advantages and disadvantages of the various alternative fuels.
- Explain the differences between diesel fuel and gasoline.
- Describe the common types of fuel injection used on today's diesel engines.
- Describe the various techniques used to allow current diesel engines to meet emission standards.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE		REPAIR ORDER		
Year: 2015	**Make:** Land Rover	**Model:** Range Rover	**Mileage:** 48,588	**RO:** 18825
Concern:	Vehicle towed in. Customer recently bought truck, no history. Engine won't start and there's a warning message displayed on the dash.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

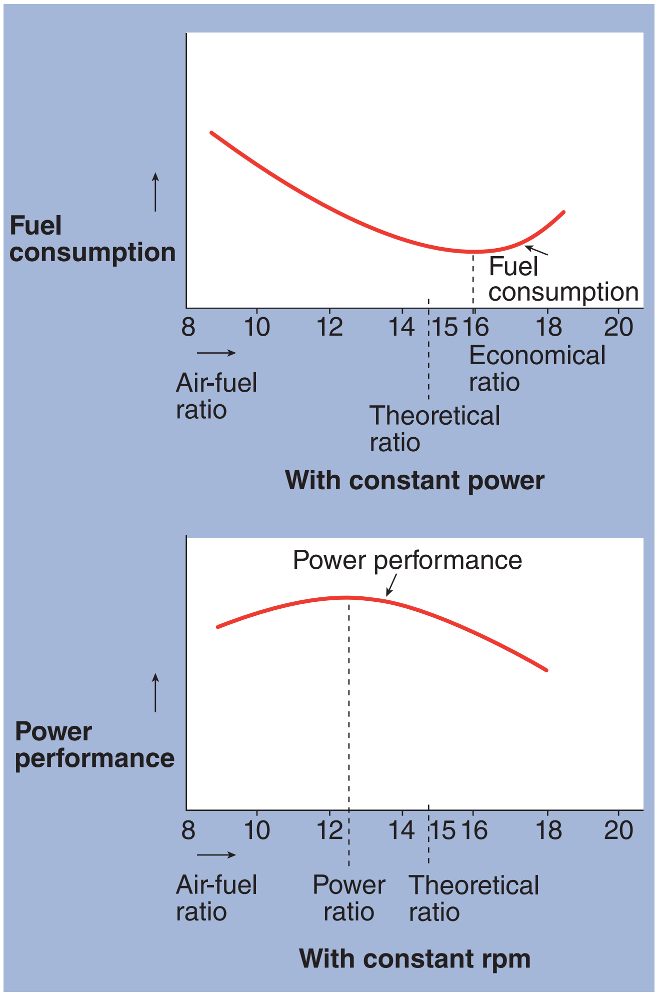


FIGURE 28–1 Fuel consumption and performance at various air-fuel ratios.

ratio below 14.7:1 and provide more power from the engine but greater fuel consumption **(Figure 28–1)**.

Crude Oil

Crude oil is also called **petroleum**, which means oil from the earth. The name fits; crude oil is drawn out of oil reservoirs and sands below the earth's surface. The oil extracted from the earth is called crude because it has yet to be processed or refined. Crude oil is commonly referred to as a fossil fuel because it is naturally produced by the decaying of plants and animals that lived a long time ago and were covered by dirt for many years. Crude oil is a liquid that varies in appearance. Normally, it has a dark brown or black color, but it can also be yellow or greenish.

Although the composition of crude oil varies, it typically is:

- 84 percent carbon
- 14 percent hydrogen
- 1 percent to 3 percent sulfur, in the form of hydrogen sulfide, sulfides, disulfides, and elemental sulfur
- Less than 1 percent nitrogen
- Less than 1 percent oxygen
- Less than 1 percent metals, normally nickel, iron, vanadium, copper, and arsenic
- Less than 1 percent salts, in the form of sodium chloride, magnesium chloride, and calcium chloride

The high concentration of carbon and hydrogen is why products produced from crude oil are called hydrocarbon fuels or compounds.

Petroleum Products

Most of the petroleum extracted from the earth is processed into hydrocarbon products, such as asphalt, wax, gasoline, diesel fuel, kerosene jet fuel, heating and other fuel oils, lubricating oils and greases, liquefied petroleum gas, and natural gas. About 16 percent of the crude oil is processed to make a variety of products, such as polymers, plastics, detergents, deodorants, and medicines.

Hydrocarbons Hydrocarbons (HCs) in crude oil have many different lengths and structures. Therefore, the only thing the different hydrocarbons have in common is that they contain carbon and hydrogen. The number of carbon atoms in an HC molecule defines its length. Sometimes that number, when combined with the number of hydrogen atoms, is called a chain. The HC with the shortest chain is methane (CH_4), which is a very light gas. Longer chains with five or more carbons are liquids or solids. Asphalt has thirty-five or more carbon atoms. HCs contain a great amount of energy, which

SHOP TALK

You may hear crude oil being called sweet or sour. These terms describe the sulfur content of the oil. Crude oil that has a high content of sulfur is called "sour" oil, whereas oil with low sulfur content is called "sweet."

is why they have been used as a source of energy for many years.

Each of the different HCs must be separated from crude oil in order to be useful. This separation process is called refining. After refining, one barrel (42 gallons or 159 liters) of crude oil will produce 20 gallons (75.7 L) of gasoline, 7 gallons (26.5 L) of diesel fuel, and smaller amounts of various other petroleum products.

Refining

A refinery is the place where the separation occurs. The easiest and most common way to separate the various HCs (called fractions) is through a process called **fractional distillation (Figure 28–2)**. The basis of this method is simply that the different HC compounds have progressively higher boiling points. Here are some examples:

- Propane will boil at less than 104 °F (40 °C).
- Gasoline will boil at 104° to 401 °F (40° to 205 °C).
- Jet fuel will boil at 350° to 617 °F (175° to 325 °C).
- Diesel fuel will boil at 482° to 662 °F (250° to 350 °C).
- Lubricating oil will boil at 572° to 700 °F (300° to 370 °C).
- Asphalt will boil at temperatures greater than 1,112 °F (600 °C).

During fractional distillation, crude oil is heated with high-pressure steam to about 1,112 °F (600 °C). This causes all of the crude oil to boil, forming vapor. The vapor moves into the fractional distillation column which has many trays or plates. As the vapor moves up the column, it cools. The vapor condenses or becomes a liquid when it reaches the point in the column where the temperature is equal to the fractions' boiling temperature. Therefore, the fractions with the lowest boiling point will condense at the highest level within the column and those with high boiling points will condense at lower levels. The various trays collect the condensation and pass the liquid out of the column.

Very few of the fractions that leave the column are ready to be used. They must be treated and

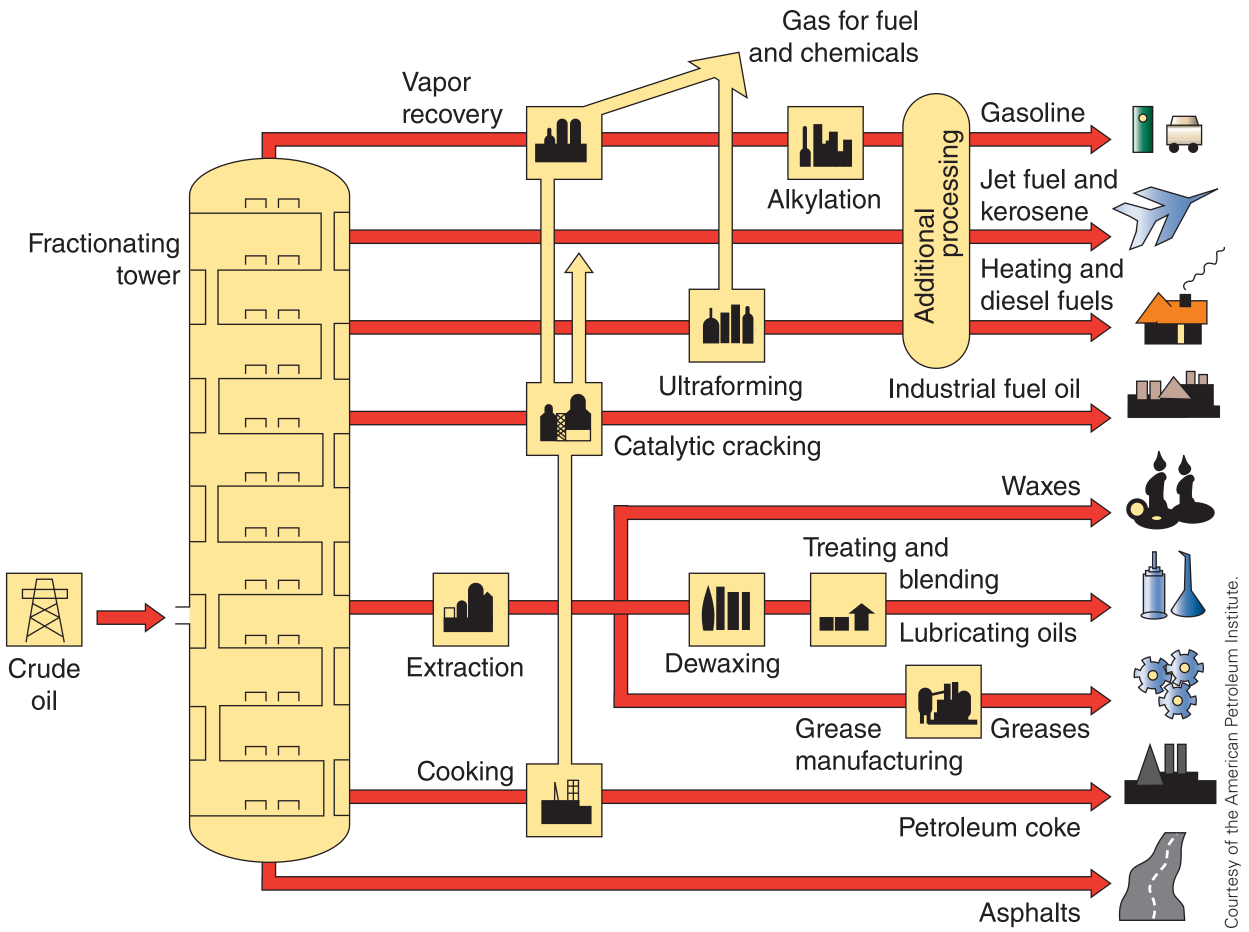


FIGURE 28–2 The refining process for crude oil.

cleaned to remove impurities. Also, refineries combine the various fractions to make a desired product. For example, different octane ratings of gasoline are possible by mixing different fractions. Some fractions are chemically altered so they can be used for their specific application, and others are chemically processed to produce other fractions. The finished products are stored until they can be delivered to their markets.

Chemical Processing Some fractions are processed chemically to produce a different type of HC. Doing this allows the refineries to alter some HCs to meet market demands. Through processing, if the demand for gasoline is high, diesel fuel can be altered to become gasoline.

The process of breaking down HCs with a higher boiling point into an HC with a lower boiling point is called cracking. During cracking, the HCs are introduced to high temperature and sometimes high-pressure conditions, forcing the HCs to break apart. Catalysts are often used to speed up the cracking process.

Also, the structure of HC molecules can be rearranged to provide a different HC. This is commonly used to produce octane boosters for gasoline.

Cleaning and Blending The fractions captured from fractional distillation and chemical processing are treated in a variety of ways to remove all impurities. Some of the techniques used by refineries include passing the fractions through sulfuric acid to remove unsaturated HCs, a drying column to remove water, and hydrogen-sulfide scrubbers to remove sulfur.

After they are cleaned, the base fraction is blended with small amounts of other fractions to make various products, such as various grades of gasoline and lubricating oil and greases.

Concerns

Fossil fuels are the world's most important energy source. However, their use comes with costs. Although it appears that there is plenty of oil available today, we may run out in the future.

It is estimated that there is approximately 3.74 trillion barrels (440 km^3) of oil reserves, including oil sands, available. This seems like a lot; however, the current level of oil consumption is about 84 million barrels (3.6 km^3) per year. This means the oil from known oil reserves will be gone by 2039.

Another concern is that when HCs are burned, they release CO_2. This is a growing concern because CO_2 has been linked to climate change. Although there is much emphasis on reducing CO_2 emissions, it is important to realize that of the total amount of CO_2 emissions worldwide, less than 4 percent is man-made. The rest is from nature; things like breathing and plant and animal decay contribute greatly to the buildup of CO_2 in the atmosphere. Burning fossil fuels for transportation contributes to about one-quarter of the man-made CO_2 emissions. Reducing this has been the goal of manufacturers and governments.

The declining amount of oil in reserves and the concern for the environment are the leading factors in the development and use of alternate fuels and energy sources.

Gasoline

Gasoline is a complex mixture of approximately 300 various ingredients, mainly HCs. The chemical symbol for this liquid is C_8H_{15}, which indicates that each molecule of gasoline contains eight carbon atoms and fifteen hydrogen atoms. Gasoline is a colorless liquid with excellent vaporization capabilities.

Oil refiners must meet gasoline standards set by the American Society for Testing and Materials (ASTM), the EPA, some state requirements, and their own company standards. Many of the performance characteristics of gasoline can be controlled during refining and blending. Many additives are blended into gasoline before it is available to the public **(Figure 28–3)**. The major factors affecting fuel performance are antiknock quality, volatility, sulfur content, and deposit control.

Antiknock Quality

An **octane** number or rating was developed by the petroleum industry so the antiknock quality of a gasoline could be rated. The octane number is a measure of the fuel's tendency not to experience detonation in the engine. The higher the octane rating, the less the engine will have a tendency to knock.

Two methods are used for determining the octane number of gasoline: the motor octane number (MON) method and the research octane number (RON) method. Both use a laboratory single-cylinder engine equipped with a variable head and knock meter to measure knock intensity. A test sample of the fuel is used in the engine as the engine's compression ratio and air-fuel mixture are adjusted to develop specific knock intensity. There are two primary standard reference fuels: **isooctane** and **heptane**. Isooctane does not knock in an engine but is not used in gasoline because of its expense. Heptane knocks

Purpose	Additive
Octane enhancer	Methyl *t*-butyl ether (MTBE) *t*-butyl alcohol (TBA) Ethanol Methanol
Antioxidant	Butylated methyl, ethyl and dimethyl phenols Various other phenols and amines
Metal deactivator	Disalicylidene-*N*-methyldipropylene- triamine *N,N*'-disalicylidene-1,2- Ethanediamine Other related amines
Ignition controller	Tri-o-cresylphosphate (TOCP)
Icing inhibitor	Isopropyl alcohol
Detergent/dispersant	Various phosphates, amines, phenols, alcohols, and carboxylic acids
Corrosion inhibitor	Carboxylic, phosphoric, and sulfonic acids

FIGURE 28-3 The various additives blended with gasoline for today's vehicles.

severely in an engine. Isooctane has an octane number of 100. Heptane has an octane number of zero.

A fuel of unknown octane value is run in the test engine equipped with a variable compression cylinder head and a knock meter. The severity of knock is measured. Various proportions of isooctane and heptane are run in the engine to duplicate the severity of the engine knock when the test fuel was run. When the knock caused by the isooctane and heptane mixture matches that caused by the fuel being tested, the octane number is established by the percentage of isooctane in the mixture. For example, if 85 percent isooctane and 15 percent heptane produced the same knock severity as the tested fuel, that fuel would be rated as having an octane rating of 85.

The octane rating required by law and the one displayed on gasoline pumps is the **Antiknock Index (AKI)**. It is the average of RON and MON. The AKI is stated as (R+M)/2.

Most modern engines are designed to operate efficiently with regular grade gasoline and do not require high-octane gasoline. One of the things to remember about high-octane fuel is that it burns slower than low-octane gasoline. This is why it is less likely to cause detonation. Most engine control systems have a sensor to detect if a knock is occurring so the PCM can retard the ignition timing to prevent detonation. Higher-octane gasoline is used in high-performance engines because they have high compression ratios, which provide greater power output.

Volatility

Gasoline is very volatile. It readily evaporates, so it readily mixes with air for combustion. The volatility of gasoline affects the following performance characteristics or driving conditions:

- *Cold Starting and Warm-up:* A fuel can cause hard starting, hesitation, and stumbling during warm-up if it does not readily vaporize. A fuel that vaporizes too easily in hot weather can form vapor in the fuel delivery system, causing **vapor lock** or a loss of performance. If gasoline vaporizes while it is in a fuel line, it can stop the flow of gasoline. Rather than flow through the line, the pressurized fuel will compress the vapor, not move it. Vapor lock can cause a variety of driveability problems. Gasoline blended for summer (hot weather) use is less volatile (does not evaporate as easily) than winter gasoline.
- *Altitude:* Gasoline vaporizes more easily at high altitudes, so volatility is controlled in blending according to the elevation of the location where the fuel is sold.
- *Crankcase Oil Dilution:* A fuel must vaporize to prevent diluting the crankcase oil with liquid fuel or break down the oil film on the cylinder walls, causing scuffing or scoring. The liquid eventually enters the oil in the crankcase, forming an accumulation of sludge, gum, and varnish as well as affecting the lubrication properties of the oil.

There are three methods of measuring the volatility of a fuel. The most common is the **Reid vapor pressure (RVP)** test. The RVP test is performed by placing a sample of gasoline into a sealed metal container that has a pressure measuring device attached to it. The container is submerged in heated (100 °F or 38 °C) water. As the fuel is heated, it vaporizes. Remember, the more volatile a fuel is, the easier it will vaporize. As fuel vaporizes, it creates vapor pressure within the container. Vapor pressure is measured in psi.

Sulfur Content

Some of the sulfur in the original crude oil may be found in refined gasoline. Sulfur content is reduced at the refinery to limit the amount of corrosion it can cause in the engine and exhaust system. When the hydrogen in the fuel is burned, one of the by-products

of combustion is water. Water leaves the combustion chamber as steam but can condense back to water when passing through a cool exhaust system. When the engine is shut off and cools, steam condenses back to a liquid and forms water droplets.

When the sulfur in the fuel is burned, it combines with oxygen to form **sulfur dioxide**. This compound can combine with water to form sulfuric acid, which is a highly corrosive compound. This acid is the leading cause of exhaust valve pitting and exhaust system deterioration. Sulfuric acid also attacks the linings of the main and rod bearings. This is one reason engine oil needs to be changed regularly. With catalytic converters, the sulfur dioxide can cause the obnoxious odor of rotten eggs during engine warm-up. To reduce corrosion caused by sulfuric acid, the sulfur content in gasoline is limited to less than 0.01 percent.

Deposit Control Several additives are added to gasoline to control harmful deposits; these include gum or oxidation inhibitors, detergents, metal deactivators, and rust inhibitors.

Basic Gasoline Additives

At one time, all a gasoline-producing company needed to do to provide its product was to pump the crude from the ground, run it through the refinery to separate it, dump in a couple of grams of lead per gallon, and deliver the finished product to a service station. Of course, automobiles were much simpler then and what they burned did not seem critical. As long as the gasoline vaporized easily and did not cause engine knock, everything was fine.

Back then, lead compounds, such as tetraethyl lead (TEL) and tetramethyl lead (TML), were added to gasoline to increase its octane rating. However, since the mid-1970s, vehicles have been designed to run on unleaded gasoline only. Leaded fuels are no longer available as automotive fuels. Because of the poisoning effect lead has on humans and on catalytic converters; today's gasoline is limited to a lead content of 0.06 gram per gallon. Now, to achieve the desired octane rating, methylcyclopentienyl manganese tricarbonyl (MMT) is normally added to gasoline.

Anti-Icing or Deicer

Isopropyl alcohol is added seasonally to gasoline as an anti-icing agent to prevent fuel line freeze-up in cold weather.

Metal Deactivators and Rust Inhibitors

These additives are used to inhibit reactions between the fuel and the metals in the fuel system that can form abrasive and filter-plugging substances.

Gum or Oxidation Inhibitors

Some gasoline contains aromatic amines and phenols to prevent the formation of gum and varnish. During storage, harmful gum deposits can form due to the reaction between some gasoline molecules with each other and with oxygen. Oxidation inhibitors are added to promote gasoline stability. They help control gum, deposit formation, and staleness.

Gum content is influenced by the age of the gasoline and its exposure to oxygen and certain metals such as copper. If gasoline is allowed to evaporate, its residue can form gum and varnish.

Detergents

Detergent additives are designed to do only what their name implies—clean certain critical parts inside the engine. They do not affect octane.

Performance TIP

Adding nitrous oxide to the air-fuel mixture is not something done by oil refineries. Rather, it is commonly done by those seeking more instantaneous power from their engines. Nitrous oxide is injected as a dense liquid. When nitrous oxide is heated, it breaks down into nitrogen and oxygen. This provides more oxygen inside the cylinder when the fuel ignites. Because there is more oxygen, more fuel can be injected into the cylinder. The engine therefore produces more power. Nitrous oxide also improves engine performance by cooling the gases in the cylinder, thereby making the air denser. Nitrous oxide is injected into the engine's intake when the driver pushes a button to activate the system. Nitrous kits, which include nearly all that is needed to add the system to an engine, are available for many engines. The nitrous tanks typically store enough nitrous for 3 to 5 minutes of operation.

Oxygenates

Oxygenates are compounds, such as alcohols and ethers, that contain oxygen. By carrying oxygen, the fuel tends to lean the mixture. Oxygenates improve combustion efficiency, thereby reducing emissions. Many oxygenates also serve as excellent octane enhancers when blended in gasoline **(Figure 28–4)**. Oxygenated fuels tend to have lower CO emissions.

It should be noted that the use of oxygenated gasoline may cause a slight decrease in fuel economy in late-model vehicles. This is due to the HO_2S detecting extra oxygen and the PCM responding to this by richening the mixture.

Oxygenates added to gasoline produce what is referred to as **reformulated gasoline (RFG)**. RFG is also called "cleaner-burning" gasoline and costs slightly more than normal gasoline. RFG can be used in most engines with no modifications. RFG was formulated to reduce exhaust emissions.

Ethanol

By far the most widely used gasoline oxygenate additive is **ethanol** (ethyl alcohol), or grain alcohol. Ethanol is a noncorrosive and relatively nontoxic alcohol made from renewable biological sources. Blending 10 percent ethanol into gasoline results in an increase of 2.5 to 3 octane points. With ethanol-blended gasoline, air toxics are about 50 percent less. Ethanol decreases CO emissions due to the higher oxygen content of the fuel.

Ethanol can also loosen contaminants and residues that may have gathered in the vehicle's fuel system. All alcohols have the ability to absorb the water in the fuel system that results from condensation. This reduces the chances of fuel line freeze-up during cold weather.

Methanol

Methanol is the lightest and simplest of the alcohols and is also known as wood alcohol. It can be distilled from coal or other sources, but most of what is used today is derived from natural gas.

Many automakers continue to warn motorists about using a fuel that contains more than 10 percent methanol and CO solvents by volume. It is far more corrosive to fuel system components than ethanol, and it is this corrosion that has automakers concerned. Methanol is also highly toxic and there are safety concerns with ingestion, eye or skin contact, and inhalation.

Methanol can be used directly as an automotive fuel but the engine must be modified for its use. It can also be used in flexible fuel vehicles as M85, which is 85 percent methanol. However, this is not very common. In the future, methanol could be the fuel of choice for providing hydrogen to power fuel cell vehicles.

MTBE

In the past, methyl tertiary butyl ether (MTBE) was used as an octane enhancer because of its excellent compatibility with gasoline. Methanol can be used to make MTBE. However, MTBE production and its use have declined because it was found to contaminate groundwater. As of 2004, MTBE is no longer used in gasoline and has been replaced by ethanol and other oxygenates such as tertiary amyl methyl ether (TAME) and ethyl tertiary butyl ether (ETBE).

Aromatic Hydrocarbons

These are petroleum-derived compounds, including benzene, xylene, and toluene, that are being used as octane boosters.

Top Tier Gasoline

As fuel injection and advanced emission control systems became standard on modern engines, deposits left from fuel additives became a concern. The various substances in gasoline, such as olefins, can break down and leave gummy deposits on intake

	Ethanol	MTBE	ETBE	TAME
Chemical formula	CH_3CH_2OH	$CH_3OC(CH_3)_3$	$CH_3CH_2OC(CH_3)_3$	$(CH)_3CCH_2OCH_3$
Octane, (R+M)/2	115	110	111	105
Oxygen content, % by weight	34.73	18.15	15.66	15.66
Blending vapor pressure, RVP	18	8	4	1.5

FIGURE 28–4 The typical properties of the common oxygenates.

valves and fuel injectors. These deposits can affect how well the engine runs, and also have an effect on exhaust emissions. To help reduce the problems resulting from the fuel breaking down, Top Tier Detergent Gasoline was developed.

Typically called Top Tier gas, this fuel is a result of the automobile manufacturers and fuel suppliers working together. A fuel that meets the Top Tier gas rating has special detergents that do not break down under the high heat loads common to gasoline direct injection engines. Top Tier gas uses a detergent package that has been tested against performance standards. The goal of Top Tier gas is to reduce the chance of intake valve and combustion chamber deposit formation and injector fouling. Most brand name gasoline providers offer top tier gas and diesel fuel.

Gasoline Quality Testing

Two tests can be done to test the quality of gasoline: the Reid vapor pressure test and the alcohol content test.

Testing the RVP of Gasoline

RVP is a measure of the volatility of gasoline. Fuels that are more volatile vaporize more easily, creating more pressure. Increasing the RVP of a gasoline permits the engine to start easier in cold weather. The RVP of winter blend gasoline is about 9.0 psi. Summer grade is typically around 7.0 psi.

A special fuel vapor pressure tester is needed to test the RVP of gasoline. Make sure the gasoline that is being tested is cool. Then put a sample in the tester's container and secure the seal in the container as soon as the gasoline is in it. Put hot water in another container and put the container holding the fuel into it. Make sure that most of the container holding the fuel is covered by water. Connect the pressure gauge assembly to the container holding the gasoline. Put a thermometer in the water. When the water temperature is 105 °F (40 °C) for at least 2 minutes, take your pressure reading and compare it to specifications.

Alcohol in Fuel Test

Pump gasoline may contain a small amount of alcohol, normally up to 10 percent. If the amount is greater than that, problems may result, such as fuel system corrosion, fuel filter plugging, deterioration of rubber fuel system components, and a lean air-fuel ratio. These fuel system problems caused by excessive alcohol in the fuel may cause driveability complaints such as lack of power, acceleration stumbles, engine stalling, and no-start. If the correct amount of fuel is being delivered to the engine and there is evidence of a lean mixture, check for air leaks in the intake and then check the gasoline's alcohol content.

There are many different ways to check the percentage of alcohol in gasoline. Some are more exact than others and some require complex instruments.

PROCEDURE

To check the amount of alcohol in a sample of gasoline:

STEP 1 Obtain a 100-milliliter (mL) cylinder graduated in 1 mL divisions.

STEP 2 Fill the cylinder to the 90 mL mark with gasoline.

STEP 3 Add 10 mL of water to the cylinder so it is filled to the 100 mL mark.

STEP 4 Install a stopper in the cylinder, and shake it vigorously for 10 to 15 seconds.

STEP 5 Carefully loosen the stopper to relieve any pressure.

STEP 6 Install the stopper and shake vigorously for another 10 to 15 seconds.

STEP 7 Carefully loosen the stopper to relieve any pressure.

STEP 8 Place the cylinder on a level surface for 5 minutes to allow liquid separation.

STEP 9 Observe the liquid. Any alcohol in the fuel is absorbed by the water and settles to the bottom. If the water content in the bottom of the cylinder exceeds 10 mL, there is alcohol in the fuel. For example, if the water content is now 15 mL, there was 5 percent alcohol in the fuel. NOTE: Because this procedure does not extract 100 percent of the alcohol from the fuel, the percentage of alcohol in the fuel may be higher than indicated.

Alternatives to Gasoline

The actual cost of using gasoline in engines is not limited to the price per gallon or liter. There are other factors, or costs, that need to be considered: our environment, our dependence on foreign oil supplies, and the depletion of future oil supplies. Any reduction in the use of fossil fuels will have benefits for generations to come. Let us look at some simple facts:

- The number of household vehicles in the U.S. is growing and nearly tripled from 1969 to 2001. Last year, in North America nearly 20 million new cars and light trucks were sold. These numbers do not include the automobiles on the road that were not bought that year. There are well over 250 million vehicles on the road.
- It is estimated that the total miles covered by those automobiles, in one year, is well over 2,000 billion. To put this in perspective, let us assume the average fuel mileage of all those vehicles is 20 miles per gallon. This means over 100 billion gallons of oil are burned by automobiles each year.
- By 2020, oil consumption is expected to grow by nearly 40 percent and our dependence on foreign oil sources is projected to rise to more than 60 percent.
- A 10 percent reduction in fossil fuel consumption by cars and light trucks would result in using 24 million less gallons of oil each day.

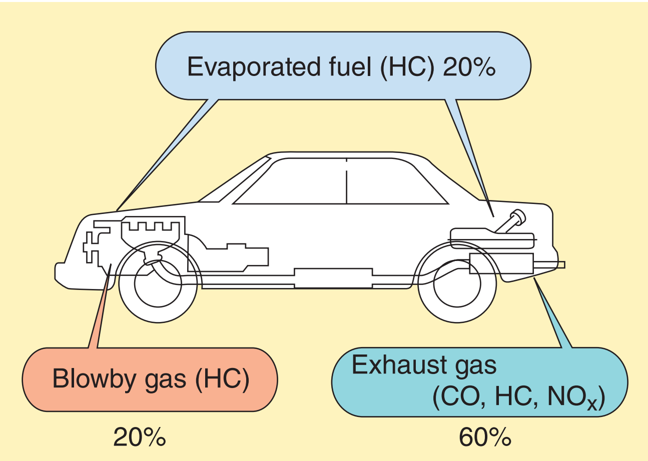


FIGURE 28–5 Gasoline-powered vehicles emit a wide assortment of pollutants.

- Americans spend close to $100,000 per minute to buy foreign oil, and oil purchases are a major contributor to the national trade deficit.
- Automobiles and gasoline contribute to environmental damage. Not only do automobiles emit pollutants **(Figure 28–5)**, but the extraction, production, and marketing of gasoline also leads to air pollution, water pollution, and oil spills.
- Because of the heavy reliance on fossil fuels, the transportation industry is one of the sources of carbon dioxide and other heat-trapping gases that cause global climate change.

Alternative Fuels

The concerns of burning fossil fuels and the decline of their reserves have led to a comprehensive search for alternative fuels. While looking at the viability of an alternative fuel, many things are considered, including emissions, cost, availability, energy density, safety, engine life, fueling facilities, weight and space requirements for fuel tanks, and the range of a fully-fueled vehicle. By using alternative fuels, we not only can reduce our reliance on petroleum, but we can reduce emissions and the effects an automobile's exhaust has on global warming. Many of these fuels are also being considered as the fuel of choice for fuel cell electric vehicles.

Much attention has been paid to renewable fuel sources. **Renewable fuels** are those derived from nonfossil sources and produced from plant or animal products or wastes (biomass). Biomass fuels, such as biodiesel and ethanol, can be burned in internal combustion engines. Biomass fuels tend to be carbon neutral, which means that during combustion, they release the same amount of CO_2 that was absorbed from the atmosphere when the plant or animal was living. Combustion does not cause an increase in CO_2 emissions. Ethanol and methanol are used as oxygenates for blending with gasoline. They can also be used as the primary energy source for internal combustion engines. However, because ethanol is made from renewable sources it is the most commonly used.

Energy Density Each of these alternative fuels can be looked at in terms of **energy density**. This is the amount of energy provided by a standard weight of each. Energy density is typically rated as joules per kilogram. A joule can be defined as the energy required to produce 1 watt of power for 1 second. Refer to **Table 28–1** to review the energy densities of common energy sources.

TABLE 28–1 THE ENERGY DENSITIES OF COMMON ENERGY SOURCES

Material	Approximate energy per kilogram
Uranium 238	20 terajoules
Hydrogen	143 megajoules
Natural gas	53.6 megajoules
LPG propane	49.6 megajoules
Gasoline	47.2 megajoules
Diesel fuel	46.2 megajoules
Gasohol E10	43.54 megajoules
Biodiesel	42.20 megajoules
Gasohol E85	33.1 megajoules
Coal	32.5 megajoules
Methanol	19.7 megajoules
Supercapacitor	100 kilojoules
Lead-acid battery	100 kilojoules
Capacitor	360 joules

Ethanol

Ethanol is a high-quality, low-cost, high-octane fuel (rated at 115) that burns cleaner than gasoline. The use of ethanol as a fuel is not new. Ford's Model T was designed to run on ethyl alcohol (ethanol). Ethanol (CH_3CH_2OH), commonly called grain alcohol, is a renewable fuel made from nearly anything that contains carbon **(Figure 28–6)**. It is most commonly produced by fermenting and distilling corn, cornstalks, wheat, sugar cane, other grains, or biomass waste. Ethanol can be used as a high-octane fuel in vehicles and is often mixed with gasoline to boost its octane rating.

Because ethanol is an alcohol, it can absorb moisture that may be present in a fuel system. The absorbed water is simply passed with the fuel and burned by the engine. However, if the moisture content in the fuel becomes too high, the water will separate from the fuel and drop to the bottom of the fuel tank. If this is suspected, remove all fuel and water from the tank and refill it with clean ethanol-blended fuel.

For automotive use, ethanol is blended with gasoline. The common blends are an E10 blend, which is 10 percent ethanol and 90 percent gasoline, E15, and E85, which is 85 percent ethanol. Most gasoline-powered vehicles in North America can run on blends of up to 10 percent ethanol, and some are equipped to run on E85 **(Figure 28–7)**.

The use of E85 has many advantages over the use of traditional gasoline:

- It is produced in the United States and can reduce our reliance on foreign oil.
- Vehicles do not need many modifications to use it.
- Its emissions are cleaner than those of a gasoline engine.
- CO_2 emissions are much lower.
- Ethanol-blended fuel keeps the fuel system clean because it does not leave varnish or gummy deposits.

However, the infrastructure for E85 is weak. There are few fuel filling stations that offer E85. The amount

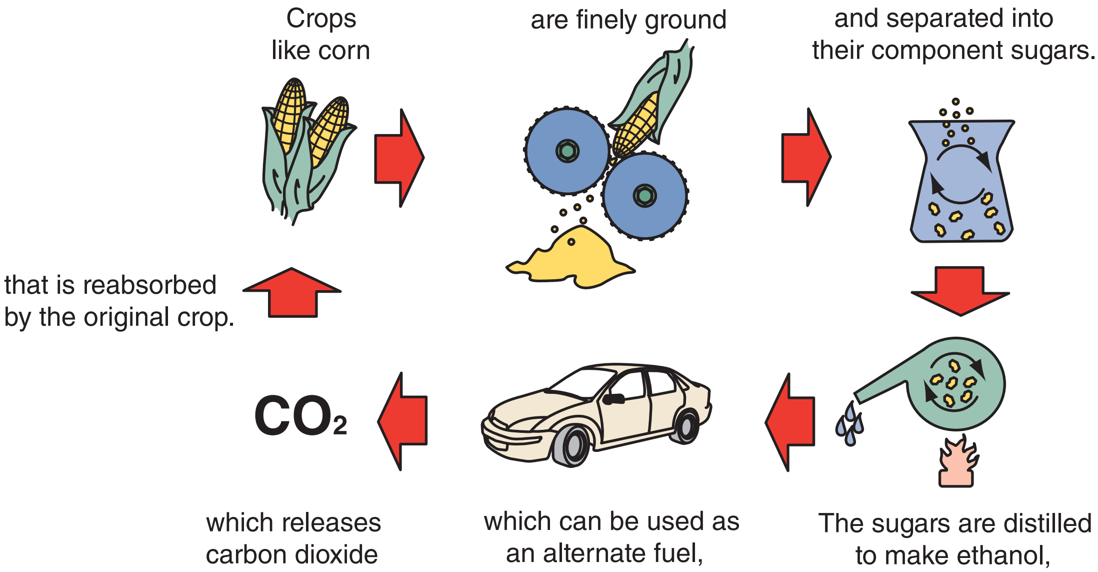


FIGURE 28–6 The carbon cycle of ethanol.

FIGURE 28–7 Two forms of ethanol fuel available at the pump.

of energy it takes to produce E85 is more than the energy it provides. E85 also has about 25 percent less energy than gasoline; therefore, fuel economy will decrease by about that much in a typical vehicle.

Methanol

Methanol (CH_3OH) is a clean-burning alcohol fuel that is often made from natural gas but can also be produced from coal and biomass. Because North America has an abundance of these materials, the use of methanol can decrease the dependence on foreign oils. Methanol is very corrosive and an engine designed to run on it must be equipped with special plastic and rubber components, as well as a stainless steel fuel system. Methanol use as a fuel has declined through the years but may become the fuel for fuel cell vehicles. Currently, these alcohols are mixed with 15 percent gasoline, creating M85. The small amount of gasoline improves the cold-starting ability of the alcohols.

SHOP TALK

After 40 years of running on methanol, a nonrenewable fuel made from natural gas, the Indy Racing League (IRL) in 2007 switched to ethanol to power the engines **(Figure 28–8)** in their race series. Also, in 2011 NASCAR mandated the use of E15 in all of their racing. According to NASCAR, E15 is good for racing, good for the environment, and good for America.

FIGURE 28–8 An Indy ethanol-fueled race engine.

Propane/LP Gas

Propane, also referred to as **liquefied petroleum gas** or **LP gas**, is used by many fleets around the world in taxis, police cars, school buses, and trucks **(Figure 28–9)**. LP gas is similar to gasoline chemically. It is called liquid petroleum because it is stored as a liquid in a pressurized bottle. The pressure

FIGURE 28–9 A propane-fueled delivery truck.

increases the boiling point of the liquid and prevents it from vaporizing. LP gas burns clean because it vaporizes at atmospheric temperatures and pressures. This means it emits less HCs, CO_2, and CO. Propane is a clean-burning fuel that provides a driving range closer to gasoline than other alternative fuels.

Propane allows for quick starting, even in the coldest of climates. It also has a higher octane rating than gasoline. However, there is a reduction of engine power output (about 5 percent) because it is difficult to fill the cylinders with the gas. Propane is a dry fuel that enters the engine as vapor. Gasoline, on the other hand, enters the engine as tiny droplets of liquid. LP gas is a good alternative to gasoline but it is a fossil fuel and therefore is not a favored alternative fuel for the future.

LP gas vehicles have designated engine fuel controls and special tanks or cylinders to store the gas **(Figure 28–10)**. However, the gas is stored at about 200 pounds per square inch. Under this pressure, the gas turns into a liquid and is stored as a liquid. When the liquid propane is drawn from the tank, it warms and changes back to a gas before it is burned in the engine. The propane fuel system is a completely closed system.

Compressed Natural Gas

Natural gas, **compressed natural gas (CNG)** and liquefied natural gas (LNG), is a very clean-burning fuel. There is an abundant supply of natural gas. It burns cleaner and it is less expensive than gasoline. Combustion with CNG also results in 25 percent less CO_2 emissions because natural gas has lower carbon content. In addition, natural gas is nontoxic, so it isn't harmful to soil or water. These factors make the use of natural gas an attractive alternative fuel, especially for high-mileage, centrally-fueled fleets that do not travel far from their central location.

The main substance in natural gas is methane. Natural gas is a highly flammable colorless gas and is commonly used in homes for heaters, stoves, and water heaters. CNG and LNG are considered alternative fuels under the Energy Policy Act of 1992. CNG is used in light- and medium-duty vehicles, whereas LNG is used in transit buses, train locomotives, and long-haul semi-trucks.

CNG must be safely stored in cylinders at pressures of 2,400, 3,000, or 3,600 pounds per square inch **(Figure 28–11)**. This is the biggest disadvantage of using CNG as a fuel. The space occupied by these cylinders takes away luggage and, sometimes, passenger space. As a result, CNG vehicles have a shorter driving range than comparable gasoline vehicles. Bi-fuel vehicles are equipped to store both CNG and gasoline and will run on either.

FIGURE 28–11 The storage tanks for CNG.

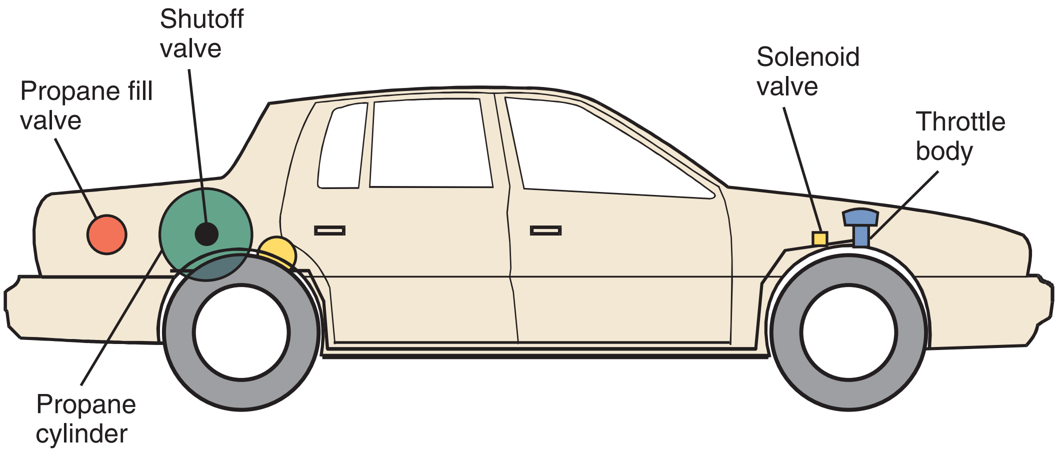


FIGURE 28–10 The layout of a propane-fueled car.

Natural gas turns into a liquid when it is cooled to –263.2 °F (–164 °C). Because it is a liquid, a supply of LNG takes up less room in the vehicle than does CNG. Therefore, the driving range of an LNG vehicle is longer than a comparable CNG vehicle. For vehicles needing to travel long distances, LNG is a good choice. However, the fuel must be dispensed and stored at extremely cold temperatures. This requires refrigeration units that also take up space. This is why LNG is not a practical fuel for personal use and is only used in heavy-duty applications.

The use of natural gas as a fuel has advantages due to its domestic availability, vast distribution infrastructure, low cost, and clean-burning qualities. However, the space taken by the CNG cylinders and their weight, about 300 pounds, can be considered a disadvantage in most applications.

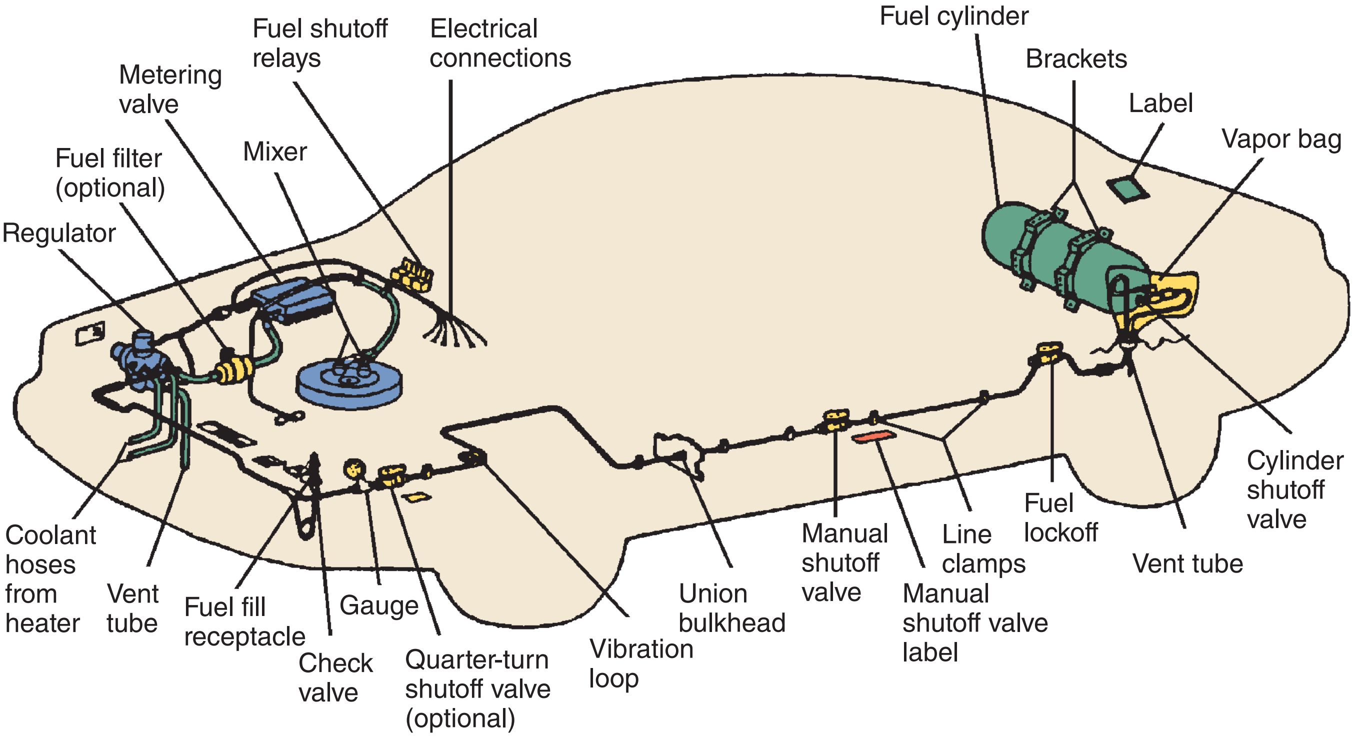
The basic components of a natural gas vehicle (NGV) are shown in **Figure 28–12**. The CNG fuel system moves high-pressure natural gas from the storage cylinder to the engine. It also reduces the pressure of the gas so it is compatible with the engine's fuel-management system. The natural gas is injected into the engine intake air the same way gasoline is injected into a gasoline-fueled engine, the high temperatures and pressures in the combustion chamber quickly ignite the gas.

There are three basic types of natural gas vehicles:

- Dedicated, which are designed to run only on natural gas. These can be light or heavy-duty vehicles.
- Bi-fuel vehicles have two separate fuel systems that allow them to run on either natural gas or gasoline and they are typically light-duty vehicles.
- Dual-fuel, which are normally used only with heavy-duty applications. These have natural gas and diesel fuel systems.

Honda Civic Natural Gas Vehicle The Honda Civic converted to use CNG is based on a typical Civic sedan **(Figure 28–13)**: the same engine, transmission, accessories, and body. The major differences reflect the modifications to the engine. In a normal Civic the 1.8 liter engine is rated at 140 hp @ 6,500 rpm and 128 lb-ft. @ 4,300 rpm. The engine in the CNG car is rated lower at 110 hp @ 6,500 rpm and 106 lb-ft. @ 4,300 rpm. The CNG engine also has a higher compression ration; 12.7:1 compared to 10.6:1. Both have the same EPA emissions rating and about the same fuel mileage estimates.

The natural gas system is comprised of the fuel tank, fuel receptacle, manual shut-off valve, high-pressure fuel filter, fuel lines, fuel pressure regulator, low-pressure fuel filter, and injectors; the entire



Courtesy of Teleflex GFI Control Systems Inc.

FIGURE 28–12 NGV system components.

FIGURE 28-13 A CNG Honda Civic.

> **SHOP TALK**
>
> The fill nozzle on the gas dispenser may vary with the dispenser's location. The different nozzles are designed for different refueling pressures. If the wrong nozzle is used, the storage tank may be under- or over-filled. The common nozzle designations and their rated pressures are as follows:
>
> - P24—2,400 psi (16,500 kPa)
> - P30—3,000 psi (20,700 kPa)
> - P36—3,600 psi (24,800 kPa)

system is in compliance with the National Fire Protection Association's Vehicular Gaseous Fuel Systems (NFPA-52) code.

To make sure only quality and well-filtered gas enters the storage tank in a Civic; Honda highly recommends that the vehicle be refueled at a public commercial-grade CNG refueling station. They further recommend not installing a home refueling station because of the wide variation of natural gas quality delivered to homes. The major worry is moisture, which can cause damage and result in expensive repairs.

> **Warning!** Natural gas is a highly flammable and explosive gas. Serious injury, or death, can result from the ignition of leaking gas. If a leak is suspected, the car must be shut down and the leak identified and fixed.

The storage system is designed to hold CNG at the maximum of 3,600 psi/24,800 kPa. The only time a gas smell or a hiss should be heard is during refueling. Any other time may indicate there is a gas leak. If a leak is suspected, the system should be shut down immediately and the car pushed outdoors in a well-ventilated area. Turn the ignition switch to the lock position. Make sure to keep the car away from heat, sparks, and flame. Then open the car's windows and trunk to allow any trapped gas to escape. Close the manual shut-off valve by turning it one-quarter turn clockwise (to the right).

Refueling is done by opening the fuel receptacle door and removing the dust cap from the receptacle. The fill nozzle from the dispenser is then inserted into the fuel receptacle. Now turn the lever until the arrows on the nozzle point to each other. This begins the refueling process, which will end automatically once the tank is full. Once refueling is complete, disconnect the fill nozzle from the fuel receptacle by slowly turning the lever on the nozzle 180 degrees. Then securely fasten the receptacle dust cap onto the fuel receptacle. Then close the fuel receptacle door.

The fuel gauge displays the amount of gas that remains in the tank; this is determined by the system looking at the pressure and temperature of the gas in the tank. A "low" reading on the gauge means the fuel pressure has dropped to about 3,000 psi and a "full" reading indicates a tank pressure of 3,600 psi. The low fuel indicator will come on whenever the fuel level is low. It may also come on during very cold weather, although there may be ample gas in the tank. This is because the pressure in the tank will decrease when it is cold.

P-Series Fuels P-series is a new fuel classified as an alternative fuel. It is a blend of natural gas liquids, ethanol, and biomass-derived CO solvents. P-series fuels are clear, colorless, 89–93 octane, and liquid blends that are formulated to be used alone or freely mixed, in any proportion, with gasoline. Like gasoline, low vapor pressure formulations are produced to prevent excessive evaporation during summer, and high vapor pressure formulations are used for easy starting in cold weather.

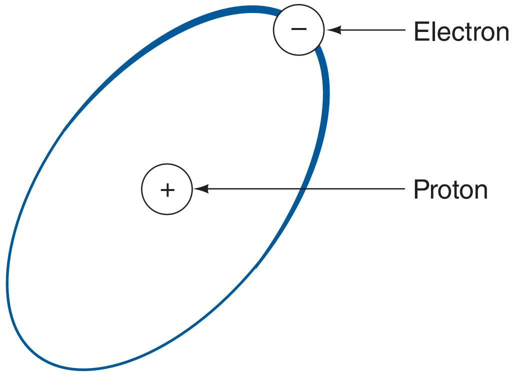


FIGURE 28–14 A hydrogen atom.

Each gallon of P-series fuel emits approximately 50 percent less CO_2, 35 percent less HCs, and 15 percent less CO than gasoline. It also has 40 percent less ozone-forming potential.

Hydrogen

Hydrogen is cited by some as the fuel of the future because it is full of energy due to its atomic structure and abundance. It is the simplest and lightest of all elements and has one proton and one electron **(Figure 28–14)**. Hydrogen is a colorless and odorless gas. It is one of the most abundant elements on earth. The combination of hydrogen and oxygen forms water.

Hydrogen is extracted from various substances through a process that pulls hydrogen out of its bond with another element or elements. Hydrogen is commonly extracted from water, fossil fuels, coal, and biomass. The two most common ways that hydrogen is produced are steam reforming and electrolysis. Currently it costs much more to produce hydrogen than it does to produce other fuels such as gasoline. This, again, is an obstacle and the focus of much research.

Hydrogen Fuel To demonstrate the energy in hydrogen, there are hydrogen bombs. Some manufacturers are experimenting with burning hydrogen in internal combustion engines. Three major auto manufacturers have developed and tested hydrogen-fueled internal combustion engines; actually these vehicles have bi-fuel capabilities. BMW's bi-fueled V12 engine uses liquefied hydrogen or gasoline as its fuel. When running on hydrogen, the engine emits zero CO_2 emissions. To store the liquefied hydrogen, the storage tank is kept at a constant temperature of –423 °F (–253 °C). At this temperature, the liquid hydrogen has the highest possible energy density.

Ford and Mazda have also developed internal combustion engined vehicles with hydrogen power. Mazda is using its rotary engine, which it claims is ideal for using hydrogen fuel. The concept vehicles from both manufacturers are also bi-fuel vehicles. Ford has converted a V10 and a 2.3-liter, I-4 engine to run on hydrogen. Engine modifications include a higher compression ratio, special fuel injectors, and a modified electronic control system. When running on hydrogen, the engine is more than 10 percent more efficient than when it runs on gasoline and emissions levels are very close to zero. Because the fuel contains no carbon, there are no carbon-related emissions (CO, HC, or CO_2).

Typically, an engine running on hydrogen produces less power than a same-sized gasoline-powered engine. Ford added a supercharger with an intercooler to the engines to compensate for the loss of power.

Infrastructure and Storage Other than manufacturing costs, the biggest challenge for hydrogen-powered vehicles is the lack of an infrastructure. Vehicles need to be able to be refueled quickly and conveniently.

Hydrogen is normally stored as a liquid or as a compressed gas. When stored as a liquid, it must be kept very cold. Keeping it that cold adds weight and complexity to the storage system. The tanks required for compressed hydrogen need to be very strong, and that translates to weight. Also, higher pressures mean more hydrogen can be packed into the tank but the tank must be made stronger before the pressure can be increased.

Flex Fuel Vehicles

Flexible fuel vehicles (FFV) can run on ethanol or gasoline, or a mixture of the two **(Figure 28–15)**. The alcohol fuel and gasoline are stored in the same tank. This gives the driver flexibility and convenience when refilling the fuel tank. Many vehicles are fitted with systems that allow the use of multiple fuels. These include vehicles from Chrysler, Ford Motor Co., General Motors, and Nissan. Flex fuel vehicles may have a clover leaf symbol (internally or externally) that shows they can use multiple fuels, in addition label at the fuel receptacle clearly states that up to E85 or gasoline can be used **(Figure 28–16)**.

Most of these have a virtual fuel sensor that relies on inputs from the HO_2S for oxygen readings. These systems adjust the air-fuel mixture according to the oxygen readings of the different fuel compositions that may be in the fuel tank.

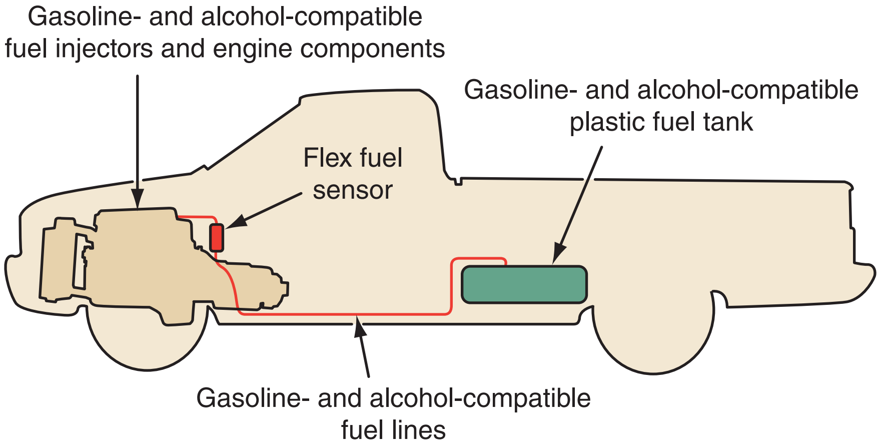


FIGURE 28–15 A flexible fuel vehicle.

FIGURE 28–16 A common flex fuel label on the outside of the vehicle.

FIGURE 28–17 Diesel fuel traditionally costs more than gasoline.

Diesel Fuel

Diesel fuel is designed to be used by diesel engines and is therefore not an alternative fuel for gasoline engines. Diesel fuel is a fossil fuel but it has different properties and characteristics than gasoline. Diesel fuel is heavier and has more carbon atoms, and it has about 15 percent more energy density. Diesel fuel also evaporates much more slowly than gasoline—its boiling point is actually higher than the boiling point of water. The downside of diesel fuel is that it costs more per gallon than gasoline **(Figure 28–17)**.

Diesel fuel is used to power a wide variety of vehicles and other equipment. It fuels the diesel trucks you see moving down the highway moving heavy loads. It also is used in trains, boats, buses, farm equipment, emergency response vehicles, electric generators, and many other applications.

Cetane Ratings

Diesel fuel should ignite almost instantaneously when it is injected into a cylinder. The fuel's ignition quality is expressed by a **cetane rating (CN)**. The cetane rating of diesel fuel is a measure of the ease with which the fuel can be ignited **(Figure 28–18)**. Because diesel fuel ignites with compression instead of a spark, it is most efficient when it ignites as quickly as possible.

The cetane rating of the fuel is based on a test that uses a single-cylinder test engine with a variable compression ratio. As a result of the test, the fuel is assigned a cetane number. Cetane is a colorless, liquid hydrocarbon that ignites immediately when introduced to compression heat and pressures. Pure cetane has a numerical rating of 100 and diesel fuels are compared to cetane and rated according to its performance relative to pure cetane.

Actually, the cetane number represents the amount of time the fuel delays ignition after it has been introduced into the combustion chamber. Obviously, if the fuel ignites instantaneously (no delay), it will have a rating of 100. A short delay period allows the fuel to burn more completely, and

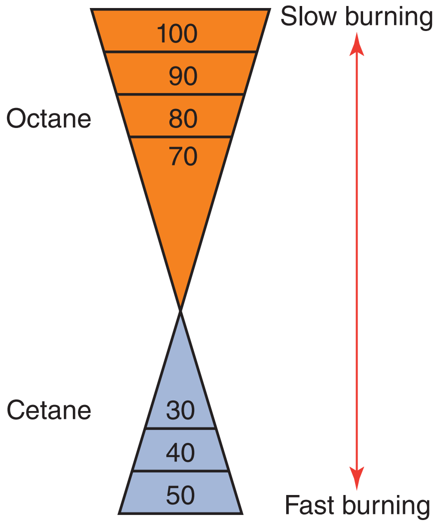


FIGURE 28–18 A comparison of cetane and octane ratings.

the engine will run more smoothly with more power while producing low emissions. Fuel that takes a longer time to ignite does not allow the engine to work as efficiently. Generally speaking, the cetane number expresses the fuel's ability to start the engine at low temperatures and warm up quickly, without misfires.

Today's diesel engines run best with a fuel rated between 45 and 55 CN. The typical ignition temperature of CN 45 fuel is around 482 °F (250 °C). The ignition temperature for a CN 40 fuel would be higher, about 550 °F (290 °C). The cetane number can be improved by adding compounds such as ethyl nitrate, acetone peroxide, and amyl nitrate. The required cetane rating for an engine depends on many factors including its engine design, size, speed of operation, and atmospheric conditions. Running a diesel engine with a fuel with a lower than recommended CN may cause abnormal noise and vibration, lower power output, excessive deposits and wear, and hard starting. The following is a list of commonly available diesel fuels with their cetane ratings:

- Regular diesel—CN 48
- Biodiesel blend (B20)—CN 50
- Premium diesel—CN 55
- Biodiesel (B100)—CN 55
- Synthetic diesel—CN 55

Grades of Diesel Fuel

The minimum quality standards for diesel fuel grades are established by the American Society for Testing Materials. They have defined two basic grades of diesel fuels; Number 1 and Number 2. Number 2 fuel is the most popular and distributed. However it contains a significant amount of paraffin wax. Wax, however, does contain a great amount of energy and adds to the fuel's viscosity and ability to lubricate, but paraffin wax may cause cold weather problems. As the fuel gets colder, wax crystals in the fuel lines can grow and inhibit the flow of the fuel, causing fuel starvation.

Number 1 diesel fuel is designed for extremely cold temperatures. It is less dense than #2 and has a different boiling point and less paraffin wax. Most often #1 is blended with #2 to improve cold weather starting. In moderately cold climates, the blend may be nine parts #2 mixed with one part #1. In very cold climates, the ratio may be as high as 50:50. Fuel economy can be expected to decrease during cold weather because of the use of #1 fuel in the diesel fuel blend.

Biodiesel Fuels

Biodiesel is an alternative fuel for diesel engines. **Biodiesel fuel** is not made from petroleum, rather it is made from renewable biological sources. Most commercially available biodiesel fuel is made from soybean oil. However, it is also produced from animal fats, recycled cooking oil, canola oil, corn, and sunflowers. The use of biodiesel fuel is not new; the first diesel engine ran on peanut oil. Biodiesel is considered a renewable fuel. To produce more fuel, more crops need to be planted.

Biodiesel can be used in diesel engines with little or no modifications to the engine. Pure biodiesel is biodegradable, nontoxic, and free of sulfur and aromatics. It can be used by itself or blended with petroleum-based diesel fuel. The two most common blends are B5, which is 95 percent petroleum-based fuel and 5 percent biodiesel fuel, and B20, which contains 20 percent biodiesel blended into regular diesel fuel.

An engine running on pure biodiesel (B100) emits much lower amounts of hydrocarbons, sulfur, carbon monoxide, carbon dioxide, and particulates when compared to running on petroleum-based fuel. However, EPA tests have shown that the use of pure biodiesel increases an engine's NO_x emissions by 10 percent.

Other than these emission-related advantages and disadvantages, biodiesel fuel can also help reduce our dependency on imported oil. In addition, its use allows diesel engines to last longer, run quieter and smoother because of the lubricant qualities of the fuel. The downside is simply cost; it costs more to produce biodiesel than petroleum-based fuel.

Most late-model diesel engines can use biodiesel fuel without modifying the engine or fuel system. However, diesel engines produced prior to 1992 need modifications, those are dependent on the manufacturer of the engine. Even the manufacturers of newer "clean" diesel engines carefully define how biodiesel should be used in their engines, For example, Volkswagen (VW) recommended that only mixtures up to 5 percent biodiesel (B5) should be used in their early automotive diesel engines. To show how things change regarding this fuel, recently VW has allowed the use of fuel blends with 20 percent biodiesel and recommends the use of B5, at all times, because of its better lubricating properties. The manufacturer's recommendations are very important since vehicle warranties may become invalid if the wrong fuel is used.

Ultra-Low Sulfur Diesel Fuel

As of 2007, nearly all diesel fuel available in the United States, Canada, and Europe is Ultra-low sulfur diesel (ULSD) fuel. This has become the standard diesel fuel with low sulfur content **(Figure 28–19)**. The previous standards allowed diesel fuel to contain up to 500 ppm of sulfur (S500). S15 or ULSD is a much cleaner fuel that has a maximum sulfur content of 15 ppm. Engines running on this fuel emit less NO_x, soot, and other unwanted sulfur compounds. It is important to note that the use of this new fuel plus the new emissions devices for diesel engines has resulted in more than a 90 percent reduction in soot and NO_x **(Figure 28–20)**.

However, in the refining process necessary to reduce the amount of sulfur, the amount of paraffin is also reduced. Paraffin is vital to the lubrication of a diesel engine. Therefore to offset the loss of paraffin, and to protect the engine, injection pump, and the injectors, additives are blended into the fuel to increase lubricity. Blending ULSD fuel with a biodiesel fuel will increase its lubricity, and in the correct proportions, may allow the disadvantages of using ULSD to be dismissed.

FIGURE 28–19 A ULSD fuel dispenser.

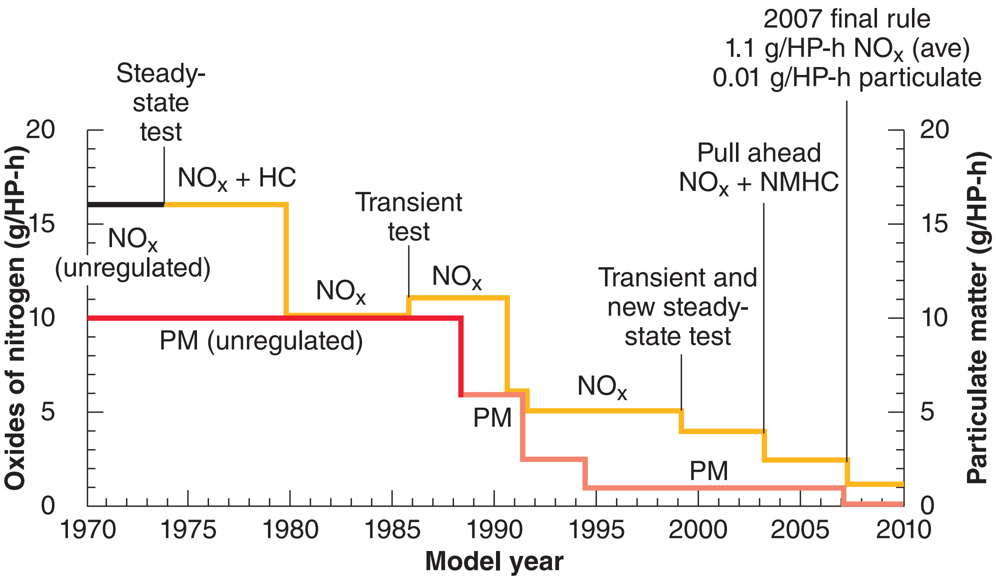


FIGURE 28–20 Current EPA NO_x emission standards for diesel engines.

Diesel Engines

Diesel engines in cars and light trucks will become more common soon. There are many reasons for this, one of which is that low sulfur diesel fuel is now available in the United States. This has eliminated some of the concerns about a diesel engine's high emission levels. Diesel engines provide more torque **(Figure 28–21)** than a gasoline engine of the same size and consume less fuel per mile.

The fuel injected into a diesel engine is ignited by the heat of compression. A diesel engine needs a compression ratio of at least 16:1. Intake air is compressed until its temperature reaches about 1,000 °F (540 °C). This high compression ratio and the resulting high compression pressures make a diesel engine more fuel efficient than a gasoline engine. Because a diesel engine has very high compression pressures and produces high amounts of torque, a diesel engine is made stronger and heavier than the same size gasoline engine. Because of their basic construction, diesel engines tend to last longer and therefore have higher resale values.

The fuel efficiency of a diesel also results from the fact the engines do not suffer from throttle losses since intake air is not controlled by a throttle. Engine speed and power output is controlled by the amount of fuel injected into the cylinders. It is important to note that many newer diesels have a throttle valve, but it is only used by the emission control system and is not designed to control engine speed.

Typically the cited reasons against owning a diesel-powered automobile or light truck include:

- Diesel vehicles are usually more expensive.
- Noise
- Diesel fuel is more expensive than gasoline.
- Diesel fuel is available at about half of all service stations.
- Fuel smell
- Exhaust emissions
- Cold weather starting

Diesel Combustion

Nearly all available diesel engines for cars and light and medium duty trucks are based on the four-stroke cycle **(Figure 28–22)**. The primary difference between the strokes of a gasoline engine and a diesel engine takes place during the power stroke. Since the fuel in a diesel is not delivered until the piston on the compression stroke is near TDC and the heat formed during that stroke is what ignites the fuel, the actual combustion process can take three separate steps **(Figure 28–23)**.

Near the end of the compression stroke, fuel is injected but ignition does not immediately begin. In other words, there is a delay in ignition and this is determined by the cetane rating of the fuel. Once the

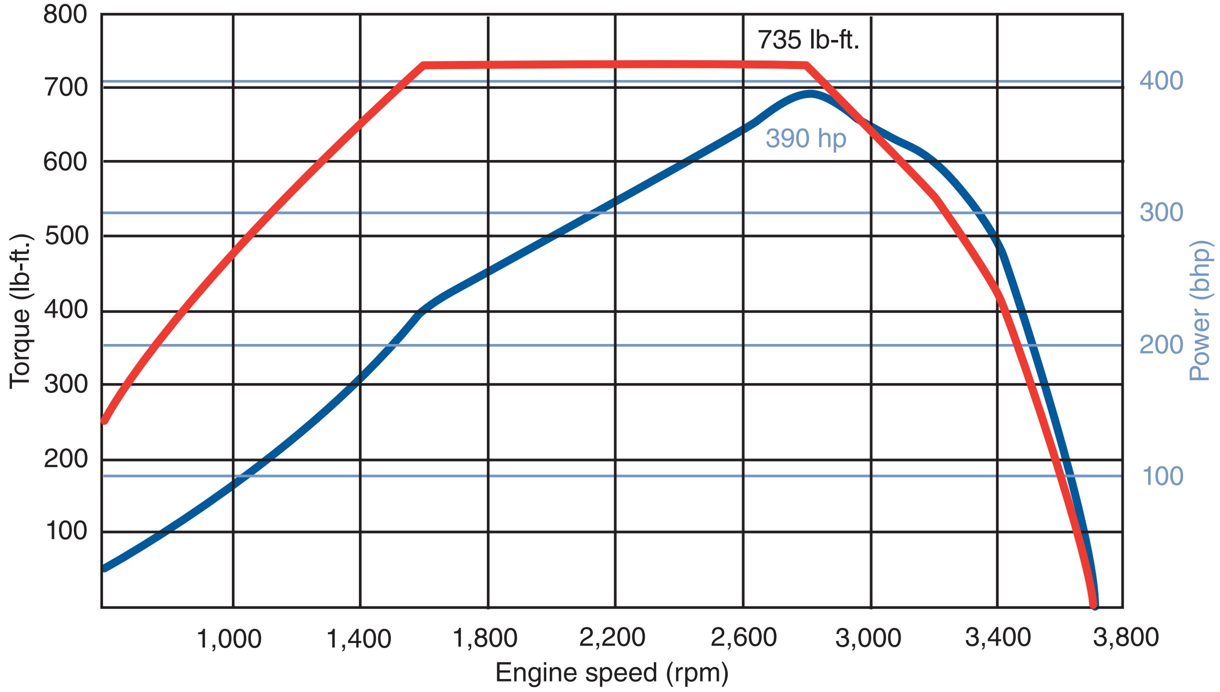


FIGURE 28–21 The power and torque curves for a late-model Ford Power Stroke diesel engine.

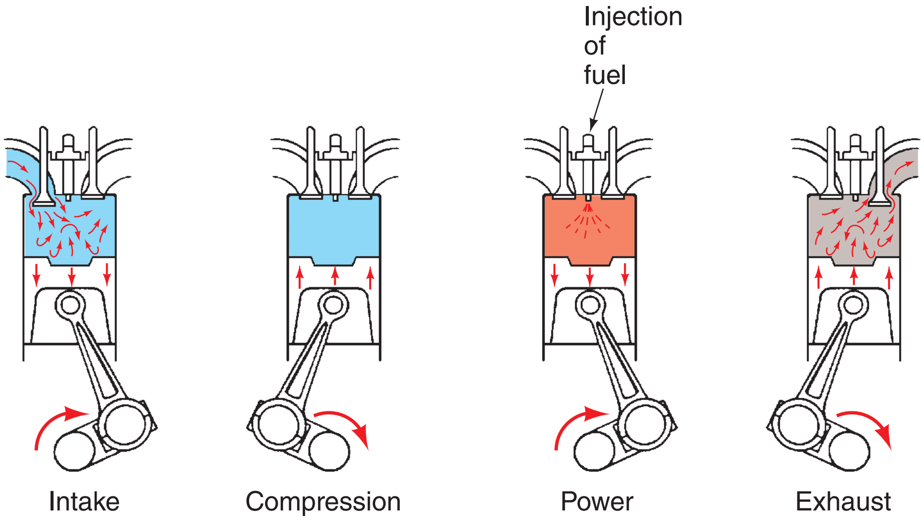


FIGURE 28–22 The four-stroke cycle of a diesel engine.

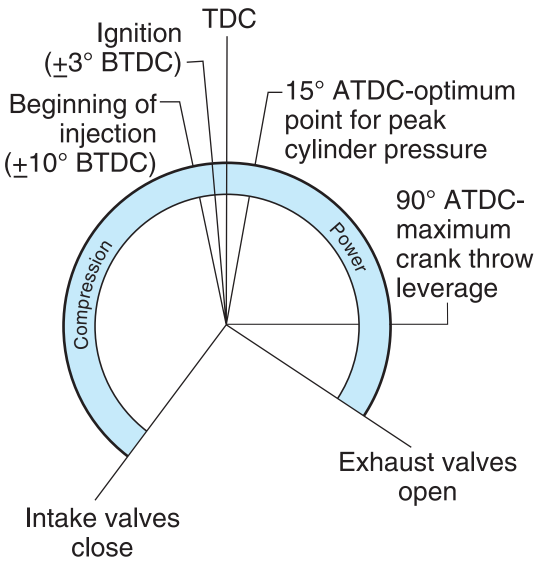


FIGURE 28–23 The events ("steps") that occur during the compression and power strokes of a diesel engine.

fuel begins to burn, pressure in the cylinder greatly increases. After this, the remaining fuel in the combustion chamber begins to burn and this process continues until all of the fuel that is mixed with air burns.

Engine Control Systems

Since 2007, all diesel-powered vehicles sold in the U.S. that have a gross vehicle weight of 14,000 pounds (6,350 kg) or less are equipped with OBD II. This is basically the same system as used in gasoline vehicles. Like those systems, a scan tool can be used to retrieve DTCs and other data. The MIL is illuminated when certain DTCs are set. The DTCs are set by the PCM based on input from a variety of sensors and by the various monitors in the system.

Diesel OBD II monitors all systems that may affect the emissions from the engine. These monitors check the electrical status of the inputs and outputs of each circuit. They also look at the data being sent to determine if it makes sense and is in line with other data. The monitors also watch how the actuators respond to the commands from the PCM. The mandatory monitors include:

- *Comprehensive Component Monitor*—This performs functional and rationality tests on emission-related circuits.
- *Misfire Monitor*—This monitor will set the MIL when a misfire occurs, when the engine is at idle, if the vehicle has an automatic transmission. The MIL will not be set if the vehicle has a manual transmission.
- *Glow Plug Monitor*—If a problem with the glow plugs is detected, the MIL will be set. This only occurs on vehicles that weigh less than 8,500 pounds (3,856 kg).

Although many of the monitors for a diesel engine are similar to those for a gasoline engine, some are unique to the diesel. Examples are the EGR cooler monitor and Diesel Oxidation Catalyst (DOC) efficiency monitor. The EGR cooler monitor checks the efficiency of the cooler by monitoring the temperature difference between the inlet and outlet sensors with the EGR valve open. The DOC monitor relies on exhaust gas temperature sensors and the monitor runs during active regeneration of the Diesel Particulate Filter (DPF). If the temperature of the exhaust gas does not increase to the desired minimum, a DTC is set and the MIL is illuminated.

The control system monitors the engine while it is running and makes adjustments to ensure overall

efficiency. Inputs that are critical to efficient operation are those related to cylinder pressures. By monitoring the pressures inside the cylinders, the PCM can make accurate decisions about the combustion process.

Most engines equipped with cylinder pressure sensors are fitted with glow plugs that have an integrated pressure sensor **(Figure 28–24)**. These sensors are basically a normal glow plug and have been modified to allow the center electrode to move up and down. The movement of the electrode is in response to cylinder pressure. The movement changes the position and pressure the electrode has on a sensing element. Depending on these factors, the sensing element sends a voltage signal to the PCM.

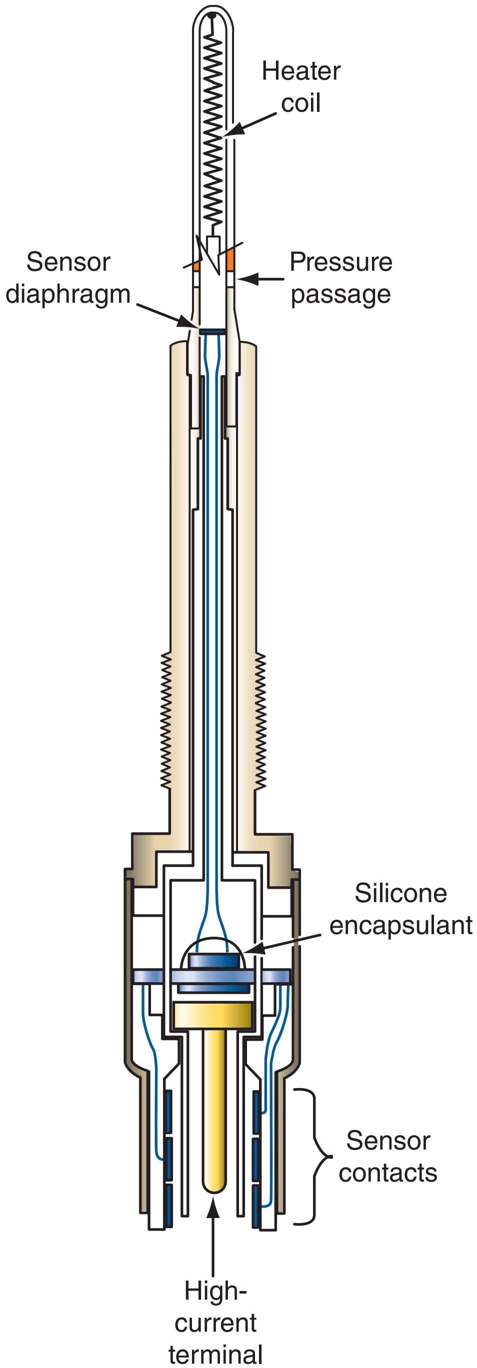


FIGURE 28–24 A piezo-resistive cylinder pressure sensor integrated into a glow plug.

Diesel Fuel Injection

The A/F mixture of a diesel can vary from as rich as 8.5:1 at full load to as lean as 20:1 at idle. Ideally, engine fueling should be managed to produce peak cylinder pressures at somewhere around 10 to 20 degrees ATDC.

Most of today's diesel engines use direct fuel injection, in which fuel is injected directly into the cylinder. In an indirect injection (IDI) diesel engine, fuel is injected into a small prechamber, which is connected to the combustion chamber by a small opening. Initial combustion takes place in this chamber. This slows the rate of combustion, which tends to reduce engine noise. Many IDI systems were mechanically operated and the fuel pump not only supplied fuel system pressure, but also controlled the timing of the injectors.

With direct injection (DI), the pistons have a depression where initial combustion takes place **(Figure 28–25)**. DI engines are typically more efficient than indirect injection engines but tend to have more engine noise. Many of today's engines are equipped with a common rail system. These systems have a high pressure fuel pump that delivers fuel under a constant pressure to fuel passage, pipe, or rail. The injectors are connected to the rail and fuel can be delivered to the cylinders whenever the engine is running.

The individual injectors are normally controlled by the PCM. Electronic controls allow the engines to run more efficiently, smoother, and cleaner.

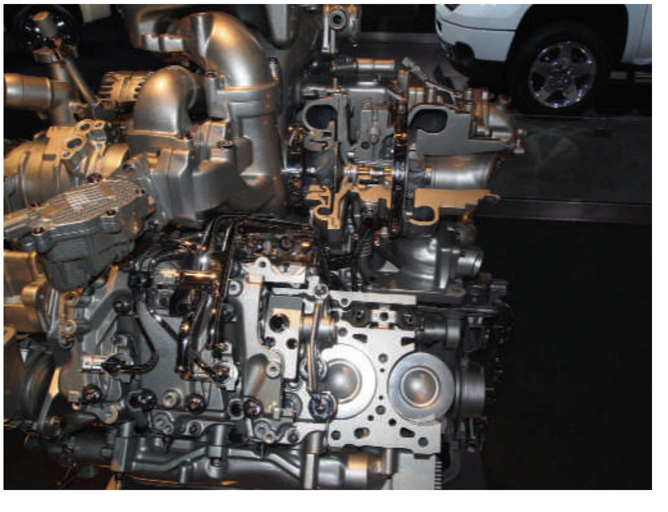


FIGURE 28–25 Notice the depression at the top of the pistons of this GM Duramax diesel.

Injector Nozzles

An injector nozzle is the part that delivers the fuel into the engine's cylinders. The nozzles are threaded into or clamped onto the cylinder head; there is one for each cylinder. Many nozzles are spring loaded valves that, when the injector is activated, spray fuel into the combustion chamber or a precombustion chamber. Nearly all of today's diesel engines have multiple-orifice hydraulic or electro-hydraulic nozzles.

The exact type of nozzle used, mainly depends on the type of injection system. However, the tip of all nozzles has many orifices or holes from which atomized fuel is sprayed into the cylinders. The pressure of the fuel determines how much the fuel will be broken down into droplets. It is important to note that a change in pressure regulates the amount of fuel delivered. The time an injector is turned on also determines fuel quantity.

Electronic Unit Injection (EUI)

Electronic unit injector (EUI) systems have been used since the 1980s but primarily in heavy-duty trucks. Volkswagen used EUIs in their TDI engines until 2010 **(Figure 28–26)**. Since then they use a common rail injection system which will be discussed later.

In these systems, the injector's pressure is the result of a camshaft-driven high pressure pump. However, the engine's PCM controls the amount of fuel sprayed into the cylinders and the timing of the spray. Although effective, EUIs did not allow for the precise control of injection needed to meet today's driving needs and emission standards.

Hydraulic Electronic Unit Injection (HEUI)

Hydraulic Electronic Unit Injection (HEUI) relies on engine oil pressure to control the operation of the individual injectors **(Figure 28–27)**. The engine oil opens the injector by pressing down on a diaphragm inside each injector. In turn, the diaphragm pushes on the fuel inside the injector and pressurizes it from 3,000 to 21,000 psi. Fuel under that pressure is directly injected into the cylinders. Since the injectors in this system pressurize the fuel for delivery into the cylinders there is no need for an expensive and difficult to control high-pressure fuel pump.

These systems were widely used until 2010. The system as used in Ford's 6.0, 6.4, and 7.3 Power Stroke diesels is comprised of:

- A high pressure engine oil pump and reservoir
- Engine oil pressure regulator
- High-pressure (stepper) pump

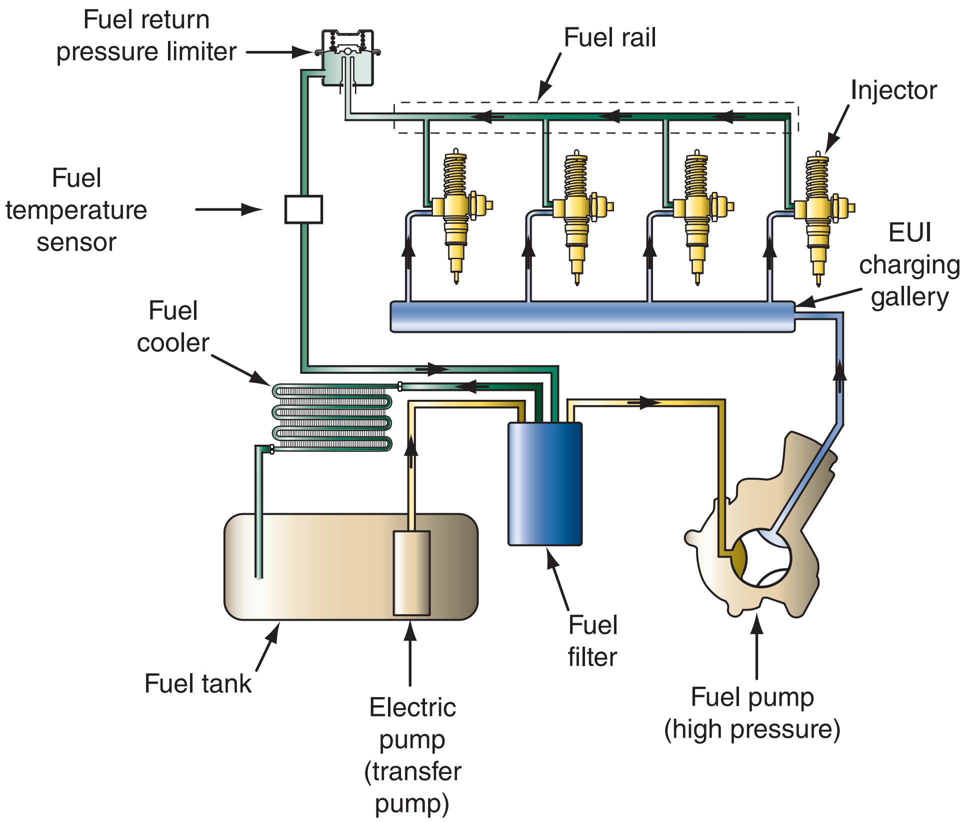


FIGURE 28–26 A pre-2010 VW TDI EUI fuel system.

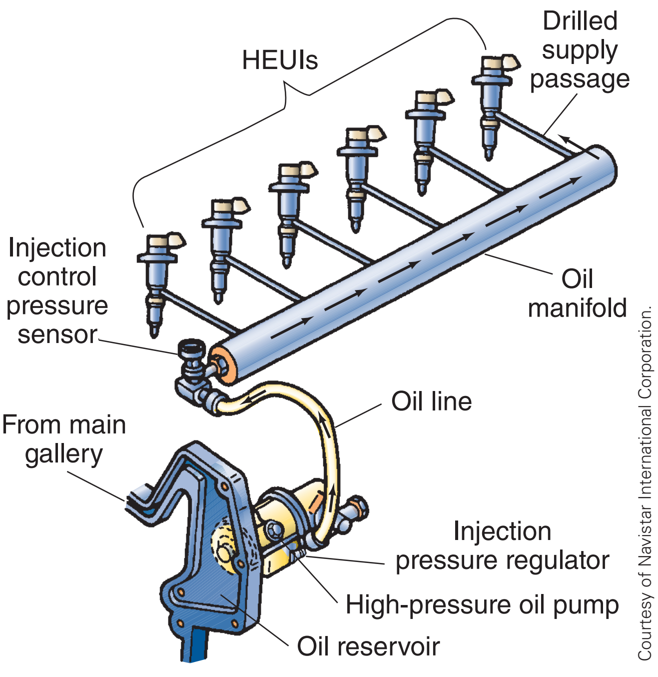


FIGURE 28-27 The oil system that forces the HEUI injector open when the PCM allows it.

- Actuation oil pressure sensor
- Passages in the cylinder head for fuel flow to the injectors
- HEUI Injectors
- Electronic Control Module (ECM)

Operation Fuel is drawn out of the tank by a fuel pump. The fuel, under low pressure, passes through fuel lines and the fuel filter, water separator, and fuel heater. The fuel is then delivered to the fuel passages in the cylinder head or rail. Oil from the engine's lubrication system is pumped into a high-pressure pump. This pump increases the engine oil's pressure to a precisely controlled amount. The engine oil's path includes a return to the engine's oil reservoir. The pressurized oil is then sent to the injectors. The presence of the pressurized oil actuates the injectors. The PCM controls the pressure buildup and the actual actuation pressures are between 485 psi (33 bar) and 4,000 psi (275 bar). The PCM therefore controls the amount of fuel injected into the cylinders.

Importance of Maintenance It is very important that the correct type of oil be used in a HEUI-equipped engine. It is also very important to adhere to a strict oil change interval. Since the engine's oil is what activates the fuel injectors, the wrong or contaminated oil can cause HEUI injector problems.

Common Rail Injection

A **common rail (CR)** fuel system is one that has a fuel rail that carries high-pressure fuel to the individual injectors **(Figure 28–28).** Since the injectors are electronically controlled, the pressurized fuel is immediately available at each injector. Each electro-hydraulic injector (EHI) is switched open and closed by the PCM. Some late-model CR systems have an intensifier in the injector that allows for an increase in fuel pressure. Each fuel injector is positioned directly above the piston and is connected to the fuel rail by steel lines. The amount and pressure of the fuel injected into the cylinders is controlled by the PCM.

Since 2010, nearly all "on the highway" diesel engines use CR fuel injection systems. The use of CR allows the engines to meet diesel emissions standards and fuel economy expectations. They also provide for:

- Lower engine noise levels
- Balanced engine cylinder pressures
- High injection pressures independent of engine speed
- The injectors can be switched on and off at high speeds and allow for as many as seven injection "events" during a single power stroke.

High Pressure Pump Normally the high-pressure pump that feeds fuel to the common rail is a three-piston assembly. The pump is driven by the camshaft. The high pressure to the injectors is

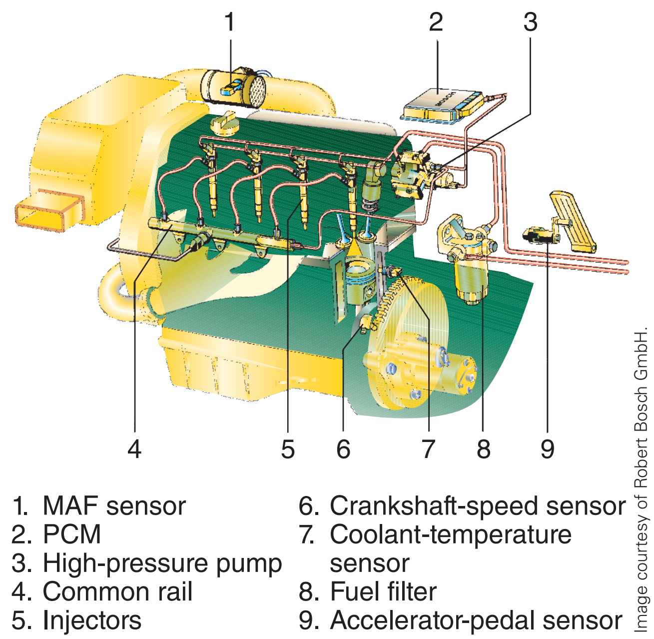


FIGURE 28-28 A common rail system for a four-cylinder engine.

necessary to allow the injectors to spray very atomized fuel. Fuel from a CR system can be injected at pressures up to 30,000 psi (2,068 bar).

Injector Control Typical of all late-model computer-controlled systems, a CR setup has a processor that monitors conditions according to inputs received and then commands certain outputs to react in a commanded way and to ensure efficient operation. The communication between the processor and the inputs and outputs may be digital or analog signals. It is important to note that when the CR system is working properly, the engine will run much quieter than a typical diesel engine.

In a typical non-CR engine, fuel is injected once per power stroke. When it is injected, it takes a while for it to mix well enough to ignite. Once this happens, the fuel quickly ignites and causes a large pressure increase in the combustion chamber. This results in the common knock of a diesel engine. In a CR system, the injection cycle begins with one or two very small sprays of fuel—this is called pilot injection. This pilot injection warms the air in the combustion chamber. When the rest of the fuel is injected, it is able to ignite quickly.

Processing The PCM controls fuel pressure and the timing of the injectors based on inputs of various sensors. This is called fuel mapping and the PCM looks at the inputs, compares them to the instructions stored in its memory, and then commands the appropriate outputs to provide the best injection events for emissions and efficiency.

The PCM and its inputs and outputs are connected through a multiplexed system. CAN-C **(Figure 28–29)** is a serial bus and can handle up to 15 different control modules and can communicate with others through a gateway. CAN-C is a two-wire serial bus that can handle only one message at one time. However, since that message travels to the bus at nearly the speed of light, a great number of messages can be sent and received within one second **(Figure 28–30)**.

Inputs Many different inputs provide the current status of the engine to the PCM. Many of these are the same as used on other diesel and gasoline engines and are tied into the powertrain bus. Different from other engine control systems, a CR system also monitors ambient air temperature and retards the engine's timing of the engine in cold weather and retards injection timing to allow for easier starting.

The system also includes a Fuel Rail Pressure (FRP) sensor. The FRP sends the actual fuel pressure to the PCM. The FRP is threaded into the fuel rail. The FRP is a 3-wire variable capacitance sensor. The PCM supplies a 5-volt reference signal and the FRP sensor sends a portion of that to the PCM to indicate fuel pressure. The FRP sensor monitors fuel rail pressure continuously to provide a feedback to the PCM.

There is also a Fuel Rail Temperature (FRT) sensor mounted in the fuel line between the secondary fuel filter and the high-pressure fuel pump. The PCM monitors the fuel's temperature before the fuel enters the high-pressure pump. Since fuel temperature affects fuel viscosity, the PCM uses this input to control fuel pressure regardless of the actual fuel temperature.

Some light-duty diesel engines have an electronic throttle assembly that controls the amount of fuel injected into the engine. Because a diesel engine does not have a throttle plate, the only way to control engine speed is by controlling the amount of fuel injected into the engine. Rather than using a

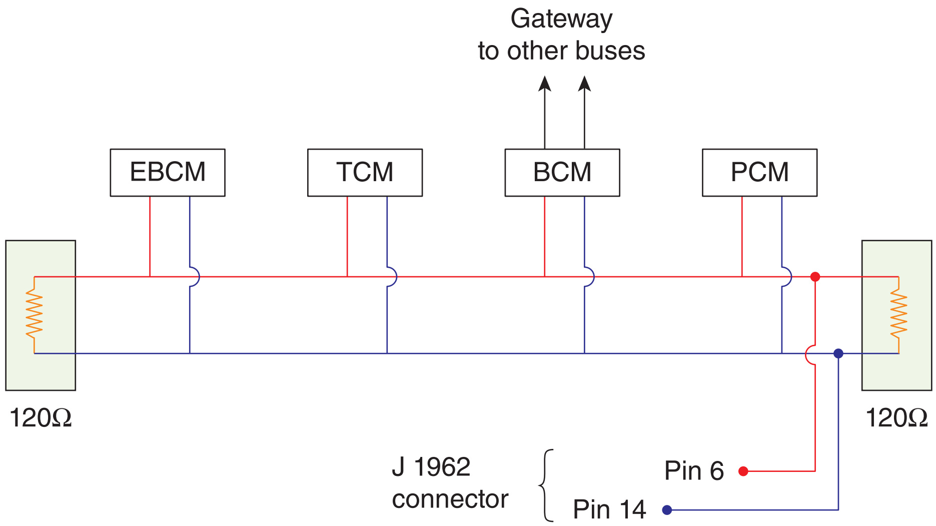


FIGURE 28–29 A typical serial data bus.

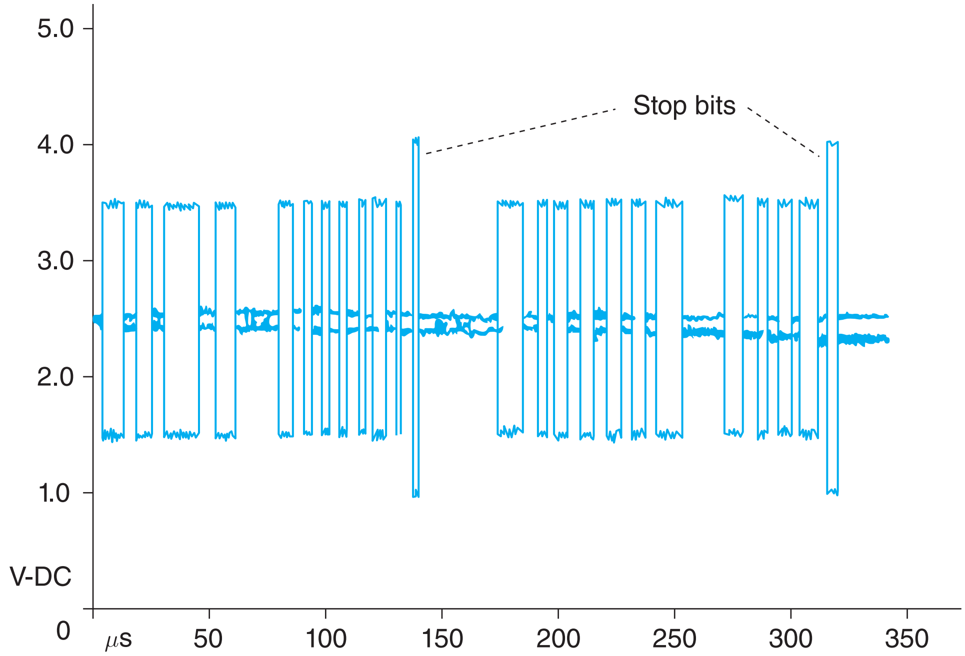


FIGURE 28–30 A scope pattern of a properly functioning CAN-C bus showing a 2.0V differential throughout. The two 3.0V differentials between the CAN high and low voltages indicate the end of a message.

mechanical link from the accelerator pedal to the injection pump, the throttle-by-wire system uses an accelerator pedal position (APP) sensor. The sensor is actually three separate sensors in a single assembly that changes input voltage according to the position of the accelerator pedal. The PCM looks at the voltage signals from each of the three sensors and compares them to what they should be if there are no faults. If an error is detected, engine and vehicle speed are often reduced to allow the system to operate in spite of the discrepancies from the sensors.

Outputs The primary outputs to control fuel delivery in a CR system are the rail pressure control valve, the injectors, and glow plugs. Fuel pressure in the rail is controlled by the PCM according to the input from the rail pressure control valve. This valve is a linear proportioning solenoid that controls a spool valve to send pressurized fuel to the rail or to the return circuit.

The injectors may be activated by a solenoid or piezo electronics. Piezo injectors are used in late-model CR systems because they can respond very quickly to the commands from the PCM.

Most late-model diesel engines have electronic controls that allow for easier starting in cold weather and smooth operation when things are cold. However, some diesel engines have a **glow plug (Figure 28–31)** to warm the intake air to help cold weather starting and running. When a diesel engine is very cold, its compression stroke may not raise the intake air to a high enough temperature to ignite the fuel. A glow plug is used to heat the air. A glow plug is a 12-volt heating element used to help to start a cold diesel engine by providing heat to help the fuel ignite.

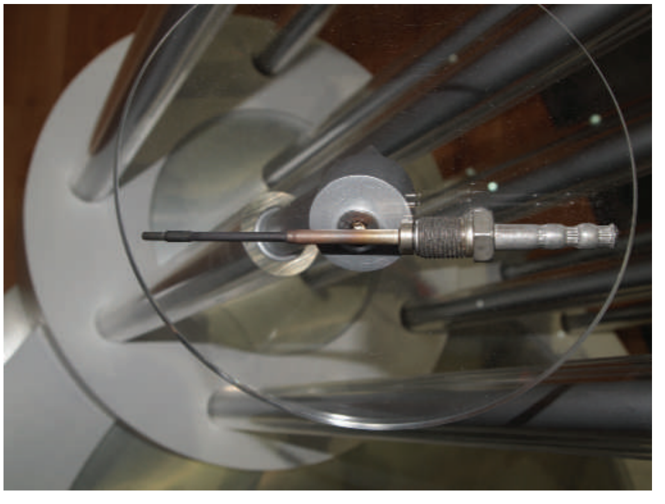


FIGURE 28–31 A glow plug.

Most glow plugs are controlled by the PCM, which monitors engine and intake air temperatures. Glow plugs are cycled on and off depending on the temperature of the engine. The PCM also keeps the glow plugs energized after the engine starts to improve the engine's idle after starting.

Solenoid Injectors

In a CR system, pressurized diesel fuel is applied to the injectors, which are controlled by a PCM via a solenoid. Since the injectors are controlled by the computer, combustion can be controlled to provide maximum engine efficiency with the lowest possible noise and low exhaust emissions.

The solenoid is attached to the injector nozzle and opens to allow fuel to flow through a fuel passage in the injector body and into the combustion chamber **(Figure 28–32)**. The solenoid does not directly move the needle valve (pintle). The needle opens the injector when it is raised, but does so by moving an auxiliary valve that causes an imbalance in the pressure exerted at each end of the pintle. The high fuel pressure in the chamber forces the valve upward, compressing the valve's return spring and forcing the valve open. When the valve opens, fuel sprays into the combustion chamber as a hollow cone spray.

The solenoid is pulsed by the PCM, therefore some fuel moves to the top of the valve and helps to close the valve when the solenoid is turned off. The instant the solenoid is energized, the valve opens and fuel again flows through the nozzle. The fuel that moves to the top of the valve can return to the fuel tank. The continuous supply of pressurized fuel at the injector ensures there is fuel available each time the valve opens.

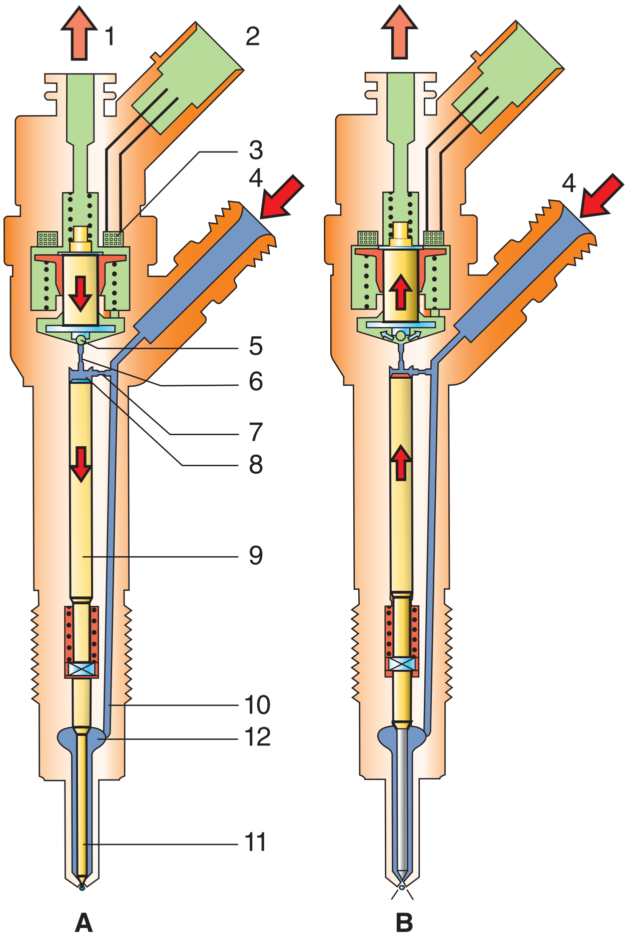


FIGURE 28–32 A solenoid injector.

Piezoelectric Injectors

Piezoelectric injectors operate in much the same way as solenoid injectors, except they do not rely on an electrical winding or coil. The injectors have no moving parts. Rather a piezo injector relies on many, very thin layers of piezoelectric crystal material stacked on each other at the orifice of the injector's nozzle **(Figure 28–33)**. When electricity is applied to

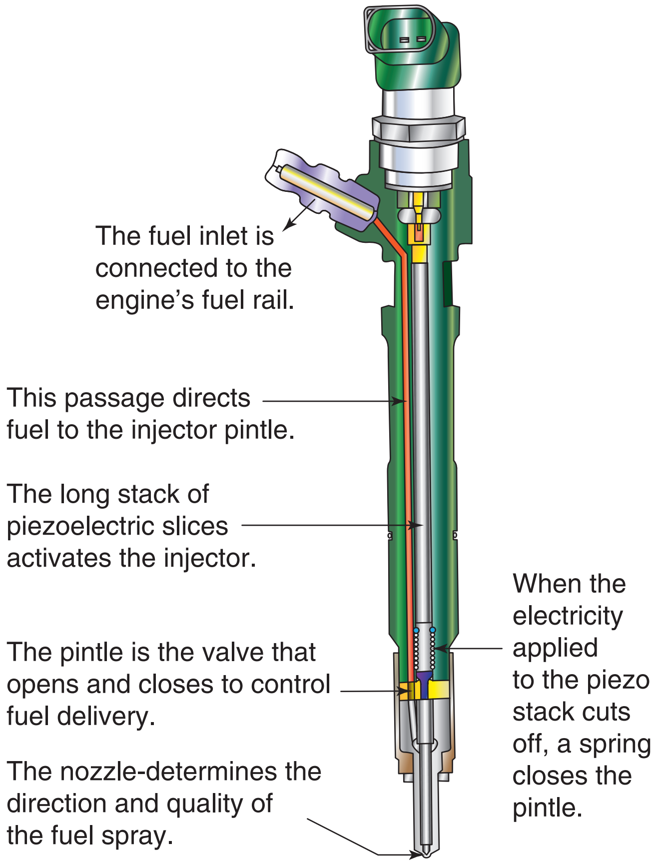


FIGURE 28–33 A piezoelectric injector.

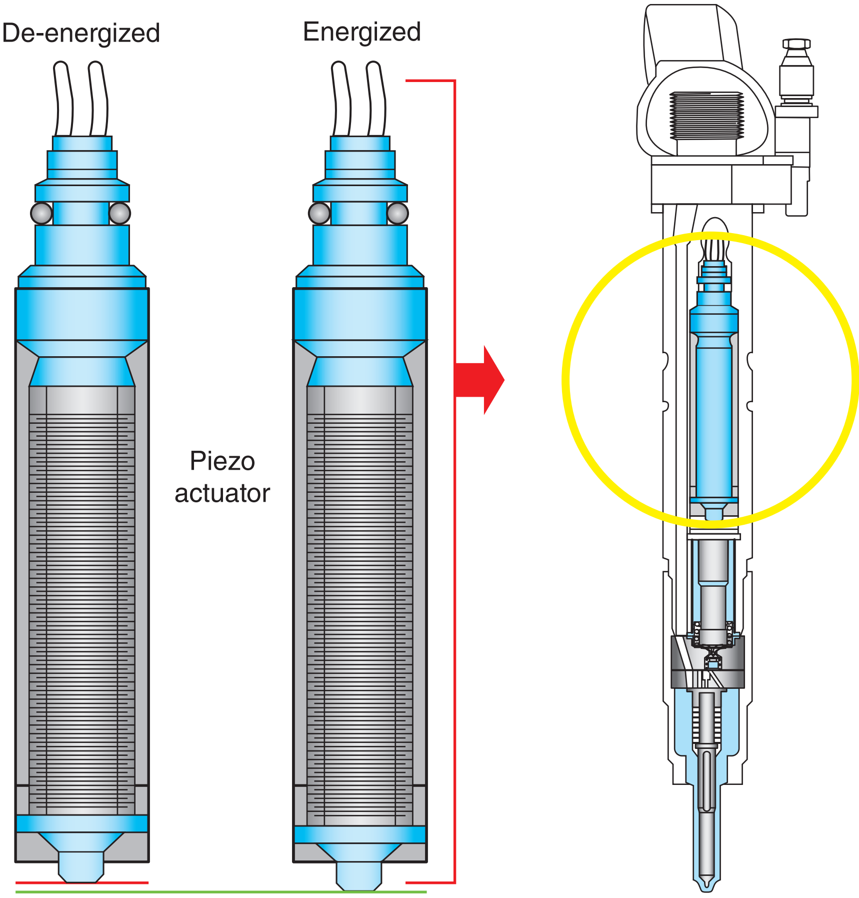


FIGURE 28–34 The action of a piezoelectric injector.

the stack, it expands slightly (approximately 0.004 inches). The expansion, however, is enough to allow fuel to spray out of the nozzle **(Figure 28–34)**. When no electricity is applied to the stack, fuel cannot leave the nozzle because the piezo layers are tightly jammed against each other and the pintle closes by the force of a return spring. Current applied to the injector, as well as the operation of the injectors, is controlled by the PCM.

A crystal is a clear, transparent mineral, such as quartz. Other piezoelectric crystals include table sugar and tourmaline. Quartz is one of the most common piezoelectric minerals; it is used in many devices such as radios and watches.

Piezo material is a type of crystal that rapidly expands when it is exposed to electrical current. They also retract just as quickly when current to them is stopped. However, the amount the crystals expand and retract is very small. The slight change in shape forms small gaps between the layers of the piezo material. This allows for a precisely controlled flow of fuel out of the injector.

Each injector has at least 400 separate layers of piezo material and the total expansion of that stack is only 0.004 inches (0.102 mm).

Piezoelectric materials can also emit a small amount of voltage when they are struck, squeezed, or exposed to vibration. Piezoelectric materials are often used in pressure sensors.

The advantages of piezo over solenoid injectors are:

- They offer improved fuel economy.
- Since there are moving parts, they have a longer life.
- They reduce combustion noise.
- They allow for more precise and rapid control of injection intervals.
- They offer improved combustion.
- They reduce exhaust emissions.
- They can allow seven or more smaller and staggered sprays of fuel during a single power stroke.

Fuel Delivery

The fuel tank for a diesel engine has a larger filler neck than those found on gasoline vehicles. This is one reason some consumers make the mistake of putting gasoline in their diesel tank. Also since diesel

fuel is not as volatile as gasoline; the fuel tank is not fitted with evaporative emission control devices.

The fuel in the tank is drawn out by an in-tank transfer pump **(Figure 28–35)**. This pump is normally an electrically driven, low pressure, high volume pump. The pump may run continuously or cycled by the PCM. The purpose of the pump is to supply fuel to the injection pump. The injection pump is used to increase the pressure of the fuel so it can be injected.

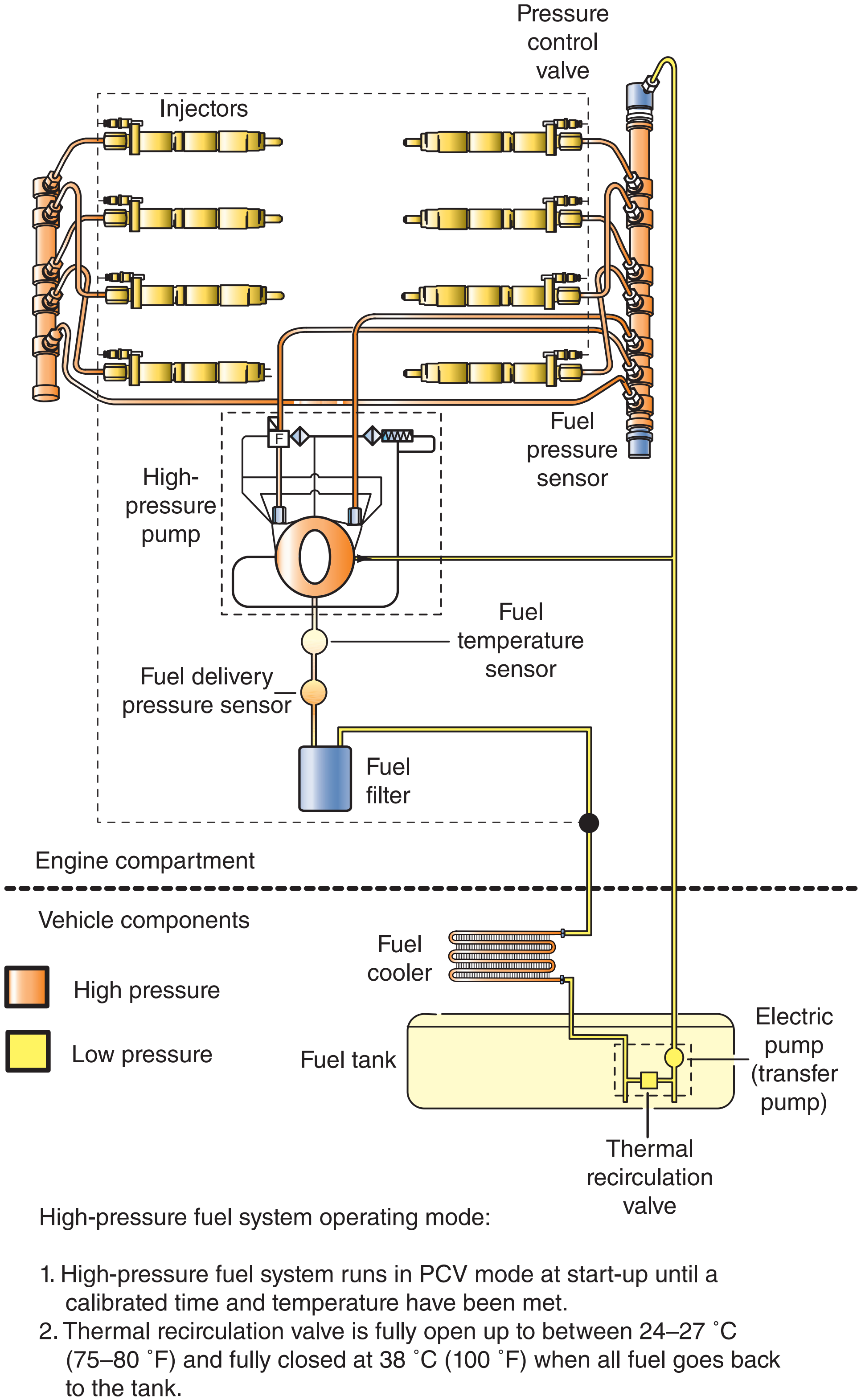


FIGURE 28–35 A fuel supply system for a V8 diesel engine with common rails.

Somewhere between the transfer pump and the injectors is a water/fuel separator, which may be part of the fuel filter. Because water is heavier than fuel, it sinks to the bottom of the separator. Draining the water out of the separator is part of a normal preventative maintenance service for diesel engines. Typically there is a float inside the separator. The float completes the circuit for a water-warning lamp when the level of water in the separator reaches a point where it should be drained. It is important to drain the water; it can cause premature wear because it is not a good lubricant. It can also damage the injector nozzles because water is not easily atomized.

High-pressure fuel lines connect the high-pressure fuel pump to the fuel rails and injectors. Often the high-pressure pump is driven by a gear on the front of the camshaft.

Timing the Pumps The high-pressure pumps used in common rail systems may need to be timed to the engine. Timing the pumps not only creates a starting point for any timing changes made by the engine controls, but it also keeps the engine balanced. Always check the specifications for the proper procedure for adjusting the timing of an injector pump.

The gear for the pumps is driven by a gear on the camshaft **(Figure 28–36)**. The camshaft gear is driven by a gear on the end of the crankshaft **(Figure 28–37)**. All three gears must be properly timed to each other.

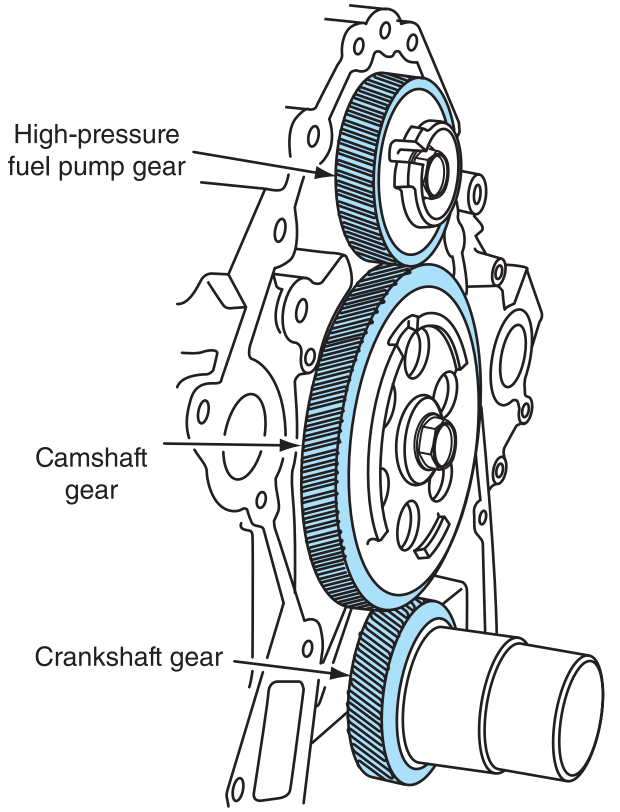


FIGURE 28–37 The crankshaft, camshaft, and fuel pump gears must be perfectly aligned.

Turbochargers

Nearly all current diesel engines are equipped with a turbocharger **(Figure 28–38)**. With a turbocharger, smaller engines can deliver as much power as larger ones while providing improved fuel mileage. Most new diesels have a variable geometry turbocharger, which has an adjustable nozzle that varies the velocity of the exhaust gases as they push on the blades of the turbine wheel.

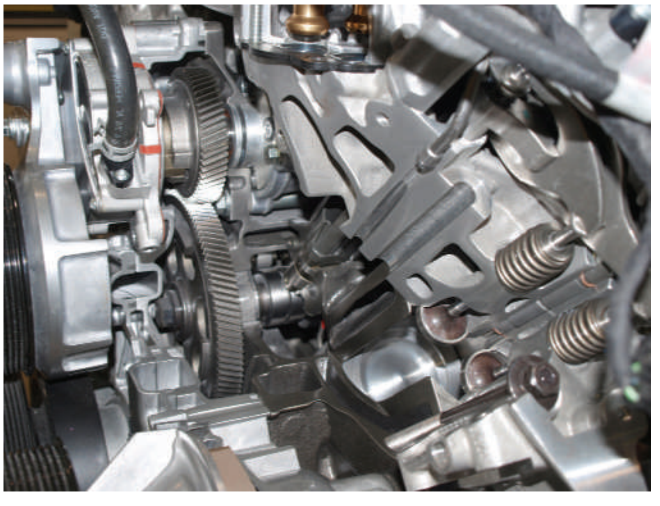


FIGURE 28–36 The high-pressure pump is driven by the camshaft via gears.

FIGURE 28–38 A late-model automotive diesel engine with a turbocharger.

Diesel Emission Controls

Emissions have always been an obstacle with diesel cars. However, with new technologies (such as CR systems) and cleaner fuels, their emissions levels can be comparable to the best of gasoline engines. In fact, today's diesel engines must meet the same emissions standards as a gasoline engine. Even without these technologies, diesel engines emit small amounts of carbon monoxide, hydrocarbons, and carbon dioxide. However, diesel engines naturally emit high amounts of (PM) particulate matter (soot) and NO_x emissions. To decrease these emissions, many new diesel vehicles have an assortment of catalysts and an EGR system to clean the exhaust before it leaves the tailpipe; others use Selective Catalytic Reduction (SCR) systems **(Figure 28–39)**.

Diesel Oxidation Catalysts

Diesel oxidation catalysts (DOC) have been used on all light-duty diesel vehicles since 2007. They are a

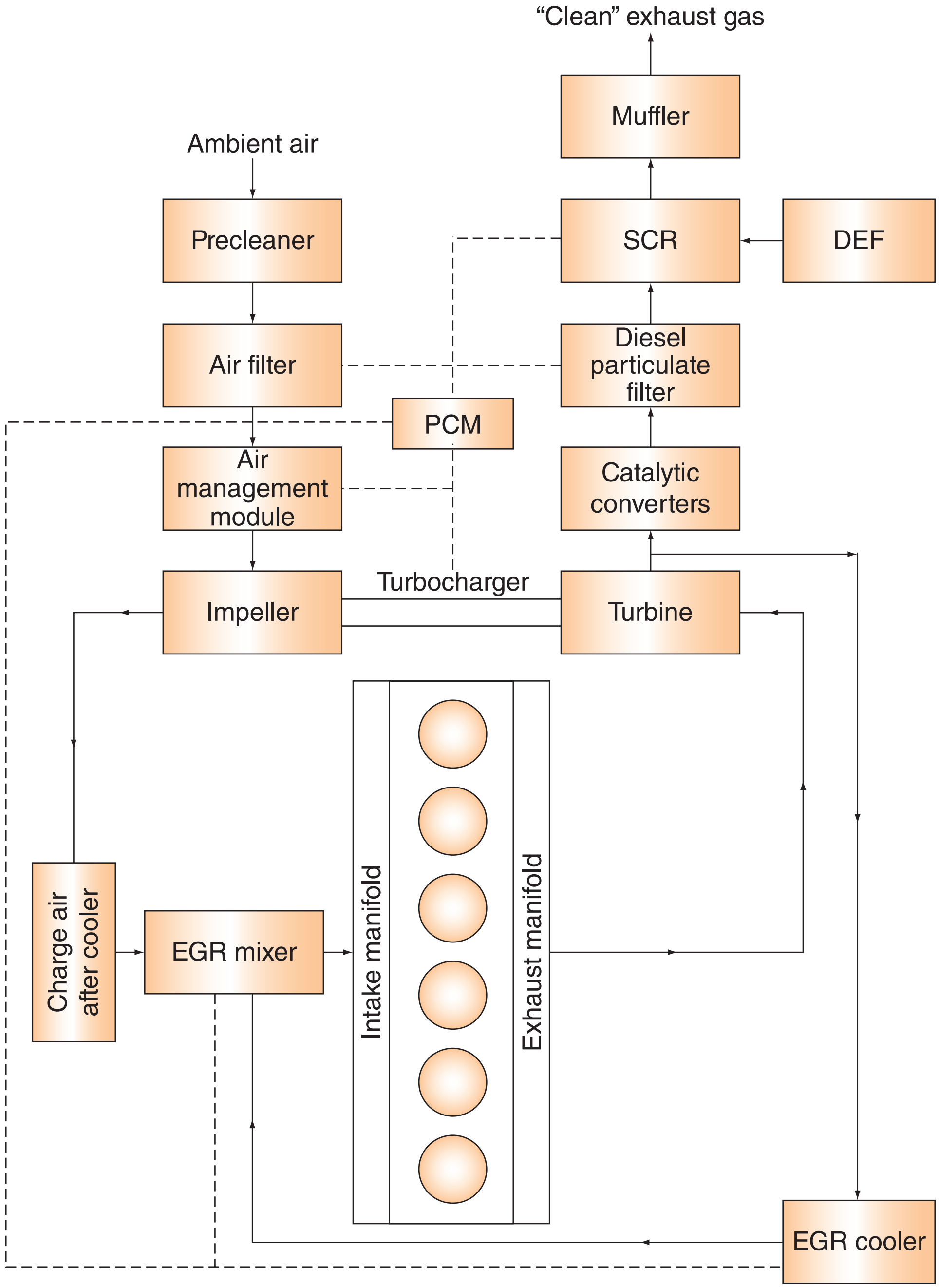


FIGURE 28–39 The flow of the intake and gases for a typical diesel engine.

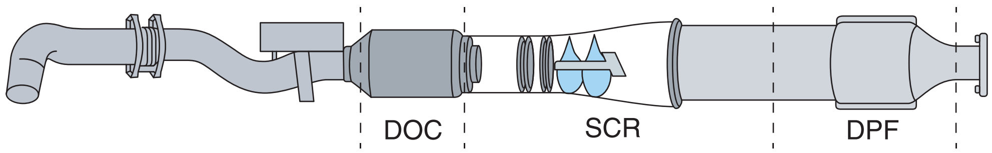


FIGURE 28–40 A catalytic converter and particulate trap for a diesel engine.

flow-through honeycomb-style substrate assembly placed in the exhaust stream **(Figure 28–40)**. Similar to the catalytic converters used on gasoline engines, the substrate is wash coated with a layer of catalyst materials, such as platinum, palladium, and other base metal catalysts.

The main purpose of a DOC is to convert fuel-rich gases in the exhaust to heat, which reduces the amount of CO, HC, and other compounds that cause obnoxious exhaust odors.

Diesel Exhaust Particulate Filter

Particulate matter refers to the tiny particles of solid or semisolid material present in the exhaust of a diesel engine. Soot is a natural byproduct of the combustion of diesel fuel.

Diesel particulate filters have been used in all light-duty diesel vehicles since 2007. A DPF works with the oxidation catalyst and an EGR valve to remove a majority of the NO_x, soot, and unburned hydrocarbons in the exhaust of a diesel engine. The DPF reduces the soot in the exhaust stream by about 90 percent.

The exhaust gas flowing from the DOC moves into the DPF. The DPF then captures the particulates before they are released into the atmosphere. The exhaust passes through a silicon carbide filter that has honeycomb-cell-channels to trap the soot. Because every other channel through the filter is blocked at one end, exhaust is forced through the porous walls of the blocked channels. The porous channels trap the soot as the exhaust passes over them. The cleaned exhaust then flows out through the open channels.

The trapped soot particles can eventually clog the filter, which will increase exhaust backpressure and eventually cause an increase in fuel consumption, decrease power output, and possibly cause engine damage. Therefore, the filter needs to be periodically purged of the particulates; this purging is referred to as regenerating the filter. To do this, the PCM allows a measured amount of raw fuel to enter the filter. This causes the temperature of the filter to greatly increase. The heat then burns the trapped soot and the filter is regenerated or renewed.

Several factors can trigger the PCM to perform regeneration: distance since last regeneration, fuel used since last regeneration, engine run time since last regeneration, and exhaust differential pressure across the DPF. Differential pressure sensors (DPS) are placed at the entrance and exit points of the filter. By monitoring the exhaust pressure at two points, the PCM can determine the differential in exhaust pressure and determine how freely the exhaust is flowing through the filter.

To determine when and how much fuel should enter the exhaust, the PCM relies on the inputs from two exhaust gas temperature sensors. One of the sensors is placed at the entry point of the filter and the other is placed at the exit. It is important that the PCM has complete control over the fuel entering the exhaust because that determines the temperature of the filter. If the temperature does not increase enough, the soot will not be completely burned away. However, if the temperature reaches too high of a level, the substrate in the filter can be damaged.

In addition to the delivery of fuel, the PCM also controls the intake air valve. This can serve as a restriction to air flow which will increase the temperature of the engine. In some cases, the intake air heater may be activated to increase the engine's temperature.

Ash Loading Regeneration of the catalyst will not burn off ash. Only soot is burned off during regeneration. Ash is a non-combustible by-product from normal oil consumption. Ash accumulation in the PDF can cause a restriction in the DPF. To service a DPF, it is removed and cleaned or replaced. Low ash engine oil (API CJ4) is required for all diesel vehicles with a DPF system. CJ-4 oil is limited to 1 percent ash.

Exhaust Gas Recirculation (EGR) Systems

An EGR system injects a sample of an engine's exhaust into the cylinders. By doing this, combustion temperatures are reduced and this reduces the

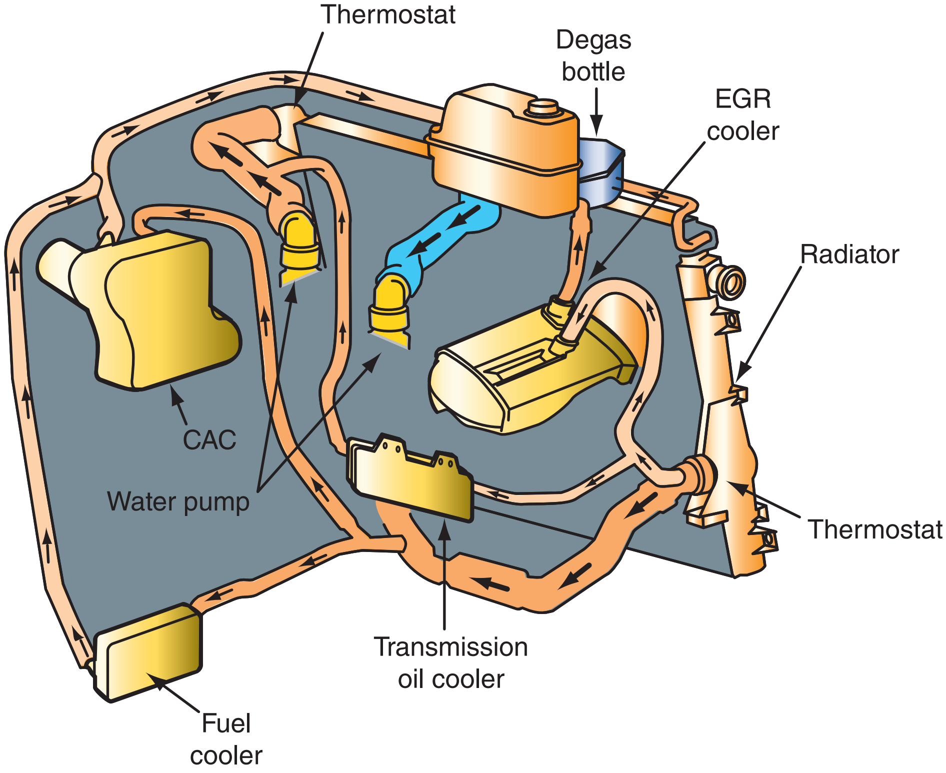


FIGURE 28–41 The various heat exchangers, including an EGR cooler, used on Ford Power Stroke engines.

amount of NO_x produced during combustion. The system includes lines that carry some exhaust gas from the exhaust to the intake ports, an EGR control valve, and a cooling element used to cool the exhaust gases. The action of the EGR valve is controlled by the PCM and may use a DC stepper motor to move the valve stem open. The valve stem returns to the closed position by a return spring after the stepper motor relaxes.

EGR systems have a cooler in which engine coolant passes through it **(Figure 28–41)**. By cooling the exhaust gas before it enters the engine through the EGR valve, the gas becomes denser and keeps combustion chamber temperatures low. The amount of EGR gases that flow through the cooler is determined by the PCM which receives input from an EGR temperature sensor.

Selective Catalytic Reduction Systems

The **selective catalytic reduction (SCR)** unit fits in the exhaust between the DOC and DFE **(Figure 28–42)**. It reduces NO_x emissions when a reductant is injected over the SCR catalyst. The use of a SCR breaks down NO_x into water vapor and nitrogen (N_2), thereby reducing the amount of EGR needed to greatly decrease NO_x. In some cases, an SCR equipped engine does not need an EGR valve to meet emission standards.

A **reductant**, also called a reducing agent, is a material that donates an electron to another material during the redox process. As explained in an earlier chapter, when a reductant gives up an electron it becomes oxidized. Oxidation and reduction always

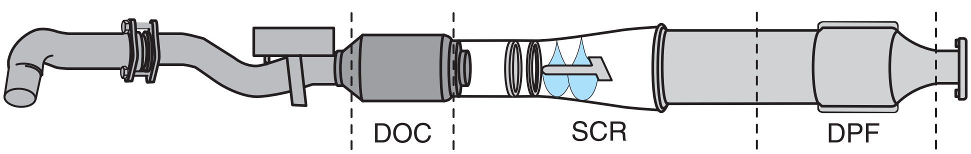


FIGURE 28–42 The main parts of an exhaust after treatment system on a diesel engine.

occur simultaneously: One substance is oxidized by the other, which is reduced. During oxidation, a molecule provides electrons. Basically, a reductant removes oxygen from a substance and combines with the oxygen to form another compound. In the case of an SCR system, oxygen is separated from the NO_x and is combined with hydrogen to form water. It is claimed that the use of an SCR system reduces NO_x emissions by approximately 80 percent.

The common reductants used in SCR systems are ammonia and urea water solutions. Urea is commonly used as a nitrogen-rich fertilizer. In North America, urea **(Figure 28–43)** is referred to as diesel exhaust fluid (DEF) and is called AdBlue in Europe. It should be noted that the catalytic converters are only effective when the reductant is injected into them when they are within a particular temperature range. The vehicle's PCM is programmed to keep the temperature of the exhaust within that range.

The PCM also controls when and how much DEF is injected into the exhaust stream just ahead of the SCR converter **(Figure 28–44)**. The amount of reductant sprayed into the exhaust is proportional to the amount of NO_x in the exhaust. To determine this, the system uses inputs from a NO_x sensor. Normally, the reductant is injected at a rate of 2 to 4 ounces (57 to 113 grams) to a gallon of ultra low sulfur diesel fuel (ULSD).

In the system there is a mixer that mixes the reductant with the exhaust. The mixer has an atomizer and a twist mixer. The reductant is evenly distributed in the exhaust stream by the twist mixer. The atomizer breaks down the reductant into fine droplets so it can easily mix with the exhaust.

FIGURE 28–43 A container of urea (DEF).

The reductant is stored in a separate designated tank. The size of the tank varies with the manufacturer but represents the amount of urea used during a typical maintenance or required oil change cycle. Light-duty trucks typically have about a five gallon DEF tank. SCR systems are equipped with a warning

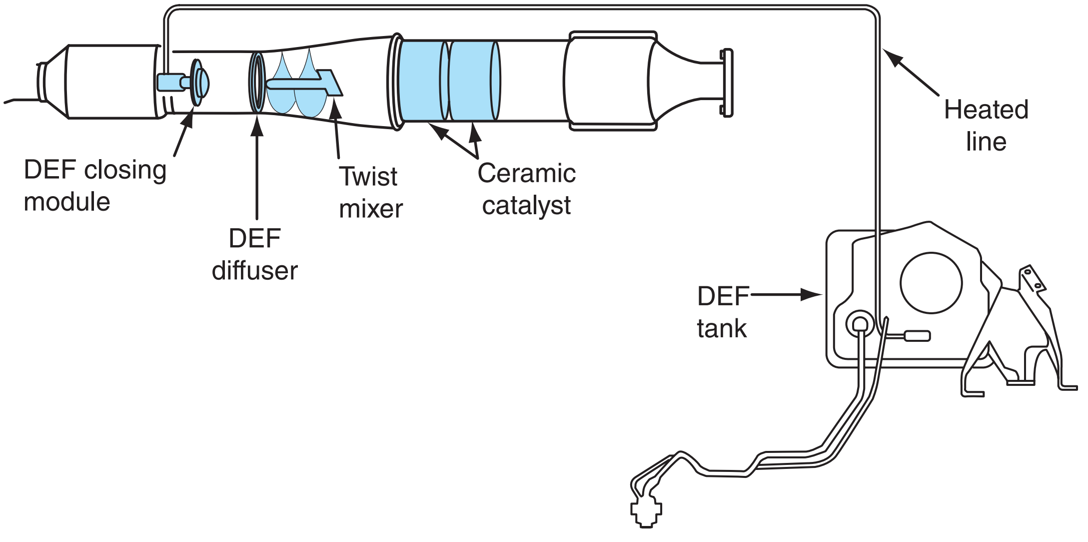


FIGURE 28–44 A SCR system and related parts.

SHOP TALK

Normally the reductant is refilled through the filler neck located next to the diesel fuel filler neck. The cap for the reductant is much smaller than the one for diesel fuel. The cap must be loosened and tightened with a wrench. The reductant's container is screwed into the filler neck and once it is tightened, the reductant will begin to flow into the reservoir.

lamp that signals to the driver that the reductant tank needs to be refilled. If the warning lamp is ignored and the tank is not refilled, engine operation will be affected and the engine may not start until the tank is refilled.

Positive Crankcase Ventilation (PCV) Systems

To meet the current emissions standards, diesel engines since 2007 are fitted with PCV systems. These systems have been standard on gasoline engines for sixty years. The PCV systems in a diesel may be referred to as closed crankcase ventilation (CCV) systems. The purpose of these systems is the same as for a gasoline engine, that being preventing crankcase gases from entering the atmosphere. Crankcase gases are composed of blowby gases from the engine's cylinders and boil-off gases from the engine's oil. The latter results from the heating of the engine oil as it evaporates. Engine blowby gases are those gases that escape past the piston rings and valves and end up in the engine's crankcase. Both of these gases need to be removed or limited, as they can affect the operation and endurance of an engine.

TDI Engines

Perhaps the most common "clean" diesels are the TDI engines made by Audi and Volkswagen. There are certainly other manufacturers, but Audi and VW seem to be the current dominant ones in North America. Both manufacturers (although they really are from the same corporation) use the same technologies. Because their efforts encompass many vehicle models, it should not be surprising that the technology is also used in Bentley and Porsche vehicles. BMW uses similar technology in their vehicles for North America and Europe.

Volkswagen has sold more diesel cars in the U.S. than any other manufacturer. **TDI** (Turbocharged Direct Injection) is a design of diesel engines, which features turbocharging and direct fuel injection **(Figure 28–45)**. Currently, there are several models in the VW TDI family: Passat, Golf, Jetta, Beetle, and Touareg. All of these are fitted with the same four-cylinder 2.0L engine that produces 140 hp at 4,000 rpm and 236 lb-ft. of torque at only 1,750 rpm. The two models that do not use this engine are the Beetle Convertible and the Touareg which use a 3.0L V-6 rated at 225 hp and 406 lb-ft. of torque.

The engines are fitted with piezoelectric injectors on a common rail **(Figure 28–46)**. They also have a variable geometry turbocharger. This turbocharger has an electric motor **(Figure 28–47)** that controls the vanes inside the unit to change the speed and angle of the exhaust gases moving against the turbocharger's turbine. This not only

FIGURE 28–45 A VW TDI engine.

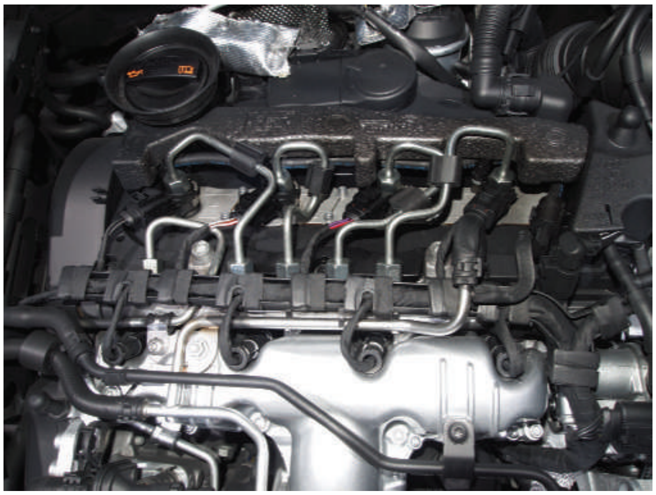


FIGURE 28–46 The common rail system on a VW TDI engine.

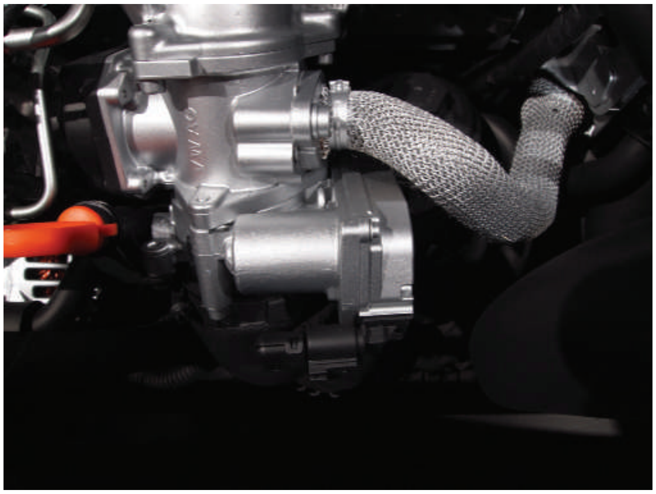


FIGURE 28–47 An electric motor controls the geometry of the vanes inside the turbocharger.

reduces the amount of lag when the throttle is opened, but it also maximizes engine output.

These are called clean diesels because they do not emit the soot or high NO_x that characterizes many diesels. Some VW diesels rely on the urea technology to treat the exhaust. Others have a particulate filter in the exhaust system.

Most TDI engines also have an intercooler to lower the temperature (and therefore increase the density) of the "charged" or compressed air from the turbo, thereby increasing the amount of fuel that can be injected and combusted. The use of the intercooler, turbocharger, and common rail direct fuel injection system allow for greater engine efficiency, and therefore greater power outputs while also decreasing emissions and providing more torque than the non-turbo and non-direct injection gasoline engines of the same size. The fuels recommended for TDI engines include pure diesel fuel, or B5, B20, or B90 biodiesel.

The engines have relatively low displacement and therefore can be quite compact. This means they have a low surface area. Because of this they experience reduced heat loss during the combustion process. This is one of the reasons they are so efficient, however they also do not provide as much heat as a gasoline engine to warm the passenger compartment, so there is a penalty there.

The availability of new VW vehicles with a diesel engine has declined in recent years. VW was caught up in a huge controversy that ended up with them paying a huge fine. It seems the engineers at VW came up with a way to allow the engines to pass emissions tests when the engine was at idle or the preferred test speed; which means the engines did not run as clean as advertised. To staid off this controversy, VW has, for the time being, halted the import of diesel vehicles into the United States.

FIGURE 28–48 An Audi race car equipped with a TDI engine.

Audi TDI R10/15 Vehicles Audi is one of the manufacturers under the VW umbrella, so they offer many competing products with VW, as does Bentley and Porsche. However, Audi has done more to market their TDI engines. Some of their showcase efforts have been the R10 and R15 race cars **(Figure 28–48)**. These cars are diesel powered and have won many notable races, including the 24 hours at LeMans and other endurance races. The race cars are fitted with V-12 diesel engines, and some of the later competition models have hybrid drivetrains. The technology has shown that diesel engines can compete well with the world's most powerful cars and engines.

Diagnostics

In most cases, diesel engines can be diagnosed with a scan tool, as well as with the same logic used to diagnose a gasoline engine. This is because the two engines have many of the same inputs and outputs; therefore the data a scan tool retrieves is similar for both types of engines. The scan tool will also display the DTCs recorded by the system **(Figure 28–49)**. Diagnostics for diesel control systems vary with the manufacturer. However, certain checks are universal regardless of the manufacturer. These include checks of:

- The action of the solenoid and injectors
- The injection actuation pressure
- Active faults in the system
- Previous faults held in memory

Fault Code	Condition Description	Probable Causes
P0122	Accelerator pedal sensor circuit low input	Grounded circuit, biased sensor, PCM
P0123	Accelerator pedal sensor circuit high input	Open circuit, biased sensor, PCM, short to 5v
P0220	Throttle switch B circuit malfunction	Short/open circuit, switch failure, operator, PCM
P0221	Throttle switch B circuit performance	Failed pedal assembly
P0230	Fuel pump relay driver failure	Open FP relay, blown fuse, open/grounded circuit
P0231	Fuel pump circuit failure	Fuse, relay, inertia switch, fuel pump, open/ short circuit
P0232	Fuel pump circuit failure	Relay failure, short circuit, pump failure
P0236	Turbo boost sensor A circuit performance	Restricted inlet/exhaust/supply hose, missing hose
P0237	Turbo boost sensor A circuit low input	Circuit open, short to ground, MAP sensor
P0238	Turbo boost sensor A circuit low high	Circuit short to power, MAP sensor
P026_	Injector circuit low Cylinder X	Harness short to ground
P026_	Injector circuit high Cylinder X	High resistant connector or harness
P026_	Cylinder X contribution/balance fault	Power cylinder, valve train or injector problem, circuit
P030_	Fault cylinder X Misfire detected	Mechanical engine failure
P0380	Glow plug circuit malfunction	Open/grounded circuit., solenoid open/shorted, failed PCM
P0381	Glow plug indicator circuit malfunction	Open/grounded circuit, lamp open, failed PCM
P0471	Exhaust back pressure sensor circuit performance	Plugged, stuck or leaking hose
P0476	Exhaust pressure control valve performance	Failed/stuck EPR control, EBP fault, EPR circuit
P0606	PCM processor fault	Internal PCM failure
P0670	Glow plug control circuit malfunction	Open/grounded circuit, failed GPCM, failed PCM
P0683	Glow plug diagnostic signal communication fault	Circuit/connector failure, failed GPCM, PCM
P1000	OBDII monitor status	OBDII monitors/drive cycle incomplete
P1139	Water in fuel lamp circuit malfunction	WIF lamp, circuit failure, fuse, PCM
P1140	Water in fuel condition	Water in fuel, grounded circuit, shorted sensor, PCM
P1247	Turbo boost pressure low	MAP hose, sensor, EBP sys, intake leaks, turbo
P1248	Turbo boost pressure not detected	MAP hose, sensor, EBP sys, intake leaks, turbo
P1249	Waste gate steady state failure	GND short, plugged hose/port, solenoid, actuator
P1261–P1268	High to low side short cylinder #1–8	Short circuit, shorted injector, failed IDM
P1271–P1278	High to low side open cylinder #1–8	Open circuit, open injector, failed IDM
P1391	Glow plug circuit low input, bank #1 (right)	Open/short/High resistant circuit, faulty relay, glow plugs
P1393	Glow plug circuit low input, bank #2 (left)	Open/short/High resistant circuit, faulty relay, glow plugs
P1395	Glow plug monitor fault, bank #1	One or more glow plugs failed or circuit fault
P1396	Glow plug monitor fault, bank #2	One or more glow plugs failed or circuit fault
P1397	System voltage out of self test range	Voltage too high or low for glow plug monitor test

FIGURE 28–49 Examples of diesel engine related DTCs.

Common faults include hard starting, no-start, extended cranking before starting, and low power. Using a scan tool, check the sensor values to help pin down the source of the problem. To do so, a diagnostic tool must be connected to the computer system and/or a computer-based, diagnostic machine must be connected to the main data bus that controls the systems.

Diesel Exhaust Smoke Diagnosis

Although some exhaust smoke is considered normal operation for most diesel engines, especially older ones, the cause of high emissions, visible emissions, and excessive smoke should be diagnosed and repaired. Basically, the exhaust emissions from a diesel engine can be described as a gas, liquid, or solid. Keep in mind that not all exhaust emissions can be seen by your eye.

Gaseous Emissions From the outside, a gaseous emission cannot be seen. However, it may contain many different undesirable elements, such as NO_x, CO, and HC.

Liquid Emissions Again, according to the eye, liquid emissions may only appear as a white to gray smoke. White smoke normally occurs during cold engine starts and the result of condensed fuel droplets. White smoke is also indicative of a cylinder misfire in a warm engine. The most common causes of white exhaust smoke are: inoperative glow plugs, low engine compression, incorrect injector spray patterns, and coolant leaks into the combustion chamber.

Gray or blue smoke is normally due to oil burning caused by worn piston rings, scored cylinder walls, or bad valve stem seals. Gray or blue smoke can also be caused by defective injectors or injector O-rings.

Solid Emissions Normally solid emissions appear as black soot, which is caused by incomplete combustion due to a lack of air or a fault in the injection system. When there is an excessive amount of soot, check the specific gravity of the fuel, the balance of the injectors, operation of the ECT and/or FRP sensor, and restrictions in the intake or turbocharger. Begin your checks by looking for restrictions in the air intake. To do so, connect a vacuum/pressure gauge to the intake air track.

Compression Testing

To test the compression on a diesel engine, remove the glow plugs or injector for the cylinder being tested. Then use a diesel compression gauge and crank the engine. A diesel engine should produce at least 300 psi (2,068 kPa) at cylinders and should be within 50 psi (345 kPa) of each other.

Cylinder Balance Test

One way to conduct a cylinder balance test on early (non-computer-controlled) diesel engines is to measure the resistance of the glow plugs after the engine has run for a while. Remember that the heating element of the glow plugs increases in resistance as their temperature increases. Therefore, all glow plugs should have about the same amount of resistance when checked with an ohmmeter before the engine has been started and after the engine has been started and ran. By looking at the resistance of the glow plugs, you may be able to identify a weak cylinder.

To test for even cylinder balance using glow plug resistance, do the following on a warm engine:

- Unplug, remove, measure, and record the resistance of the glow plug in each cylinder.
- With the electrical connectors removed from the glow plugs, start the engine.
- Allow the engine to run for several minutes to allow the engine to warm the glow plugs.
- Turn the engine off and measure the resistance of the glow plugs.
- The resistance of the glow plugs should be higher than the resistance measured at the beginning of the test. A glow plug with a different resistance is not firing correctly and that cylinder should be checked for a loss of compression.

Another way to check cylinder balance includes the use of an infrared thermometer or pyrometer to measure exhaust temperature at each exhaust port. Misfiring cylinders will run colder than the others.

Injector Opening Testing

An injector opening (pop) tester is used to check the spray pattern of an injector nozzle. The handle of the tester is depressed and the pop-off pressure is displayed on the gauge. The spray pattern should be a hollow cone, but may vary on design. The nozzle should also be tested for leakage (dripping of the nozzle) while under pressure. If the spray pattern is not correct, cleaning, repairing, or replacing the injector nozzle will correct the problem.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2015	**Make:** Land Rover	**Model:** Range Rover	**Mileage:** 48,588	**RO:** 18825
Concern:	Vehicle towed in. Customer recently bought truck, no history. Engine won't start and there's a warning message displayed on the dash.			
The technician confirms the no-start concern and warning message.				
Cause:	Found DEF tank empty and engine operation locked out.			
Correction:	Refilled DEF tank and engine now starts. Recommend customer to read owner's manual regarding vehicle operation.			

KEY TERMS

Antiknock Index (AKI)
Biodiesel fuels
Cetane rating (CN)
Common rail (CR)
Compressed natural gas (CNG)
Energy density
Ethanol
Flexible fuel vehicles (FFV)
Fractional distillation
Glow plug
Heptane
Hydrogen
Isooctane
Liquefied petroleum gas (LP gas)
Methanol
Octane
Oxygenates
Petroleum
Piezoelectric injector
Reductant
Reformulated gasoline (RFG)
Reid vapor pressure (RVP)
Renewable fuels
Selective catalytic reduction (SCR)
Sulfur dioxide
TDI
Vapor lock

SUMMARY

- Crude oil is also called petroleum. It is drawn out of oil reservoirs and sands below the earth's surface.
- The easiest and most common way to separate the various hydrocarbons (called fractions) in crude oil is through a process called fractional distillation.
- Gasoline is a complex mixture of approximately 300 various ingredients, mainly hydrocarbons.
- Gasoline's octane number or rating gives the antiknock quality of a gasoline.
- Octane ratings are measured by the motor octane number (MON) method and the research octane number (RON) method. The typical octane rating is the Antiknock Index (AKI). It is stated as (R+M)/2.
- The most common method for measuring the volatility of a fuel is the Reid vapor pressure (RVP) test.
- Several additives are put into gasoline to control harmful deposits, including gum or oxidation inhibitors, detergents, metal deactivators, and rust inhibitors.
- Oxygenates are compounds such as alcohols and ethers that are added to fuel to improve combustion efficiency and enhance octane ratings.
- The most widely used gasoline oxygenate additive is ethanol.
- Renewable fuels are those derived from nonfossil sources and produced from plant or animal products or wastes (biomass).
- Flexible fuel vehicles (FFV) can run on ethanol or gasoline or a mixture of the two. The alcohol fuel and gasoline are stored in the same tank.
- Diesel fuel is heavier and has more carbon atoms; it has about 15 percent more energy density than gasoline.
- Diesel fuel's ignition quality is measured by a cetane rating.
- Animal fats, recycled restaurant grease, and vegetable oils derived from crops such as soybeans, canola, corn, and sunflowers are used in the production of biodiesel fuel.
- Ultra-low sulfur diesel (ULSD) fuel has a maximum sulfur content of 15 ppm. Engines running on this fuel emit less NO_x soot, and other unwanted sulfur compounds.
- Diesel engines provide more torque than a gasoline engine of the same size and consume less fuel per mile.

- Hydraulic Electronic Unit Injection (HEUI) relies on engine oil pressure to control the operation of the individual fuel injectors.
- A common rail (CR) fuel system has a fuel rail that carries high-pressure fuel to electronically controlled injectors.
- Piezoelectric injectors use many very thin layers of piezoelectric crystal material stacked on top of each other at the orifice of the injector's nozzle. When electricity is applied to the stack, it expands slightly and fuel is sprayed into the cylinder.
- Diesel oxidation catalysts (DOC) are flow-through honeycomb-style substrate assemblies placed in the exhaust stream to reduce the amount of CO, HC, and other compounds in the exhaust.
- Diesel particulate filters (DPFs) work with the oxidation catalyst and an EGR valve to remove a majority of the NO_x, soot, and unburned hydrocarbons in the exhaust of a diesel engine. Selective catalytic reduction (SCR) reduces NO_x emissions by injecting a reductant into the exhaust stream over the SCR catalyst.
- A reductant, also called a reducing agent, is a material that donates an electron to another material during the redox process.
- Diesel engines can be diagnosed with a scan tool and with the same logic used to diagnose a gasoline engine.

REVIEW QUESTIONS

Short Answer

1. Pump gasoline may contain a small amount of alcohol. Name three problems that can occur if there is an excessive amount of alcohol in gasoline. What percentage of ethanol does E85 contain?
2. List five advantages the use of piezoelectric injectors has over solenoid-based injectors.
3. What does the Reid vapor pressure (RVP) test measure?
4. List three alternative fuels for an internal combustion engine and briefly explain where they come from.
5. Why is the sulfur content in gasoline limited? What is particulate matter and when is it produced?
6. What are oxygenates and why are they added to refined gasoline?
7. Name three driveability factors that are affected by the volatility of gasoline.
8. How does SCR lower the NO_x content in a diesel's exhaust?

True or False

1. *True or False?* The higher the octane rating of gasoline, the more the engine will have a tendency to knock.
2. *True or False?* The diesel fuel's antiknock quality is measured by the cetane rating.
3. *True or False?* Piezoelectric materials can emit a small amount of voltage when they are struck, squeezed, or exposed to vibration.

Multiple Choice

1. Which of the following statements about hydrogen is *not* true?
   a. Hydrogen displaces air, so any release in an enclosed space could cause asphyxiation.
   b. Hydrogen must be stored as a compressed gas.
   c. Hydrogen is nontoxic.
   d. Hydrogen is highly flammable and there is risk for an explosion.
2. Which of the following chemicals is commonly added to gasoline to increase its octane rating?
   a. Isooctane
   b. Heptane
   c. Sulfur
   d. Ethanol

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that the use of methanol in internal combustion engines has declined over the years. Technician B says that the use of MTBE as a gasoline additive has declined over the years. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. Technician A says that reformulated gasoline produces a leaner air-fuel mixture. Technician B says that RFG generates more carbon dioxide. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

3. Technician A says that dedicated vehicles are those designed to use one particular type of fuel. Technician B says that bi-fuel vehicles can operate solely on an alcohol-based fuel or unleaded gasoline, or a mixture of the two, which gives the driver flexibility and convenience when refilling the fuel tank. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. Technician A says white smoke in the exhaust of a diesel engine can be the result of a cylinder misfire in a warm engine. Technician B says blue smoke in the exhaust of a diesel engine can be caused by scored cylinder walls. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Technician A says piezo material is a type of crystal that rapidly shrinks when it is exposed to electrical current. Technician B says piezo material shrinks very slowly when current to it is stopped. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. While diagnosing a diesel engine driveability problem: Technician A says that while the scan tool data is similar to that available for a gasoline engine, all diesel engine troubleshooting procedures are unique. Technician B says a cylinder power balance check can be made by checking the resistance of the engine's glow plugs. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. While discussing chemicals that are currently added to refined gasoline in order to boost its octane: Technician A says methylcyclopentienyl manganese tricarbonyl (MMT) is normally added to gasoline. Technician B says ethanol can be added to boost the octane rating of gasoline. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. While discussing common rail fuel injection systems: Technician A says the individual injectors are activated by the high pressure present in the fuel rail. Technician B says some late-model CR systems have an intensifier in the injector that allows for an increase in fuel pressure. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. Technician A says diesel engines consume less fuel per mile than a gasoline engine of the same size. Technician B says diesel engines provide more torque than a gasoline engine of the same size. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While discussing the reasons why the use of E85 gasoline is good for consumers: Technician A says it is produced in the United States and can reduce our reliance on foreign oil. Technician B says an engine's fuel consumption is greatly reduced. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER 29

FUEL DELIVERY SYSTEMS

OBJECTIVES

- Describe the components of a fuel delivery system and the purpose of each.
- Conduct a visual inspection of a fuel system.
- Relieve fuel system pressure.
- Inspect and service fuel tanks.
- Inspect and service fuel lines and tubing.
- Describe the different fuel filter designs and mountings.
- Remove and replace fuel filters.
- Explain how common electric fuel pump circuits work.
- Conduct a pressure and volume output test on an electric fuel pump.
- Service and test electric fuel pumps.

To have an efficient-running engine there must be the correct amount of fuel. To provide this, fuel must be stored, pumped out of storage, piped to the engine, filtered, and delivered to the fuel injectors. In addition, the fuel system is designed to prevent fuel vapors from entering the atmosphere.

Many modern systems are returnless on-demand systems. In older systems, a fuel pump delivered fuel under pressure to the fuel injectors. A pressure regulator at the injectors controlled the fuel pressure by sending excess fuel back to the fuel tank. This is a return fuel system **(Figure 29–1)**.

In a mechanical returnless system **(Figure 29–2)**, the pressure regulator is in the fuel tank and excess fuel is released to the tank. There is no need for a return line. Most newer systems are electronically controlled and fuel pressure and volume are controlled by the PCM according to the existing operating conditions.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2007	**Make:** Chevy	**Model:** Colorado	**Mileage:** 148,108	**RO:** 18902
Concern:	Towed in, customer states truck barely runs, has no power, runs rough.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

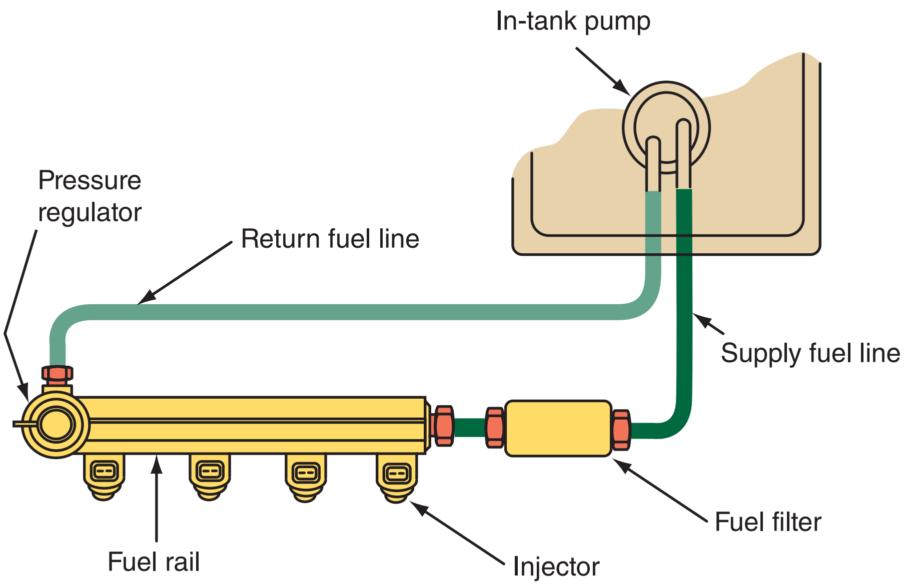


FIGURE 29–1 A return fuel delivery system.

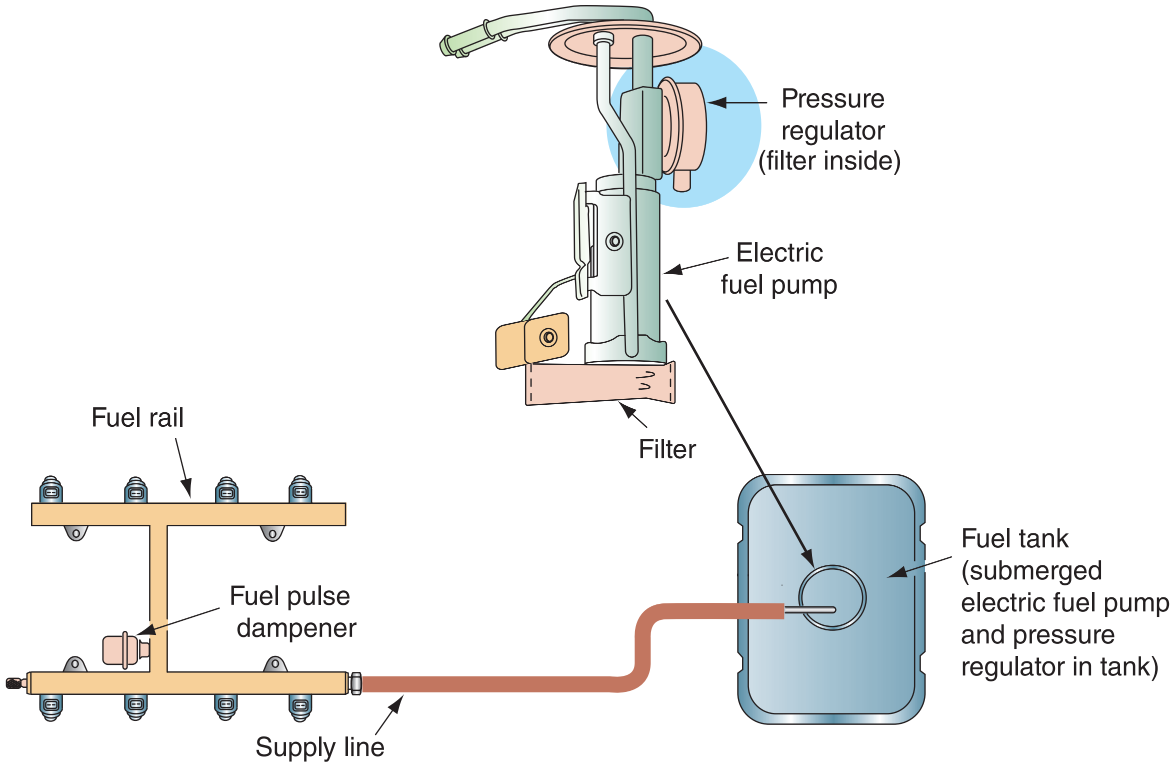


FIGURE 29–2 A returnless fuel delivery system.

In a return system, the fuel sent back to the tank has been heated by underhood temperatures. The introduction of the warm fuel to the tank causes the fuel to evaporate.

The fuel system should be checked whenever there is evidence of a fuel leak, fuel smell, or evidence of inadequate fuel supply. The fuel system should also be checked whenever

basic tests suggest that there is too little or too much fuel delivered to the cylinders. Lean mixtures are often caused by insufficient amounts of fuel drawn out of the fuel tank. Lean mixtures can cause bad results in many different diagnostic tests, including high HC, O_2, and NO_x readings on an exhaust analyzer and high firing lines on a scope.

When no fuel is delivered to the engine, the engine will not start. On carburetor and throttle-body-injected engines, it is easy to determine if fuel is being delivered. Simply look down the throttle body. If the surfaces are wet or you see fuel being sprayed while cranking the engine, fuel is there. With port injection, it is a little more difficult. Connect a fuel pressure gauge to the fuel line or rail and observe the fuel pressure while cranking the engine. Testing fuel pressure is described later in this chapter. However, if there is no fuel pressure while cranking, there is no fuel being delivered to the engine.

There are many components in the fuel system. These can be grouped into two categories: fuel delivery and the fuel injection system. Diagnosis and basic service to the fuel delivery system are covered in this chapter. All tests given in this chapter assume that the fuel is good and not severely contaminated.

Caution! Gasoline is very volatile and flammable. Never expose it to open flame or extreme heat. Disconnect the negative battery cable before doing anything that may release gas vapors. Use containers to catch gasoline and rags to wipe up any spills. Use a flashlight or an enclosed fluorescent tube or LED lamp designed for safe use around fuels. When working with a fuel system, always have a Class B fire extinguisher nearby.

Guidelines for Safely Working on Fuel Systems

Many things need to be considered before working on a fuel system. Fuel in vapor and liquid form presents many potential hazards. Fuel plus heat presents even more! Also, dispose of all drained fuel according to local regulations.

Before loosening or disconnecting fuel lines, all pressure in the system must be released. Fuel injection systems operate at high fuel pressures and are designed to hold most of that pressure when the engine is not running. This residual pressure allows for fast engine starting. When a fuel line that has pressurized fuel in it is loosened, the fuel will spray uncontrollably as soon as it can. The fuel can spray on something hot and cause a fire or spray into your eyes and cause a serious injury.

Most port fuel injection fuel rails have a fuel pressure test port (often referred to as the Schrader valve) on the fuel rail **(Figure 29–3)**. The pressure can be relieved at this port. Begin by disconnecting the negative battery cable. Then loosen the fuel tank filler cap to relieve any vapor pressure built up in the tank. Wrap a shop towel around the fuel pressure test port on the fuel rail and remove the dust cap from this valve. Connect a fuel pressure gauge to the fuel pressure test port on the fuel rail. Install a bleed hose onto the gauge and put the free end into an approved gasoline container. Then open the gauge bleed valve to relieve fuel pressure from the system into the gasoline container **(Figure 29–4)**. Be sure that all the fuel in the bleed hose is drained into the gasoline container.

If the system does not have a test port, the pressure can be relieved by loosening the fuel tank filler cap to relieve any tank vapor pressure. Then remove the fuel pump fuse or relay. Start and run the engine until the fuel in the lines is used up and the engine stops.

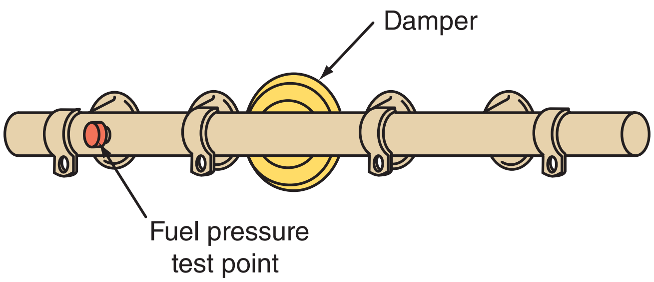


FIGURE 29–3 The typical location of the fuel pressure test port.

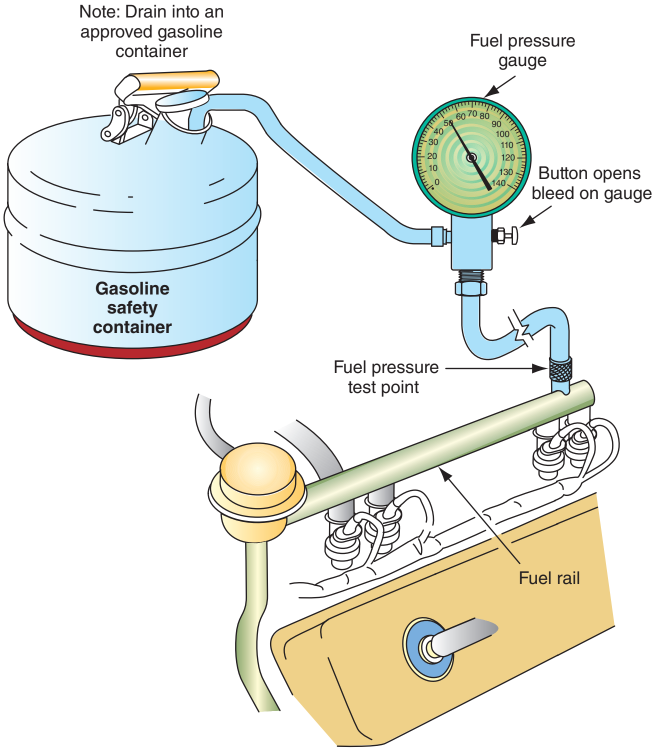


FIGURE 29–4 Relieving fuel pressure from the system.

Crank the engine with the starter for about 3 seconds to relieve any remaining fuel pressure.

Additional safety guidelines include the following:

- Pay strict attention to any and all warning labels located near the fuel system **(Figure 29–5)**.
- Always wear eye protection and follow all other safety rules to prevent injury to yourself or others when servicing fuel systems.
- When working on a fuel system in the engine compartment, disconnect the negative cable of the battery. An electrical spark may cause a fire or explosion.
- Slowly remove the fuel filler cap. If the cap is venting vapor or if you hear a hissing sound, wait until it stops before completely removing the cap.
- Do not smoke when working on or near any fuel-related component.

FIGURE 29–5 Read and follow safety warnings when working on fuel systems.

- Do not allow heat or flames to be near while working on or near the fuel system.
- Remove all electronic devices, such as cell phones and audio equipment, from your clothing when working on or near the fuel system.
- Handle and store all fuels with the utmost caution.
- Clean all fuel spills immediately; spilled fuel may be ignited by hot components.
- If a fuel line or hose is damaged in any way, replace it.
- When disconnecting or reconnecting a fuel line or hose, make sure that the mating parts are totally clean.
- After disconnecting a fuel line or hose, plug both ends to prevent dirt from entering.
- When disconnecting and reconnecting a fuel line or hose, only use the tools designed for that connection. Using the wrong tool can cause a poor connection that can result in a fuel leak.
- Use fuel line pinch-off tools or rubber fuel lines to minimize fuel spillage when changing fuel filters and pumps.

Fuel Tanks

Fuel tanks include devices that prevent vapors from leaving the tank. For example, to contain vapors and allow for expansion, contraction, and overflow that result from changes in the temperature, the fuel tank has a separate air chamber dome at the top. All fuel tank designs provide some control of fuel height when the tank is filled. Frequently, this control is achieved by using vent lines with the filler tube or tank **(Figure 29–6)**. These fuel height controls allow only 90 percent of the tank to be filled. The remaining 10 percent is for expansion during hot weather. Some fuel tanks have an overfill limiting valve to prevent overfilling of the tank.

Fuel tanks are constructed of pressed corrosion-resistant steel, aluminum, or molded polyethylene

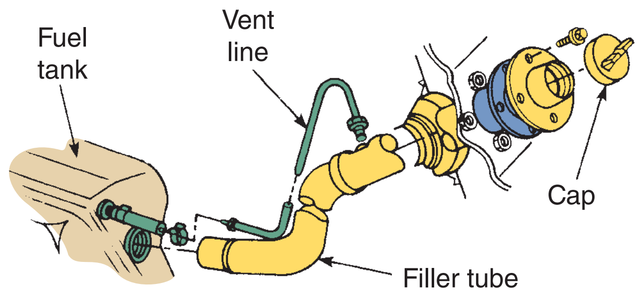


FIGURE 29–6 Vent lines within the fuel tank filler tube control the fuel level.

plastic. Aluminum and molded plastic tanks are the most commonly used.

Most tanks have slosh baffles or surge plates to prevent fuel from splashing around inside the tank. In addition to slowing down fuel movement, the plates tend to keep the fuel pickup and sending unit for the fuel gauge immersed in the fuel during hard braking and acceleration. The plates or baffles also have holes or slots in them to permit the fuel to move from one end of the tank to the other. With few exceptions, the fuel tank is located in the rear of the vehicle.

A fuel tank has an inlet filler tube and cap. The location of the filler tube depends on the tank design. All current filler tubes have a built-in restrictor that prevents the entry of the larger leaded fuel delivery nozzle at gas pumps. The filler tube can be a rigid one-piece tube soldered to the tank or can be made of multiple pieces.

Some form of liquid vapor separator is incorporated into nearly every fuel tank. This separator stops liquid fuel or bubbles from reaching the vapor storage canister. It can be located inside the tank, on the tank, in the fuel vent lines, or near the fuel pump. Check the service information for the exact location of the liquid vapor separator and the routing of the hoses to it.

Inside the fuel tank, there is also a sending unit that includes a pickup tube and float-operated fuel gauge sender unit. Most current fuel pumps are installed inside the tank and the pickup and fuel gauge sensor are part of that assembly **(Figure 29–7)**. A fuel strainer attaches to the pickup tube. The fuel strainer, sometimes referred to as a sock, is made of woven plastic. The strainer serves as a filter, stopping any rust or dirt that may be in the fuel from entering into the fuel pump. The fuel tank also has vent valves that are connected via hoses to a charcoal canister that collects HC emissions when the engine is running.

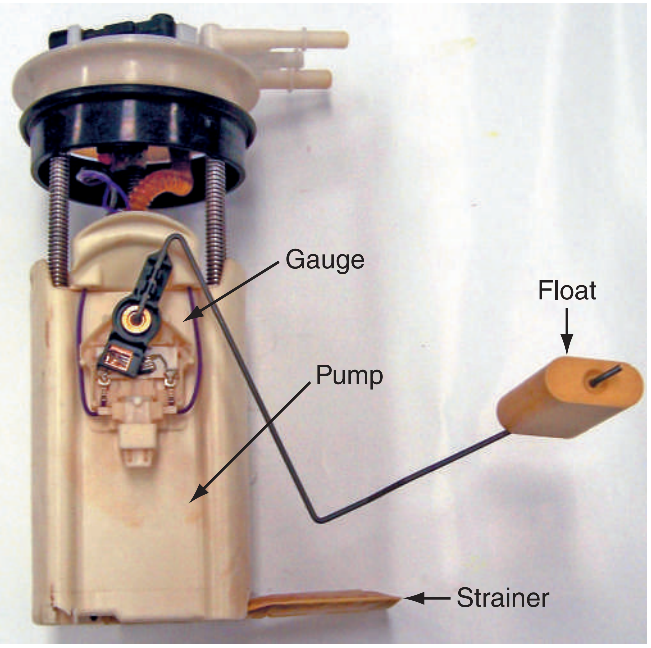


FIGURE 29–7 A combination of an electric fuel pump and sending unit.

Inspection

Fuel tanks should be inspected for leaks; road damage; corrosion and rust on metal tanks; loose, damaged, or defective seams; loose mounting bolts; and damaged mounting straps. Leaks in the fuel tank, lines, or filter may cause a gasoline odor in and around the vehicle, especially during low-speed driving and idling.

A weak seam, rust, or road damage can cause leaks in the metal fuel tank. The best method of permanently solving this problem is to replace the tank. Another method is to remove the tank and steam clean or boil it in a caustic solution to remove the gasoline residue. After this has been done, the leak can be soldered or brazed by an appropriately equipped specialty shop.

Holes in a plastic tank can sometimes be repaired by using a special tank repair kit. Be sure to follow manufacturer's instructions when doing the repair.

When a fuel tank is leaking or has water in it, the tank must be cleaned, repaired, or replaced.

Contaminated Fuel

Obviously, water does not burn. Therefore, water in the fuel tank can cause a driveability problem. To test for contaminated fuel, place a sample of fuel in a graduated container. Special fuel test beakers are available to make this test easier. Place a measured quantity of fuel into a container and mark the level. Next, add about 10 percent water to the container and mark the level. Seal the container and shake for several seconds and then let the fuel and water sit for up to 5 minutes. As the fuel and water separate, you will be able to tell by the marks you made if the amount of water is the same or has increased. This test can also help you determine if a customer has filled his or her non-flex fuel vehicle with E85 as the water and ethanol will show as a significant percentage of the volume.

If there is water in the fuel, drain the fuel tank, replace the fuel filter, and refill the tank with fresh

USING SERVICE INFORMATION

When a fuel tank must be removed, if possible, ask the customer to bring the vehicle to the shop with a minimal amount of fuel in the tank.

gasoline. Also, as fuel sits for a while, it becomes less volatile or stale. This is because some of the lighter HCs evaporate over time. When fuel is stored a long time and exposed to air and heat, the fuel begins to break down and evaporate, leaving behind large molecules of carbon and gum. The separation of these materials from the fuel lowers its volatility. Also, the molecules can collect in and restrict the fuel lines and injectors. If the molecules are injected into the cylinders, they will not burn and they can cause abrasion in the cylinders. If a fuel smells sour and has been stored for quite some time, the fuel is stale. It may be usable; however, it should be mixed with as much fresh fuel as possible.

There are many products available to partially revitalize the fuel; however, if the fuel is so stale that an engine will not run on it, drain it and refill the tank with fresh gasoline. If fuel will be stored for a while, a fuel stabilizer should be added to it before it is stored.

Fuel Tank Draining

Warning! Always drain gasoline into an approved container, and use a funnel to avoid gasoline spills.

The fuel tank must be drained prior to tank removal. Begin by removing the negative cable from the battery. Then raise the vehicle on a hoist. Make sure you have an approved gasoline container and are prepared to catch all of the fuel before proceeding. If the tank has a drain bolt, remove it to drain the fuel. If the fuel tank does not have a drain bolt, locate the fuel tank drainpipe or filler pipe. Using the proper adapter, connect the intake hose from a hand-operated or air-operated pump to the pipe. Insert the discharge hose from the hand-operated or air-operated pump into an approved gasoline container, and operate the pump until all the fuel is removed from the tank.

Fuel Tank Service

In most cases, the fuel tank must be removed for servicing. The procedure for removing a fuel tank varies depending on the vehicle make and year.

Caution! Abide by federal and state laws for the disposal of contaminated fuels. Be sure to wear eye protection when working under the vehicle.

Always follow the procedure in the vehicle manufacturer's service information. What follows is a typical procedure.

PROCEDURE

STEP 1 Disconnect the negative terminal from the battery.

STEP 2 Relieve the fuel system pressure and drain the fuel tank.

STEP 3 Raise the vehicle on a hoist or lift the vehicle with a floor jack and lower the chassis onto jack stands.

STEP 4 Use compressed air to blow dirt from the fuel line fittings and wiring connectors.

STEP 5 Remove the fuel tank wiring harness connector from the body harness connector.

STEP 6 Remove the ground wire retaining screw from the chassis if used.

STEP 7 Disconnect the fuel lines from the fuel tank. If these lines have quick-disconnect fittings, follow the manufacturer's recommended removal procedure in the service information. Some quick-disconnect fittings are hand releasable, and others require the use of a special tool **(Figure 29–8)**.

STEP 8 Wipe the filler pipe and vent pipe hose connections with a shop towel, and then disconnect the hoses from the filler pipe and vent pipe to the fuel tank.

STEP 9 Unfasten the filler from the tank. If it is a rigid one-piece tube, remove the screws around the outside of the filler neck near the filler cap. If it is a three-piece unit, remove the neoprene hoses after the clamp has been loosened.

STEP 10 Loosen the bolts holding the fuel tank straps to the vehicle **(Figure 29–9)** until they are about two threads from the end.

STEP 11 Holding the tank securely against the underchassis with a transmission jack or by hand, remove the strap bolts and lower the tank to the ground. When lowering the tank, make sure all wires and tubes are unhooked. Be careful as small amounts of fuel might still be in the tank.

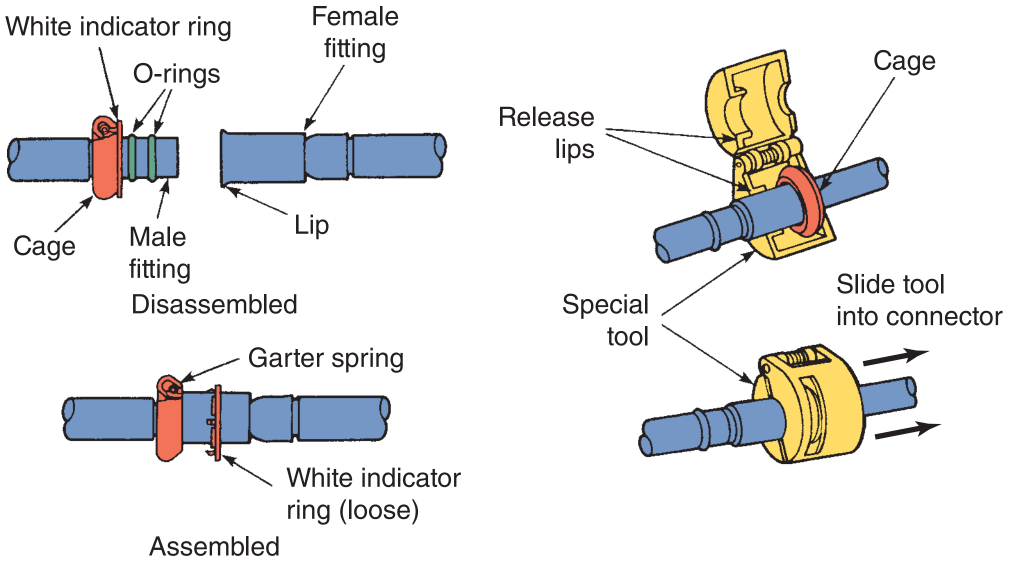


FIGURE 29–8 Some quick-connect fittings require the use of a special tool to separate them.

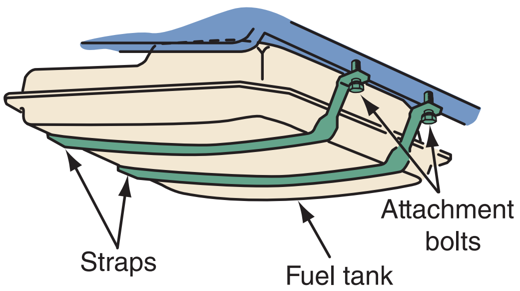


FIGURE 29–9 Front and rear fuel tank strap mounting bolts.

Warning! Do not heat the bolts on the fuel tank straps in order to loosen them. The heat could ignite the fuel fumes.

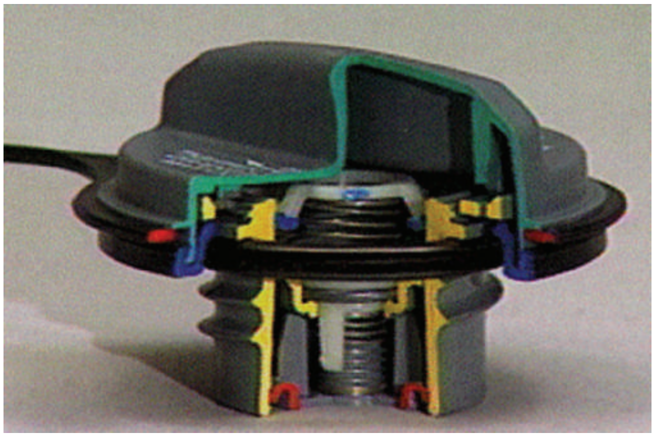
To reinstall a repaired or new fuel tank, reverse the removal procedure. Be sure that all the rubber or felt tank insulators are in place. Then, with the tank straps in place, position the tank. Loosely fit the tank straps around the tank, but do not tighten them. Make sure that the hoses, wires, and vent tubes are connected properly. Check the filler neck for alignment and for insertion into the tank. Tighten the strap bolts and secure the tank to the car. Install all of the tank accessories (vent line, sending unit wires, ground wire, and filler tube). Fill the tank with fuel and check it for leaks, especially around the filler neck and the pickup assembly. Reconnect the battery and check the fuel gauge for proper operation.

Filler Caps

Filler tube caps (commonly called gas or fuel caps) seal the fuel tank while allowing refilling of the tank. Filler caps are nonventing and have some type of pressure-vacuum relief valve arrangement **(Figure 29–10)**. Under normal conditions, the valve is closed. When extreme pressure or vacuum is present, the relief valve opens to prevent the tank from ballooning or collapsing. Once the pressure or vacuum is relieved, the valve closes.

The filler cap of late-model vehicles is tethered to the vehicle **(Figure 29–11)**. The cap is threaded into the upper end of the filler pipe. The threaded area on the cap is designed to allow any remaining tank pressure to escape during cap removal. The cap and filler neck are designed to prevent overtightening. To install the cap, turn it clockwise until a clicking noise is heard. This indicates that the cap is properly tightened and fully seated. A fuel filler cap that is not fully seated may cause a malfunction in the emission system.

Warning! When a tank filler cap is replaced, the replacement cap must be exactly the same as the original cap or a malfunction may occur in the filling and venting system, resulting in higher emission levels and the escape of dangerous HCs.



Courtesy of Stant Corporation, www.stant.com.

FIGURE 29–10 A cutaway of a pressure-vacuum gasoline filler cap.

FIGURE 29–11 The gas cap for current vehicles is tethered to the vehicle and threaded into the filler tube.

OBD II Monitor

Late-model vehicles that meet enhanced evaporative requirements have a vacuum-based evaporative system integrity check. If the gas cap is loose or missing, the ECM/PCM will detect an evaporative system leak and will illuminate a warning message. On some vehicles the "Check fuel cap" message will appear each time the engine is started until the system turns the message off. The message may turn off after the cap is replaced or tightened until at least one click is heard. If the message does not turn off, there be a leak in the system or the circuit for the message is faulty.

A fuel tank pressure (FTP) sensor is a transducer that converts the absolute pressure in the fuel tank into an input for the PCM **(Figure 29–12)**. The integrity check is done by creating a vacuum in the tank and measuring how well it holds the vacuum. If the gas cap is off or loose, the tank will not hold a vacuum. Before a vacuum is formed in the tank, the canister vent solenoid is closed to seal the entire evaporative system. Then the vapor management valve creates a slight negative pressure in the tank. If the desired amount of vacuum cannot be established, a system leak is indicated and the PCM will store a P0455 DTC and illuminate the warning message. Other possible causes for this code are disconnected or kinked vapor lines, an open canister vent solenoid, or a closed vapor management valve.

FIGURE 29–12 A fuel tank pressure (FTP) sensor.

Fuel Cap Testing

A gas cap should be checked whenever the PCM detects a leak in the evaporative system and the cap is securely fastened. Also, some states, such as California, mandate a gas cap check as part of the annual emissions tests. A gas cap is checked with a special tester. The cap is connected to the tester by an adapter specifically designed for the cap **(Figure 29–13)**. The tester then applies pressure to the cap and monitors its ability to hold the pressure. The readout on the tester simply says PASS or FAIL. A cap that has failed should be replaced. However, it is important that the correct adapter was used for the cap. If the wrong adapter was used, the cap will fail the test even if it is good.

Capless Fuel System

Ford Motor Company's Ford GT was the first modern production car to meet all emissions standards

FIGURE 29–13 A fuel cap tester with various adapters.

without a gas cap **(Figure 29–14)**. This technology is used on many 2008 and newer Ford as well as other vehicles. It is a very simple design. A spring-loaded flapper valve is positioned at the opening for the filler neck. This valve tightly seals the tank until a fuel nozzle is inserted into the opening. The nozzle opens the valve and allows for the refilling of fuel. As soon as the nozzle is removed, the valve is shut by the springs. A capless fuel system reduces the time the fuel vapors can escape during refueling. It also makes it more convenient for the consumer, because there is

FIGURE 29–14 A capless fuel filler tube with its flapper valve.

no cap to tighten. The filler door, which is outside the filler tube, helps to seal in the fuel and fuel vapors.

Fuel Lines and Fittings

The fuel lines **(Figure 29–15)** carry fuel from the tank to the fuel filter and fuel injection assembly. Fuel lines can be made of either metal tubing or flexible nylon or synthetic rubber hose. The latter must be able to resist gasoline. The hoses must also be nonpermeable, so gas and gas vapors cannot evaporate through the hose. Ordinary rubber hose, such as that used for vacuum lines, deteriorates when exposed to gasoline. Only hoses made for fuel systems should be used. Similarly, vapor vent lines must be made of material that resists attack by fuel vapors.

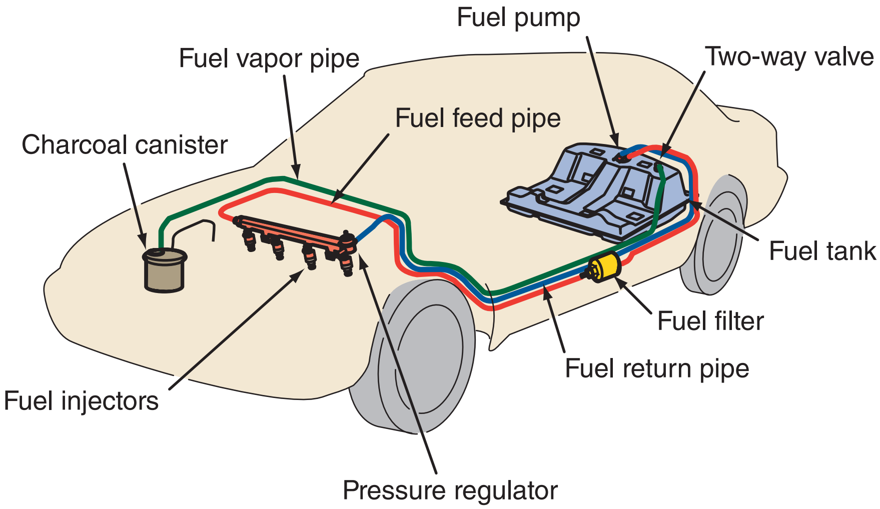


FIGURE 29–15 A typical layout of the fuel lines on a late-model car.

Fuel supply lines from the tank to the injectors are routed to follow the frame along the underchassis of the vehicle. Generally, rigid lines are used extending from near the tank to a point near the fuel pump and fuel filter. To prevent ruptures during a rear impact, the gaps between the frame and tank or fuel pump are joined by short lengths of flexible hose.

Late-model fuel tanks have hoses to allow air in the fuel tank to vent vapors into the charcoal canister when the tank is being filled with fuel. Vent hoses are usually installed alongside the filler neck. Replacement vent hoses are usually marked with the designation **EVAP** to indicate their intended use. The inside diameter of a fuel delivery hose is generally larger (5/16 to 3/8 inch [7.94 to 9.35 mm]) than that of a fuel return hose (¼ inch [6.35 mm]). The EVAP line to the tank is also often a different size or connection type than the fuel supply and return lines. This helps to prevent the lines from incorrect installation.

To control the rate of vapor flow from the fuel tank to the vapor storage tank, a plastic or metal restrictor may be placed in either the end of the vent pipe or in the vapor-vent hose itself. When the latter hose must be replaced, the restrictor must be removed from the old vent hose and installed in the new one.

Fittings

Sections of fuel line are assembled together by fittings. Some of these fittings are a threaded-type fitting, while most are a quick-release design. Many fuel lines have quick-disconnect fittings with a unique female socket and a compatible male connector. These quick-disconnect-fittings are sealed by an O-ring inside the female connector. Some of these quick-disconnect fittings have hand-releasable locking tabs **(Figure 29–16)**, while others require a special tool to release the fitting **(Figure 29–17)**.

> **Warning!** Other types of O-rings should not be substituted for a Viton O-ring.

The interior components, such as the O-rings and spacers, of quick-connect fittings are not serviceable. If the fitting is damaged, the complete fuel tube or line must be replaced.

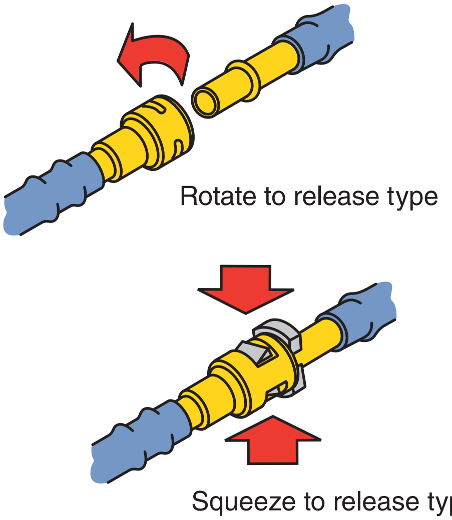


FIGURE 29–16 Quick-disconnect hand releasable fuel line fittings.

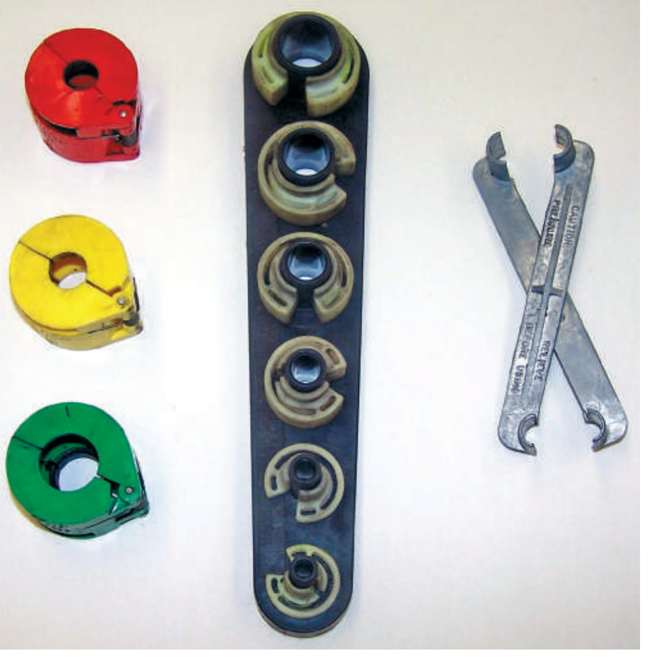


FIGURE 29–17 An assortment of quick-disconnect tools.

Some fuel lines have threaded fittings with an O-ring seal to prevent fuel leaks. These O-ring seals are usually made from Viton, which resists deterioration from gasoline. On some other fuel lines, the fuel hose is clamped to the steel line and the hose and clamp must be properly positioned on the steel line **(Figure 29–18)**.

A variety of clamps are used on fuel system lines, including the spring and screw types. Crimp, or

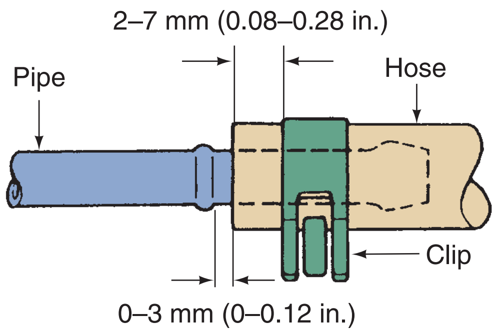


FIGURE 29–18 A fuel hose clamped to a steel tubing.

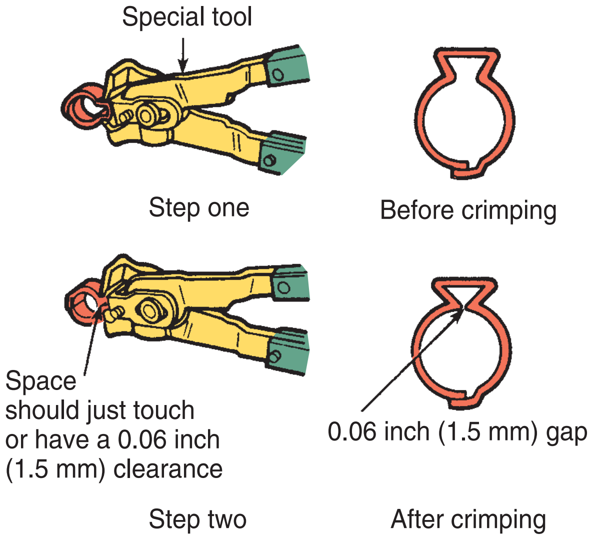


FIGURE 29–19 A special tool is required to tighten crimp clamps.

ear-type clamps **(Figure 29–19)**, are the most commonly used. These clamps are made from a single, spring strap. They are available in many different sizes and designs, each made for a particular connection. They are tightened with a special crimping tool.

Inspection

All fuel lines should occasionally be inspected for holes, cracks, leaks, kinks, or dents. Since the fuel is under pressure, leaks in the line between the pump and injection assembly are relatively easy to recognize.

Rubber fuel hoses should be inspected for leaks, cracks, cuts, kinks, oil soaking, and soft spots or deterioration. If any of these conditions is found, the fuel hose should be replaced. When a rubber fuel hose is installed, the hose should be installed to the proper depth on the metal fitting or line.

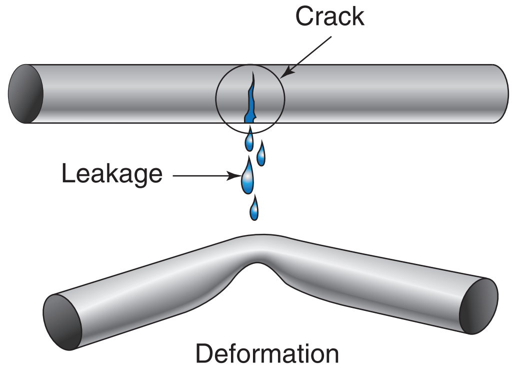


FIGURE 29–20 Steel tubing should be inspected for leaks, kinks, and deformation.

Steel tubing should be inspected for leaks, kinks, and deformation **(Figure 29–20)**. Tubing should also be checked for loose connections and proper clamping to the chassis. If the tubing's threaded connections are loose, they must be tightened to the specified torque. Some threaded fuel line fittings contain an O-ring. If the fitting is removed, the O-ring should be replaced.

Nylon fuel pipes should be inspected for leaks, nicks, scratches and cuts, kinks, melting, and loose fittings. If these fuel pipes are damaged in any way, they must be replaced. Nylon fuel pipes must be secured to the chassis at regular intervals to prevent fuel pipe wear and vibration.

Warning! Always cover a nylon fuel pipe with a wet shop towel before using a torch or other source of heat near the line. Failure to observe this precaution may result in fuel leaks, personal injury, and property damage.

Warning! If a vehicle has nylon fuel pipes, do not expose the vehicle to temperatures above 194 °F (90 °C) for any extended period to avoid damage to the pipes.

Line Replacement

When a damaged fuel line is found, replace it with one of similar construction—steel tubing with steel,

and flexible tubing with nylon or synthetic rubber. When installing flexible tubing, always use new clamps. The old ones lose some of their tension when they are removed and do not provide an effective seal when used on the new line.

Any damaged or leaking fuel line must be replaced. To fabricate a new fuel line, select the correct tube and fitting dimension and start with a length that is slightly longer than the old line. With the old line as a reference, use a tubing bender to form the same bends in the new line as those that exist in the old. Although steel tubing can be bent by hand to obtain a gentle curve, any attempt to bend a tight curve by hand usually kinks the tubing. To avoid kinking, always use a bending tool like those shown in **(Figure 29–21)**.

Nylon fuel pipes provide a certain amount of flexibility and can be formed around gradual curves under the vehicle. Do not force a nylon fuel pipe into a sharp bend, because doing so may kink the pipe and restrict the flow of fuel. When nylon fuel pipes are exposed to gasoline, they may become stiffer, making them more susceptible to kinking. Be careful not to nick or scratch nylon fuel pipes.

Caution! Do not substitute aluminum or copper tubing for steel tubing. Never use a hose within 4 inches of any hot engine or exhaust system component.

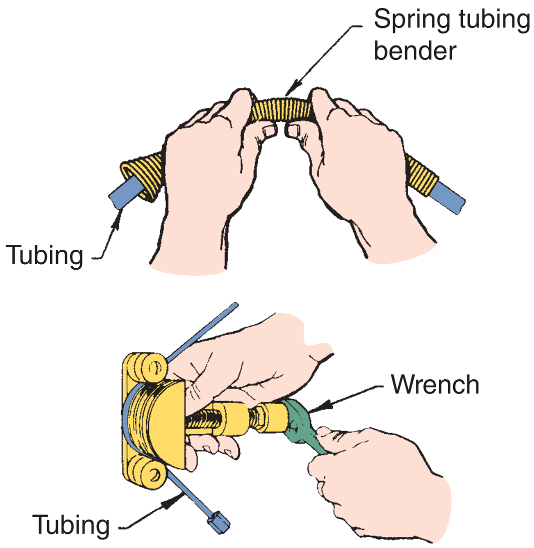


FIGURE 29–21 Two types of bending tools for steel tubing.

Warning! When connecting threaded fittings, make sure that the threads are aligned before tightening the connection. If the fittings are cross-threaded, fuel leaks will inevitably result. Also, always tighten fuel line fittings to the specified torque. If a fitting leaks, check the O-rings and seals.

Fuel Filters

Automobiles and light trucks usually have an in-tank strainer and a gasoline filter. The strainer, located in the gasoline tank, is made of a finely woven fabric. The purpose of this strainer is to prevent large contaminant particles from entering the fuel system where they could cause excessive fuel pump wear or plug fuel-metering devices. It also helps to prevent passage of any water that might be present in the tank. Servicing of the fuel tank strainer is seldom required.

A fuel filter is connected in the fuel line between the fuel tank and the engine. Many of these filters are mounted under the vehicle **(Figure 29–22)**, and others are mounted in the engine compartment. Most fuel filters contain a pleated paper element **(Figure 29–23)** mounted in the filter housing, which may be made from metal or plastic. Paper filter elements are efficient at removing and trapping small particles, as well as large-size contaminants. Fuel filters are typically contained in a metal case, but some have a plastic housing. On many fuel filters, the inlet and outlet

FIGURE 29–22 An inline fuel filter mounted under a vehicle.

FIGURE 29–23 The paper element inside a fuel filter.

fittings are identified, and the filter must be installed properly. An arrow on some filter housings indicates the direction of fuel flow through the filter.

To reduce maintenance costs, many vehicles no longer have an inline fuel filter that requires periodic replacement. The only filter is located in the tank and is replaced with the fuel pump assembly.

Servicing Filters

Fuel filters and elements are serviced by replacement only. Some vehicle manufacturers recommend fuel filter replacement at 30,000 miles (48,000 km). Always replace the fuel filter at the vehicle manufacturer's recommended mileage. If dirty or contaminated fuel is placed in the fuel tank, the filter may require replacing before the recommended mileage. A plugged fuel filter may cause the engine to surge and cut out at high speed or hesitate on acceleration. A restricted fuel filter causes low fuel pump volume.

The fuel filter replacement procedure varies depending on the make and year of the vehicle and the type of fuel system. Some vehicles do not have serviceable fuel filters. Instead, the filter is located in the tank and is serviced as part of the fuel pump module (FPM). Always follow the filter replacement procedure in the appropriate service information. Photo Sequence 26 shows a typical procedure for relieving fuel pressure and removing a fuel filter.

To install a new filter, begin by wiping the male tube ends of the new filter with a clean shop towel. Apply a few drops of clean engine oil to the male tube ends on the filter. Check the quick connectors to be sure the large collar on each connector has rotated back to the original position. The springs must be visible on the inside diameter of each quick connector. Then install the filter, in the proper direction, and leave the mounting bolt slightly loose. Install the outlet connector onto the filter outlet tube and press the connector firmly in place until the spring snaps into position. Grasp the fuel line and try to pull this line from the filter to be sure the quick connector is locked in place. Then do the same with the inlet connector. Now tighten the filter-retaining bolt to the specified torque. Once everything is connected, lower the vehicle, start the engine, and check for fuel leaks at the filter.

Fuel Pumps

A fuel pump draws fuel from the fuel tank and pushes it through fuel lines to the engine's injection system. All current vehicles use an electric fuel pump. For vehicles with gasoline direct injection, two fuel pumps are used. An in-tank electric supply pump delivers fuel to the engine. Mounted to the engine is a mechanical pump used to raise fuel pressure to between 1,500 and 2,500 psi depending on the system **(Figure 29–24)**.

An electric fuel pump can be located inside or outside the fuel tank. When the ignition is turned on, the pump starts to run and shuts off automatically when the fuel line is pressurized. When the key is in the CRANK position or the engine starts, the pump

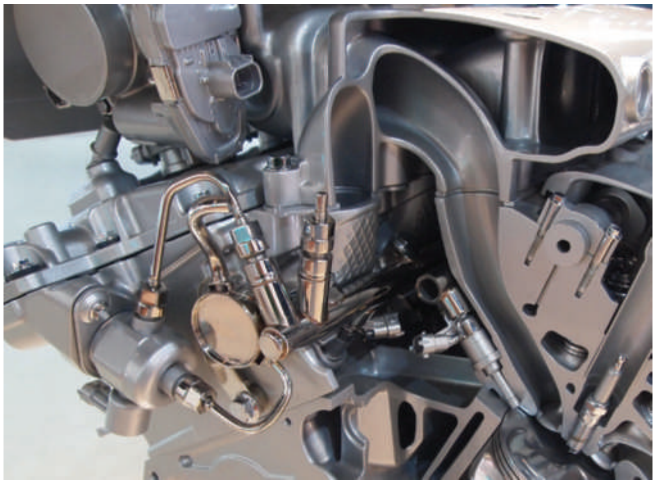
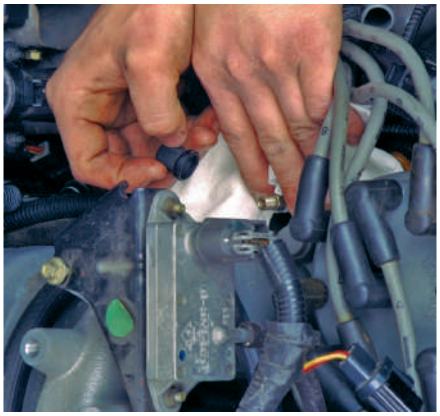


FIGURE 29–24 A fuel pump for a gasoline direct injection (GDI) system.

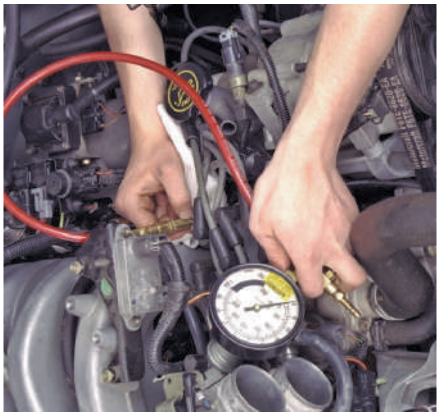
Removing a Fuel Filter on an EFI Vehicle

P26-1 Disconnect the negative cable at the battery.

P26-2 Loosen the fuel tank filler cap to relieve any fuel tank vapor pressure.



P26-3 Wrap a shop towel around the Schrader valve on the fuel rail and remove the dust cap from the valve.



P26-4 Connect the fuel pressure gauge to the Schrader valve.

P26-5 Install the free end of the gauge bleed hose into an approved gasoline container, and open the gauge bleed valve to relieve the fuel pressure.

P26-6 Place the vehicle on the hoist and position the lift arms according to manufacturer's recommendations. Then raise the vehicle.

P26-7 Flush the fuel filter line connectors with water, and use compressed air to blow debris off and away from the connectors.

P26-8 Follow the recommended procedures for disconnecting the fuel inlet connector.

P26-9 Follow the recommended procedures for disconnecting the fuel outlet connector. Then remove the fuel filter.

remains running. **Figure 29–25** shows a typical wiring diagram for an electric fuel pump.

An in-tank electric pump is usually the rotary type. Some vehicles have an in-tank pump and a second pump mounted under the vehicle. An in-tank fuel pump has a small DC electric motor with an impeller mounted on the end of the motor's shaft. A pump cover, with inlet and discharge ports, is mounted over the impeller. When the armature and impeller rotate, fuel is moved from the tank to the inlet port, and the impeller forces the fuel around the impeller cover and out the discharge port **(Figure 29–26)**.

Fuel moves from the discharge port through the inside of the motor and out the check valve and outlet connection, which is connected via the fuel line to the fuel filter and underhood fuel system

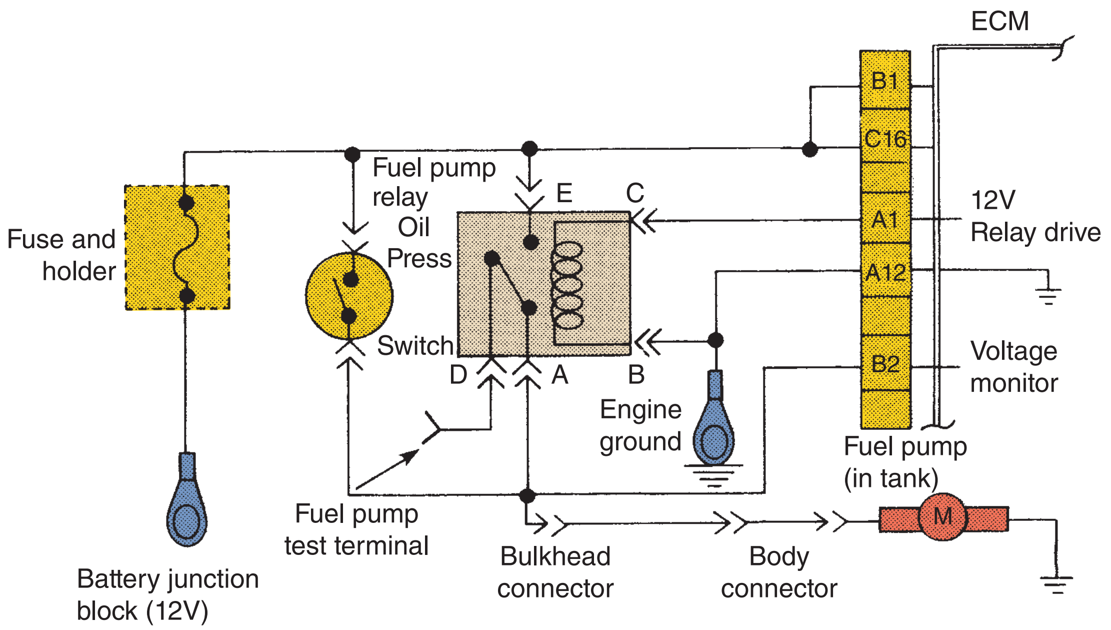


FIGURE 29–25 A typical wiring diagram for an electric fuel pump.

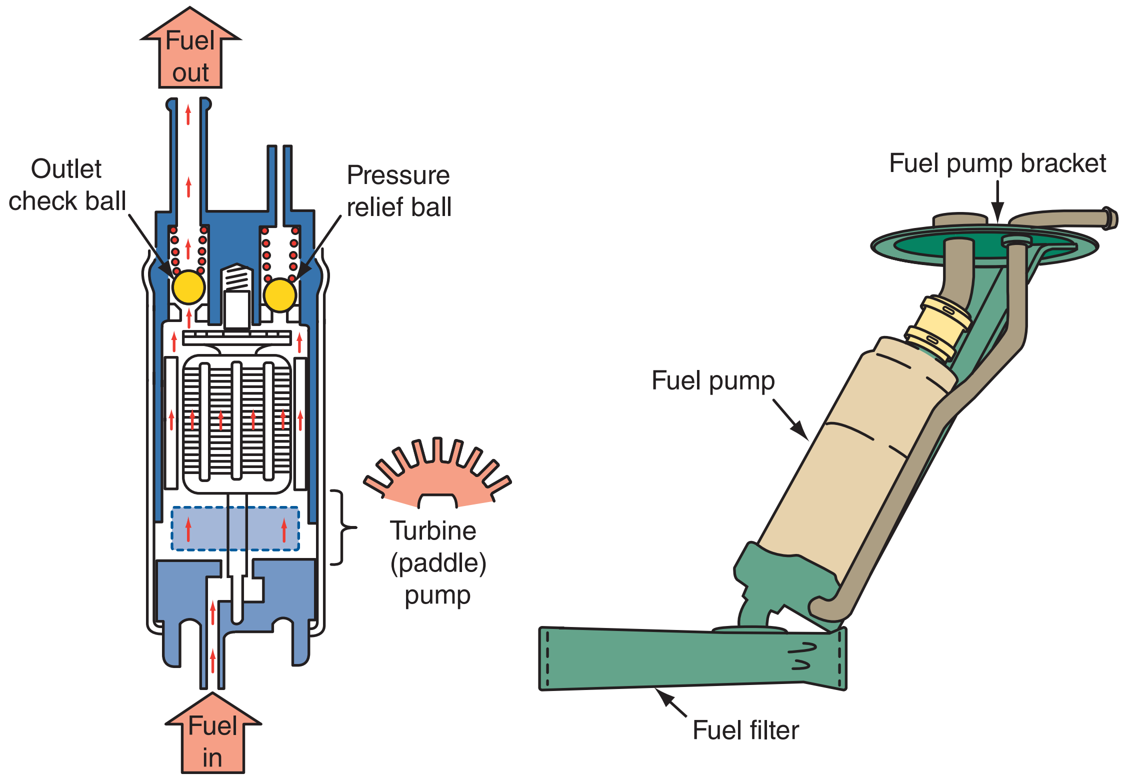


FIGURE 29–26 An electric fuel pump.

components. A pressure relief valve near the check valve opens if the fuel supply line is restricted and pump pressure becomes very high. When the relief valve opens, fuel is returned through this valve to the pump inlet. Each time the engine is shut off, the check valve prevents fuel from draining out of the fuel system and back into the fuel tank. Fuel pumps are mounted inside the tank to reduce noise, keep them cool, and keep the entire fuel line pressurized to prevent premature fuel evaporation. Although it is dangerous to have a spark near gasoline and there is a great potential for sparks between an electric motor's armature and brushes, the in-tank fuel pump is safe because there is no oxygen to support combustion in the tank.

The mechanical fuel pumps on direct injection systems are driven off of a dedicated lobe on the engine's camshaft **(Figure 29–27)**. The lobe pushes against a spring-loaded piston in the pump. Fuel enters the high-pressure pump from the electric supply pump and is then further pressurized by the movement of the piston. A solenoid is used to return excess fuel to the tank. The solenoid is controlled by the PCM and is used to maintain the correct amount of pressure in the fuel rail and injectors. The outlet of the pump is connected to a fuel rail.

Diesel Engines Fuel injection is used on all diesel engines. Older diesel engines had a distributor-type injection pump driven and regulated by the engine. The pump supplied fuel to injectors according to the engine's firing order. Newer light-duty diesel engines are equipped with common rail or direct injection (DI) systems. In these systems, an engine-driven fuel pump delivers fuel to the injectors at a very high pressure, about 26,000 psi (180 MPa or 1,800 bar). In a common rail system, the computer controls the individual injectors that are fed fuel by the common rail.

GO TO Chapter 28 for more information on diesel fuel injection systems.

Fuel Pump Circuits

Electric fuel pump circuits vary depending on the vehicle make and year. All fuel pumps on late-model vehicles are controlled by the PCM or through a designated electronic control unit tied into the PCM **(Figure 29–28)**. In most returnless systems, the output of the pump is controlled by the PCM through pulse-width modulation. In these systems, the pump's output during closed loop is monitored by a fuel rail pressure sensor.

Return Type In a GM fuel pump circuit (other manufacturers use similar systems), the PCM supplies voltage to the winding of the fuel pump relay when the ignition switch is turned on. This action closes the

FIGURE 29–27 In a GDI system, the fuel pump is driven by a dedicated lobe on the camshaft.

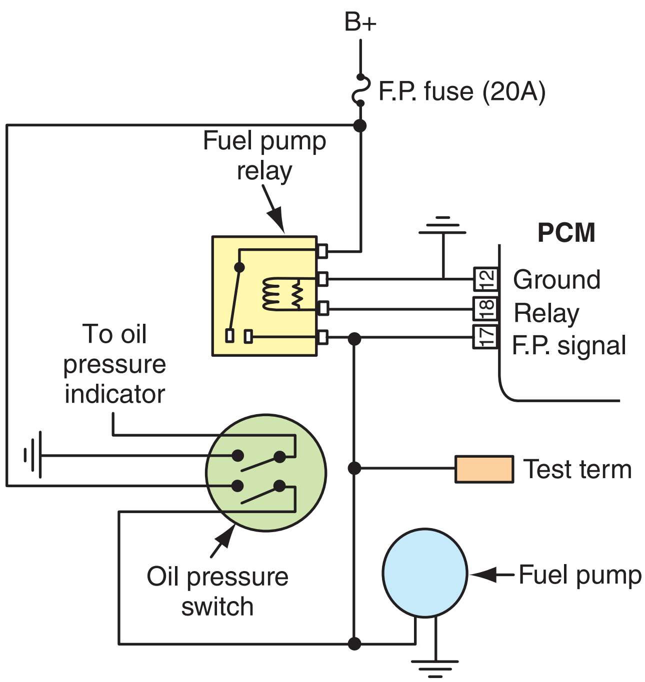


FIGURE 29–28 The basic circuit for a late-model fuel pump.

relay contacts and voltage is supplied through the relay to the fuel pump. The fuel pump remains on while the engine is cranking or running. If the ignition switch is on for 2 seconds and the engine is not cranked, the PCM turns off the voltage to the fuel pump relay to stop the pump.

The PCM may also shut off the fuel pump when the following occur:

- The vehicle experiences long, high-speed, closed throttle coast down. Fuel is shut off to prevent damage to the catalytic converters, reduce emissions, and increase the effects of engine braking.
- The engine speed exceeds a predetermined limit.
- The speed of the vehicle exceeds the speed rating of the tires.
- The vehicle has been in a collision.
- The air bag has deployed.
- A fuel line has ruptured.

An oil pressure switch is connected parallel to the fuel pump relay points. If the relay becomes defective, voltage is supplied through the oil pressure switch points to the fuel pump. This action keeps the fuel pump operating and the engine running, even though the fuel pump relay is defective. When the engine is cold, oil pressure is not available immediately, and the engine will have long crank times and be slow to start if the fuel pump relay is defective.

The fuel pump relay in Chrysler EFI systems is referred to as an automatic shutdown (ASD) relay. With the ignition switch turned on, the PCM grounds the windings of the relay and the relay points close. These supply voltage to the fuel pump, positive primary coil terminal, oxygen sensor heater, and the fuel injectors in some systems **(Figure 29–29)**.

Later model Chrysler fuel pump circuits have a separate ASD relay and a fuel pump relay. In these circuits, the fuel pump relay supplies voltage to the fuel pump, and the ASD relay powers the positive primary coil terminal, injectors, and oxygen sensor heater. The ASD relay and the fuel pump relay operate the same as the previous ASD relay. The PCM grounds both relay windings through the same wire.

Rollover Protection

Electric fuel pump circuits include some sort of rollover protection. On Ford vehicles this includes the installation of an **inertia switch** that shuts off the fuel pump if the vehicle is involved in a collision or rolls over. A typical inertia switch **(Figure 29–30)** consists of a permanent magnet, a steel ball inside a conical ramp, a target plate, and a set of electrical contacts. The magnet holds the steel ball at the bottom of the ramp. In the event of a collision, the inertia of the ball causes it to break away from the magnetic field and roll up the ramp. When it strikes the target plate, the electrical contacts open and the circuit between the PCM and fuel pump control unit opens, causing the fuel pump to turn off. The switch has a reset button that must be depressed before the pump will operate again.

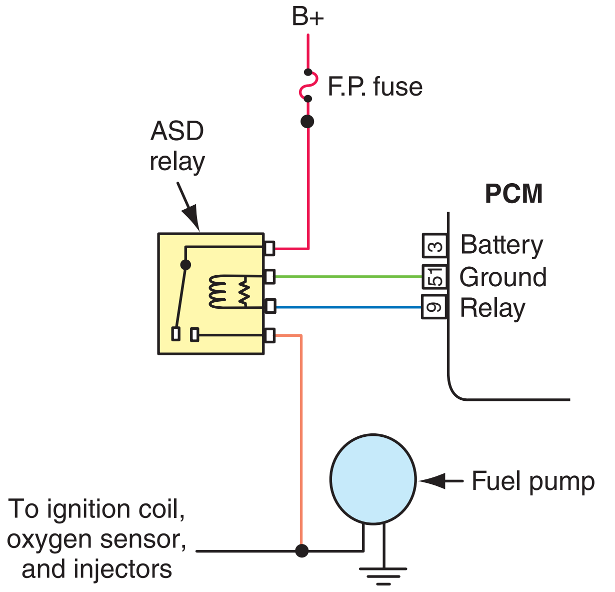


FIGURE 29–29 The basic circuit for a Chrysler fuel pump with an ASD relay.

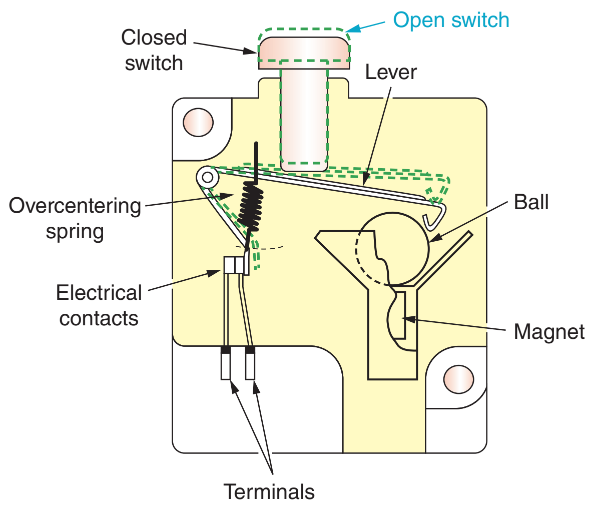


FIGURE 29–30 Details of a Ford inertia switch.

Passive Restraint Systems Most passive restraint systems will send a signal to the PCM when an air bag is deployed. The PCM, in turn, shuts down the

power to the fuel pump. In most cases, it is the center air bag sensor assembly that sends the deployment signal to the ECM through the CAN. This air bag sensor assembly contains a deceleration sensor, a safing sensor, a drive circuit, a diagnosis circuit, and an ignition control circuit. The main sensor for the deployment of an air bag and the de-powering of the fuel pump is the deceleration sensor.

The circuit constantly monitors its own operation and readiness; if it detects a malfunction, the SRS warning light will illuminate and a DTC will be stored.

Returnless Systems

In a mechanical returnless system, fuel pressure is maintained by a fuel pressure regulator located in the fuel tank. Electronic returnless systems control fuel pressure by using pulse-width modulation (PWM) of the fuel pump's power circuit. These systems may use the PCM to directly control the fuel pump or a separate fuel pump driver module may be used. In either system, the fuel pump speed is controlled by rapidly turning the fuel pump circuit on and off. The longer the time it is on, the faster the pump spins and more fuel is delivered to the engine. As demand decreases, the pump is left off longer and the fuel supply is decreased.

Electronic returnless systems use a fuel rail pressure (FRP) sensor, which may contain a fuel temperature sensor as well. The FRP sensor data is used by the PCM to control fuel pump operation and to adjust injector pulse width.

Troubleshooting

The fuel pressure test is the commonly used test for the fuel pump and related parts. Before connecting this test, carefully inspect the system for leaks and repair them before continuing. Then relieve the pressure in the system. When doing this, make sure to collect all spilled fuel. Scan tools can be used to shut down the fuel pump on many systems. Also, the PCM may set a DTC as a result of shutting off the fuel pump, make sure to clear that code after testing.

Fuel pressure is read with a fuel pressure gauge or by using a pressure transducer and a scope. The procedure for testing fuel pump pressure with a gauge is shown in Photo Sequence 27. These photos outline the steps to follow while performing the test on an engine with port fuel injection. To conduct this test on specific fuel injection systems, refer to the service information for instructions. Most domestic systems have a **Schrader valve** on the fuel rail, which can be used to connect the fuel pressure gauge. If the system does not have a Schrader valve, a tee should be installed in the fuel supply line to connect the gauge **(Figure 29–31)**.

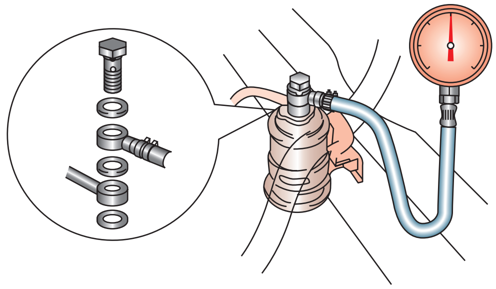


FIGURE 29–31 On fuel systems that do not have a Schrader valve, it may be necessary to fit a tee in the fuel line to connect the fuel pressure gauge.

On some engines, the fuel rail is fitted with a fuel pulsation damper. The point where the damper attaches to the fuel rail is the recommended place for connecting the pressure gauge. To connect the gauge, place a rag over the damper unit and loosen it one turn with a wrench. After all pressure is released, remove the damper unit and connect the gauge into the damper's fitting **(Figure 29–32)**.

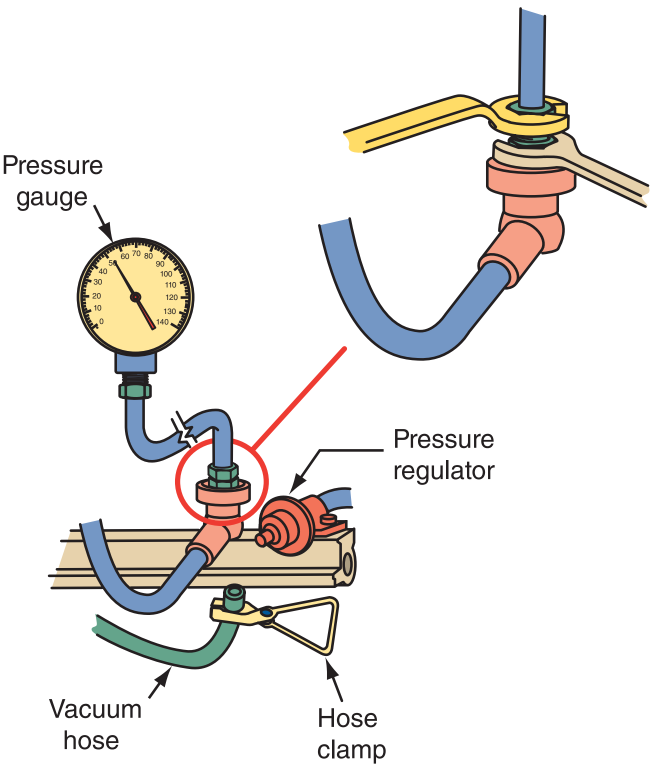
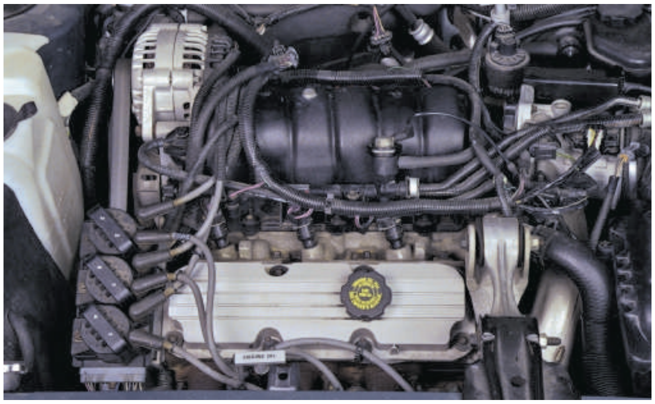


FIGURE 29–32 Connecting a fuel pressure gauge to the fuel pulsation damper fitting.

PHOTO SEQUENCE 27

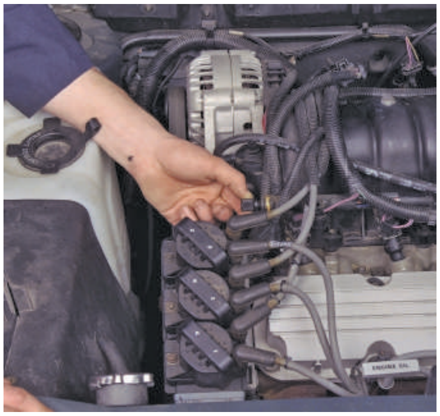
Checking Fuel Pressure on a Fuel Injection System

P27-1 Many problems on today's cars can be caused by incorrect fuel pressure. Therefore, checking fuel pressure is an important step in diagnosing driveability problems.

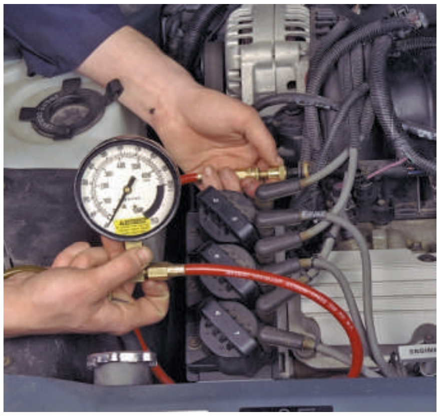


P27-2 Prior to testing the fuel pump, a careful visual inspection of the injectors, fuel rail, and fuel lines and hoses is necessary. Any sign of a fuel leak should be noted and the cause corrected immediately.

P27-3 The supply line into the fuel rail is a likely point of leakage. Check the area around the fitting to make sure no leaks have occurred.



P27-4 Most fuel rails are equipped with a test fitting that can be used to relieve pressure and to test pressure.

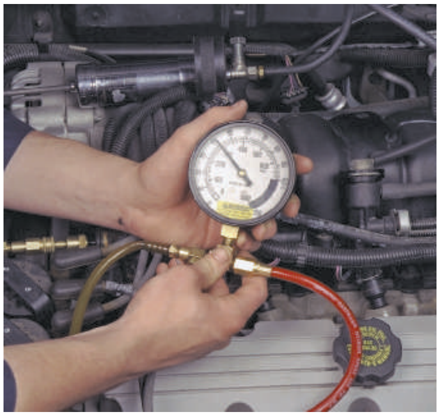


P27-5 To test fuel pressure, connect the appropriate pressure gauge to the fuel rail test fitting (Schrader valve).

PHOTO SEQUENCE 27

Checking Fuel Pressure on a Fuel Injection System *(continued)*

P27-6 Connect a hand-held vacuum pump to the fuel pressure regulator.



P27-7 Turn the ignition switch to the run position and observe the fuel pressure gauge. Compare the reading to specifications. A reading lower than normal indicates a faulty fuel pump or fuel delivery system.

P27-8 To test the fuel pressure regulator, create a vacuum at the regulator with the vacuum pump. Fuel pressure should decrease as vacuum increases. If pressure remains the same, the regulator is faulty.

P27-9 To test the fuel pressure on an engine with gasoline direct injection (GDI), you will need to use a scan tool. This is because pressure in the GDI system can exceed 2,500 psi.

P27-10 With the engine running, locate the fuel pressure PID and compare the reading to the fuel pressure specification.

P27-11 In this example, fuel pressure is within the manufacturer's specifications.

Often the specifications for fuel pressure are for key on engine off conditions. This means there will be no signal from the CKP, which means the fuel pump will not run for very long with the key on. Many systems will energize the fuel pump for only a few seconds prior to cranking. With the gauge connected, turn the key on and note the fuel pressure. You may have to cycle the key on/off several times if fuel pressure was completely relieved to install the gauge. Fuel pressure should reach the key on engine off (KOEO) specification and should not drop once the key is turned off. The action of the fuel pump can also be checked by controlling the vacuum to the fuel pressure regulator. With 20 in. Hg applied to the regulator, the fuel pressure should drop. When there is no vacuum to the regulator, the fuel pressure should rise. This check also verifies that the regulator is working properly. A quick check of fuel volume can be performed by watching fuel pressure with the engine running and the pressure regulator vacuum hose disconnected. The pressure should increase several psi with the hose disconnected. Quickly snap the throttle open and watch fuel pressure. If the fuel pump maintains sufficient volume, the pressure should only drop slightly—a couple of psi—as the injectors supply more fuel to the engine.

Warning! When testing a fuel system, do not let fuel contact any electrical wiring. Even the smallest spark could ignite the fuel.

Some manufacturers recommend that the pressure be measured while the engine is idling. Always make sure that you are using the correct conditions and specifications. Pressure will be slightly lower when the engine is running. Typically the pressure will rise and fall because the injectors are opening and closing, causing the gauge to fluctuate slightly. Major fluctuations, several psi, however, indicate air in the system.

Some technicians perform what is called a fuel pump deadhead pressure test. This test momentarily restricts the fuel return line and forces the pump to produce its maximum pressure. With a fuel pressure gauge installed and the engine running at idle, briefly clamp the fuel return line and note fuel pressure. Note, only perform this test if the vehicle has a rubber return line. Do not clamp a nylon or plastic fuel line. Do not leave the return clamped longer than it takes the fuel pressure to maximize. In most cases, a good pump will nearly double its engine running pressure. If the pressure does not increase significantly, suspect a weak fuel pump or clogged filter.

Remember, if the fuel pressure is outside specifications, driveability problems can result. Excessive pressure causes a rich air-fuel mixture and insufficient pressure results in a leaner-than-normal mixture.

Testing returnless systems is similar to systems with return lines except that fuel pressure can be monitored using a scan tool. To check if the fuel rail pressure (FRP) sensor is working, watch the fuel pressure PID while changing engine speed and load. If the pressure does not change with engine changes, suspect the pressure sensor is faulty. To double check the accuracy of the fuel pressure sensor, connect a fuel pressure gauge to the service port and compare the readings. If the FRP sensor is faulty, such as reading pressure as higher than it actually is, the PCM will command decreased fuel pressure. This can cause a lean condition as there is not enough fuel available at the injectors. It is important to note that the readings between the mechanical gauge and FRP sensor on a running engine likely will not match. This is because the pressure reading from the FRP sensor is referenced to manifold pressure and not atmospheric pressure. Refer to the manufacturer's service information to determine the variation in pressure readings.

Interpreting the Results High fuel pressure readings usually indicate a faulty pressure regulator or an obstructed return line. To identify the cause, disconnect the fuel return line at the tank. Use a length of hose to route the returning fuel into a container. Start the engine and note the pressure reading at the engine. If fuel pressure is now within specifications, check for an obstruction in the return system at the tank. The fuel reservoir check valve or aspirator jet might be clogged.

If the fuel pressure still reads high with the return line disconnected, note the volume of fuel flowing through the line. Little or no fuel flow can indicate a plugged return line. Shut off the engine and connect a length of hose directly to the fuel pressure regulator return port to bypass the return hose. Restart the engine and again check the pressure. If bypassing the return line brings the readings back within specifications, a plugged return line is the problem.

If pressure is still high, apply vacuum to the pressure regulator. If there is still no change, replace the pressure regulator. If applying vacuum to the regulator lowers fuel pressure, the vacuum hose to the regulator might be plugged, leaking, or misrouted.

On mechanical returnless fuel systems, the fuel pressure regulator is mounted in the tank with the fuel

pump. To service the regulator, the FPM must be removed from the tank. With PWM returnless systems, a faulty fuel rail pressure sensor can cause the PCM to increase fuel pressure if the sensor is reading too low.

Low fuel pressure, on the other hand, can be due to a clogged fuel filter, restricted fuel line, weak pump, leaky pump check valve, defective fuel pressure regulator, a leak in the supply line in the tank, excessive resistance in the fuel pump power or ground circuits, or dirty filter sock in the tank. It is possible to rule out filter and line restrictions by checking the pressure at the pump outlet. A higher reading at the pump outlet (at least 5 psi) means there is a restriction in the filter or line. If the reading at the pump outlet is unchanged, then the pump either is weak or is having trouble picking up fuel (clogged filter sock in the tank). Either way it is necessary to get inside the fuel tank. If the filter sock is gummed up with dirt or debris, it is also wise to clean out the tank when the filter sock is cleaned or replaced.

Another possible source of trouble is the pump's check valve. Some pumps have one, whereas others have two (positive displacement roller vane pumps). The check valve prevents fuel movement through the pump when the pump is off so residual pressure remains at the injectors. This can be checked by watching the fuel pressure gauge after the engine is shut off.

Residual Pressure Often the cause of poor starting is the lack of residual pressure in the system. This can be checked by looking at the pressure after the engine has been run and then turned off. Using a pressure transducer and GMM or DSO allows you to monitor system pressure over a period of time without having to actually wait and watch a fuel pressure gauge. The system should hold about the same pressure, for about 5 minutes, as it did during the pressure test. If the pressure drops off quickly after the engine and ignition are turned off, there is a leakage problem in an injector, fuel pump, connectors, hoses, or pressure regulator.

To test if the pump is the cause of the dropping fuel pressure, pinch off the return hose with a pair of hose-pinching pliers. Note that this can only be done on a section of rubber fuel hose. Shut the engine off and immediately pinch off the return hose. If the pressure remains at specifications, the problem is in the tank. If the pressure drops, check for a leaking injector or pressure regulator.

Fuel Volume Test If the fuel pressure is within specifications, you cannot conclude that the fuel delivery system is fine. Fuel volume or the pump's capacity to cause fuel flow is also important and should be tested according to the procedures outlined in the service information. This test measures the flow rate of the pump and can help isolate fuel system restrictions or weak pumps. The test is conducted by collecting the fuel dispensed during a period of time, which is normally 30 seconds. Disconnect the return line on returnable systems or the supply line on returnless systems and connect a hose to end of the line. Put the other end of the hose into a graduated container **(Figure 29–33)**. Turn on the fuel pump for about 30 seconds and measure the amount of fuel in the container. Normally the desired amount is 1 pint (0.47 liters). The flow of fuel into the container should be smooth and continuous with no signs of air bubbles. Results other than these indicate a bad pump or restrictions in the delivery system.

After checking the fuel pressure and volume, remove the pressure gauge and all adapters and hoses installed for the tests. Reinstall and tighten the fuel filler cap. Then turn the ignition on and check for fuel leaks.

Using a Lab Scope Monitoring the voltage and current to the fuel pump with a lab scope or GMM can give an idea of how well the pump is working. The

FIGURE 29–33 The setup for checking the fuel pump volume.

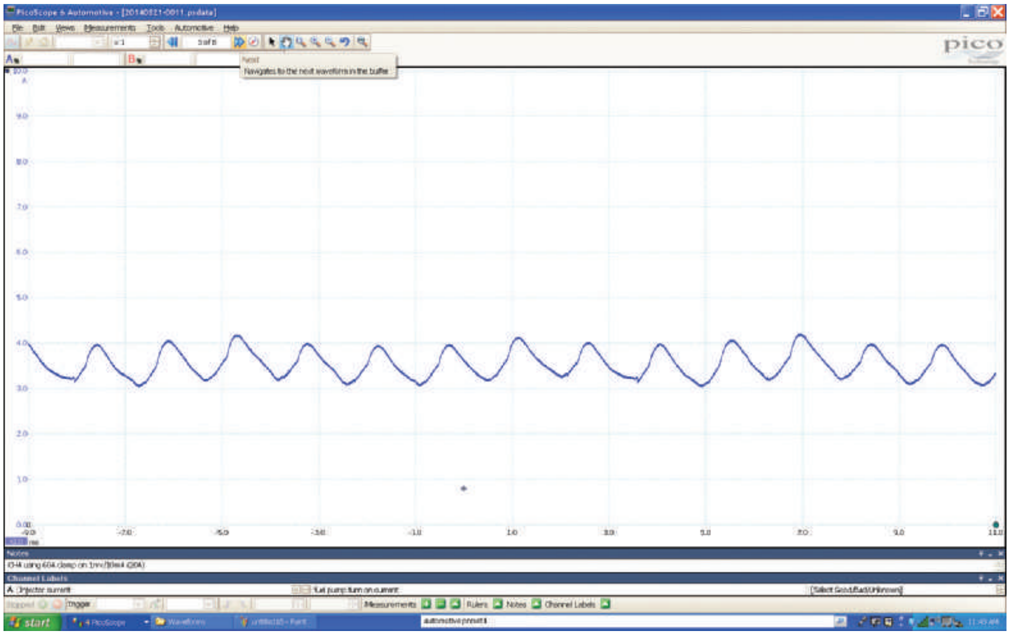


FIGURE 29–34 Monitoring a fuel pump with a lab scope or GMM can show a worn pump, as evidenced by irregular voltage spikes.

voltage traces show the voltage needed to establish current flow in the pump's windings and should be consistent throughout the time period set on the scope. The current pattern is made up of a series of small humps **(Figure 29–34)**. Each of the humps represents one commutator segment in the motor. Each of the humps should look the same. If there are variances in the pattern, a worn pump is indicated.

Using a DMM A pressure transducer can be used to connect a DMM (or lab scope) to the fuel system to measure fuel pressure. This is a safe way to monitor fuel pressure during a road test. The transducer is connected in the same way as a pressure gauge. Check the DMM's information to determine how to interpret the readings.

A DMM with a current probe can be used to monitor the current flow to the fuel pump. Looking at the current can give a good picture of the condition of the pump and the overall fuel delivery system. The normal amount of current draw for a fuel pump may be listed in the vehicle's specifications. If it is not, use the values in **Figure 29–35** as a guideline. Photo Sequence 28 shows how to look at the current to the pump. This is very valuable for diagnosing a fuel pump and its circuit.

In motor circuits, excessive current means the armature is rotating slower than normal. Therefore, if the pump is drawing too much current, it is working harder than it should. This can be caused by a restricted fuel filter or return line.

Min/Max Fuel Pressure	Normal Draw
10–15 psi (70–105 kPa)	2–4 amps
35–60 psi (240–415 kPa)	4–9 amps

FIGURE 29–35 A chart showing the typical current draw of low- and high-pressure fuel pumps.

The opposite is true; if the current levels are low, the motor is spinning too fast. This can be caused by very low fuel levels in the tank. Current can also be too low due to high resistance in the circuit. Check the connectors from the relay and to the pump. Also, check the ground circuit for the pump. If the circuit is fine, check the pump. You should not assume that the pump is the cause of a low-pressure problem until you have ruled out that the power and ground circuits for the pump are in good condition and there is not excessive voltage drop in the circuits.

SHOP TALK

All electrical tests assume that the battery is fully charged. Often when there is a fuel pump problem, the engine has been cranked often and long. This lowers the battery's voltage and will affect all tests on the pump and its circuit.

No-Start Diagnosis

When an engine fails to start because there is no fuel delivery, the first check is the fuel gauge. A gauge that reads higher than a half tank probably means there is fuel in the tank, but not always. A defective sending unit or miscalibrated gauge might be giving a false indication. Sticking a wire or dowel rod down the fuel tank filler pipe tells whether there really is fuel in the tank. If the gauge is faulty, repair or replace it.

Listen for pump noise. When the key is turned on, the pump should hum for a couple of seconds to build system pressure. On Ford vehicles, make sure the inertia switch has not been tripped. Hitting a large enough pothole can cause the inertia switch to open, shutting off the fuel pump. The pump may be energized through an oil-pressure switch (the purpose of which is to shut off the flow of fuel in case of an accident that stalls the engine). On most late-model cars with computerized engine controls, the computer energizes a pump relay **(Figure 29–36)** when it receives a cranking signal from the distributor pickup or crankshaft sensor. An oil-pressure switch might still be included in the circuitry for safety purposes and to serve as a backup in case the relay or computer signal fails. Failure of the pump relay or computer driver signal can cause slow starting because the fuel pump does not come on until the engine cranks long enough to build up sufficient oil pressure to trip the oil-pressure switch.

Many newer vehicles use FPM. The PCM monitors fuel rail pressure and communicates with the FPM to control pump output. Using a scan tool, check for fuel pump circuit codes and verify that the PCM is requesting fuel pump operation when cranking the engine. If the pump command is not active, check the service information for what conditions have to occur to either turn the pump on or keep it turned off.

The pump might be good, but if it does not receive voltage and have a good ground, it does not run. On non-PWM fuel pump circuits, check the power and ground circuits by connecting a testlight across the ground and feed wires at the pump to check for voltage. If the testlight turns on with the key on, you have verified the power and ground circuits are intact and can flow current. If the testlight does not light or is dim, use a voltmeter to read actual voltage to the pump. Next, voltage drop test the power and ground circuits to determine the cause of the problem. The latter is the better test technique because a poor ground connection or low voltage can reduce pump operating speed and output. If the electrical circuit

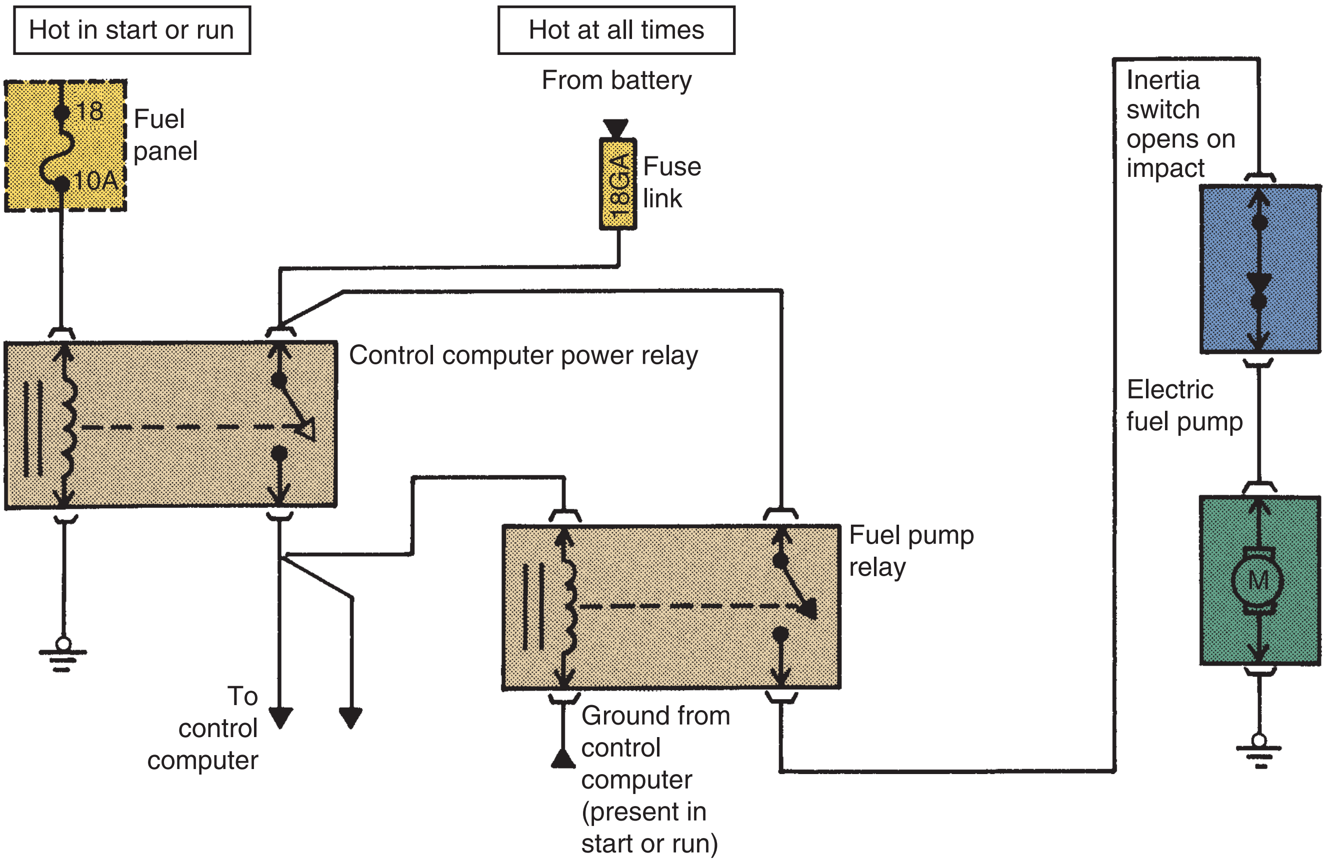


FIGURE 29–36 An electrical fuel delivery system wiring diagram.

PHOTO SEQUENCE 28

Checking Current Ramping to the Fuel Pump

P28-1 To test the fuel pump, you will need a lab scope and current clamp. Begin by installing a fender cover if working at an underhood fuse box.

P28-2 Locate the fuel pump fuse and remove it from the fuse box.

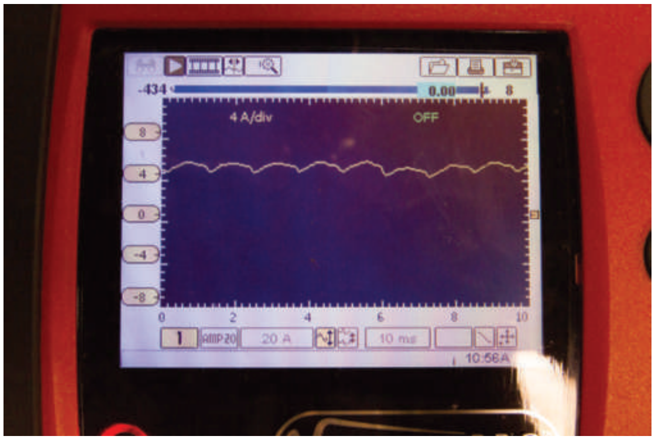
P28-3 Install a fused jumper wire in place of the fuel pump fuse. Make sure the fused jumper wire has the same amperage rating as the fuel pump circuit.

P28-4 Place the current clamp over the jumper wire with the arrow on the clamp pointing in the direction of current flow.

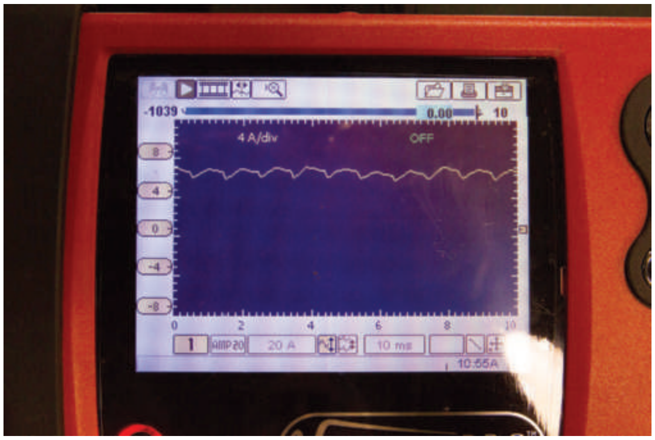
P28-5 Set the scope to display the signal from the clamp. In this example, the scope is set to measure millivolts and the clamp is set to 20 amps.

Checking Current Ramping to the Fuel Pump *(continued)*

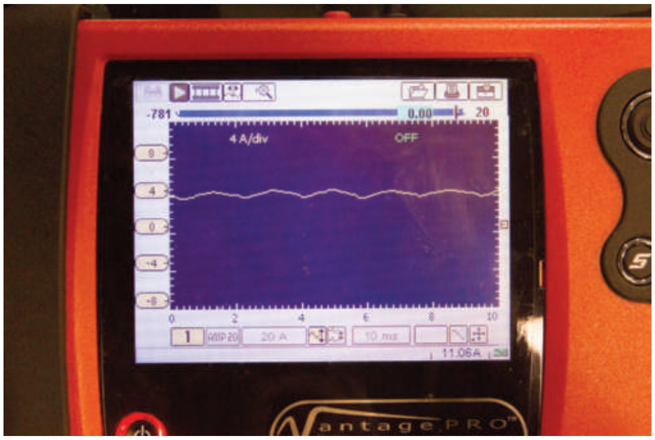
P28-6 Turn the ignition on and capture the fuel pump current draw waveform.



P28-7 This pattern shows a good fuel pump. Note the consistent humps of current flow through each commutator and winding. While pump current draw will vary depending on vehicle manufacturer and fuel system pressure, typical current draw is between 4 and 8 amps.



P28-8 This image shows a waveform from a vehicle with a clogged fuel filter, which is slowing the pump and increasing current draw.



P28-9 This image shows a waveform from a vehicle with a corroded connection at the fuel pump. Note the lower than normal amperage and pump speed.

checks out but the pump does not run, the pump is probably bad and should be replaced.

You can also test pump current draw to determine if the pump is working. Place a current probe around either the power or ground wire to the pump. Set the probe and DMM to measure pump current, typically less than 10 amps. Turn the key on or command the pump on with a scan tool and note the reading. Typical pump current draw is 4 to 9 amps. If no reading is shown and you have checked the power and ground circuits, the pump is faulty or the electrical connections inside the tank are open. Lower than specified current can indicate excessive voltage drop in the pump circuit or a pump that is spinning faster than normal. This can be caused by a leak in the supply line inside of the tank or an empty fuel tank. Higher than normal current draw indicates the pump is spinning too slowly or there is a restriction in the supply system.

No voltage at the pump terminal when the key is on and the engine is cranking indicates a faulty oil-pressure switch, pump relay, relay drive circuit in the computer, open inertia switch, or a wiring problem. Check the pump fuse to see if it is blown. Replacing the fuse might restore power to the pump, but until you have found out what caused the fuse to blow, the problem is not solved. The most likely cause of a blown fuse would be a short in the wiring between the relay and pump, or a short inside the oil-pressure switch or relay, or a bad fuel pump.

A faulty oil-pressure switch can be checked by bypassing it with a jumper wire. If doing this restores power to the pump and the engine starts, replace the switch. If an oil-pressure switch or relay sticks in the closed position, the pump can run continuously whether the key is on or off, depending on how the circuit is wired.

To check a pump relay, use a testlight to check across the relays and ground terminals to tell if the relay is getting battery voltage and ground. Next, turn off the ignition, wait about 10 seconds, and then turn it on. The relay should click and you should see battery voltage at the relay's pump terminal. If nothing happens, repeat the test, checking for control of the relay by the computer. Depending on the vehicle, the PCM may supply power or ground to control the relay. The presence of a control signal here means the computer is doing its job but the relay is failing to close and should be replaced. No control signal from the computer indicates an open in that wiring circuit or a fault in the computer itself.

Caution! Never turn on the ignition switch or crank the engine with a fuel line disconnected. This action will result in gasoline discharge from the disconnected line, which may result in a fire, causing personal injury and/or property damage.

Replacement

When replacing an electric pump, be sure that the new or rebuilt replacement unit meets the minimum requirements of pressure and volume for that particular vehicle. This information can be found in the service information. If the fuel pump is mounted in the fuel tank, the procedure for replacement is different than if the unit is external to the tank.

Internal Fuel Pump On many vehicles, the fuel tank must be removed to replace the fuel pump and/or fuel gauge sending unit. On other vehicles, the unit can be serviced through an opening under the rear seat or in the vehicle's trunk **(Figure 29–37)**. Some vehicles have a separate fuel pump and gauge sending unit, while others have both contained in a single unit. Once the fuel tank is empty and out of the vehicle, if necessary, remove the unit from the tank.

These units are often held in the tank by either a retaining ring or screws. The easiest way to remove a retaining ring is to use a special tool designed for this purpose. This tool fits over the metal tabs on the retaining ring, and after about a quarter turn, the ring comes loose and the unit can be removed **(Figure 29–38)**. If the special tool is not available, a brass drift punch and ball-peen hammer usually can do the job.

Before removing the pump, clean the tank around the opening and blow any dirt and debris off

FIGURE 29-37 Access to this fuel pump is gained by removing the rear seat.

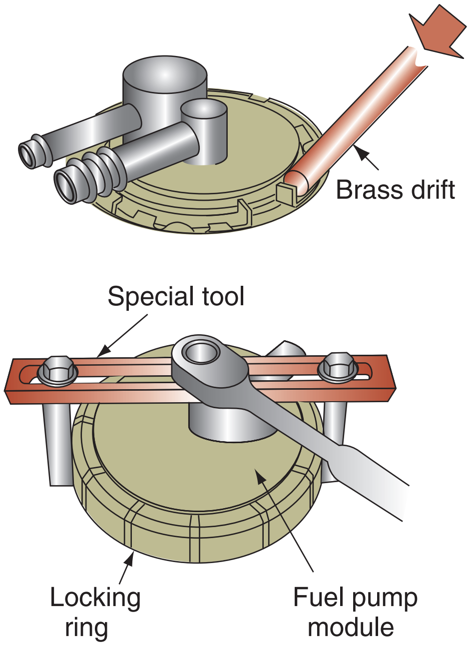


FIGURE 29–38 The locking ring for the fuel pump can be loosened and tightened with a brass drift or a tool designed for doing this.

to prevent it from falling down into the tank. When removing the unit from the tank, be very careful not to damage the float arm, the float, or the fuel gauge sender. Check the unit carefully for any damaged components. Shake the float and if fuel can be heard inside, replace it. Make sure the float arm is not bent. It is usually wise to replace the sock and O-ring before replacing the unit. Check the fuel gauge and sender unit as described in the service information. When reinstalling the pickup pipe-sending unit, be very careful not to damage any of the components.

Once the unit is removed, check the filter on the fuel pump inlet. If the filter is contaminated or damaged, replace the filter. Many technicians replace the inlet filter as part of replacing the fuel pump. Inspect the fuel pump inlet for dirt and debris. Replace the fuel pump if these foreign particles are found in the pump inlet.

If the pump inlet filter is contaminated, flush the tank with hot water for at least 5 minutes. Dump all the water out of the tank through the pump opening in the tank. Shake the tank to be sure all the water is removed. Allow the tank to sit and air dry before reinstalling it or adding fuel to it. Remember, gasoline fumes are extremely ignitable, so keep all open flames and sparks away from the tank while it is drying.

Check all fuel hoses and tubing on the fuel pump assembly. Replace fuel hoses that are cracked, deteriorated, or kinked. If replacing a piece of fuel hose within the tank, make sure the hose is rated for immersion in fuel. Using inferior fuel line will cause the line to fail and fall apart within the tank. When fuel tubing on the pump assembly is damaged, replace the tubing or the pump.

Make sure the sound insulator sleeve is in place on the electric fuel pump, and check the position of the sound insulator on the bottom of the pump.

Clean the pump and sending unit mounting area in the fuel tank with a shop towel, and install a new gasket or O-ring on the pump and sending unit. Install the fuel pump and gauge sending unit assembly in the fuel tank and secure this assembly in the tank using the vehicle manufacturer's recommended procedure. Many late-model FPMs are spring loaded and require you to position the unit and keep it pressed down during reassembly. Make sure the unit is properly positioned inside of the tank to prevent damage to the fuel sending unit and inlet filter.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2007	**Make:** Chevy	**Model:** Colorado	**Mileage:** 148,108	**RO:** 18902
Concern:	Towed in, customer states truck barely runs, has no power, runs rough.			
The technician confirms the engine runs very poorly. Checking for codes reveals a P0171–bank 1 lean. Scan data shows the fuel trim number at +25 percent and the HO_2S voltages staying very low. After confirming the MAF sensor is working correctly, he checks fuel pressure and finds it is about half of the specified pressure. He then informs the customer that the fuel pump is faulty and needs to be replaced. After selling and completing the fuel pump replacement, the truck runs the same. He then tests voltage at the pump and finds it is 12.4 volts with the key on. He then checks the voltage on the pump ground and is surprised to measure 5.2 volts on the ground circuit.				
Cause:	Found fuel pump ground wire not securely fastened to frame causing excessive voltage drop on pump ground. Voltage drop decreased pump speed and fuel delivery.			
Correction:	Removed, cleaned, and tightened fuel pump ground. Reinstalled original fuel pump; pressure within specs.			

KEY TERMS

EVAP
Inertia switch
Schrader valve

SUMMARY

- A typical fuel delivery system includes a fuel tank, fuel lines, a fuel filter, a fuel pressure regulator, and a fuel pump.
- The fuel system should be checked whenever there is evidence of a fuel leak or smell.
- The fuel system should also be checked whenever basic tests suggest that there is too little or too much fuel being delivered to the cylinders.
- Fuel delivery problems typically cause no-start or loss of power problems.
- Because electronic fuel injection systems have a residual fuel pressure, this pressure must be relieved before disconnecting any fuel system component.
- Fuel tanks have devices that prevent fuel vapors from leaving the tank. All fuel tanks have a filler tube and a nonvented cap.
- The fuel tank should be inspected for leaks; road damage; corrosion; rust; loose, damaged, or defective seams; loose mounting bolts; and damaged mounting straps.
- Leaks in the metal fuel tank can be caused by a weak seam, rust, or road damage. The best way to permanently solve these problems is to replace the tank.
- In-tank fuel pumps and fuel level gauge sending units are held in the tank by either a retaining ring or screws.
- Fuel lines are made of seamless, double-wall metal tubing, flexible nylon, or synthetic rubber hose. The latter must be able to resist gasoline and be nonpermeable to fuel and fuel vapors. Rubber hose, such as that used for vacuum lines, deteriorates when exposed to gasoline. Only hoses made for fuel systems should be used for replacement.
- Vapor vent lines must be made of material that resists attack by fuel vapors. Replacement vent hoses are usually marked with the designation "EVAP" to indicate their intended use.
- All fuel lines should occasionally be inspected for holes, cracks, leaks, kinks, or dents.
- Automobiles and light trucks have an in-tank strainer and a fuel filter. The strainer, located in the gasoline tank, is made of a finely woven fabric. The strainer prevents large contaminant particles from entering the fuel system where they could cause excessive fuel pump wear.
- To determine if the fuel pump is in satisfactory operating condition, tests for both fuel pump pressure and fuel pump capacity should be performed.
- High fuel pressure readings normally indicate a faulty pressure regulator or an obstructed return line.
- Low pressure can be caused by a clogged fuel filter, restricted fuel line, weak pump, leaky pump check valve, defective fuel pressure regulator, or dirty filter sock in the tank.
- An inertia switch in the fuel pump circuit opens the fuel pump circuit immediately if the vehicle is involved in a collision.
- SRSs automatically shut off the fuel pump when an air bag is deployed.

REVIEW QUESTIONS

Short Answer

1. List at least five safety precautions that should be adhered to when working with fuel systems.
2. Describe the operation of the evaporative system integrity check.
3. Fuel pump ___ is a statement of the volume of the fuel flow from the pump.
4. Explain the purpose of the relief valve and one-way check valve in an electric fuel pump. What type of fire extinguisher should you have close by when you are working on fuel system components?
5. What is the first thing that should be disconnected when removing a fuel tank?
6. Why is a plastic or metal restrictor placed in either the end of the vent pipe or in the vapor-vent hose on some vehicles?
7. Low fuel pump pressure causes a ___ mixture and excessive pressure causes a ___ mixture.

True or False

1. *True or False?* Fuel pressure typically is at its highest level when vacuum is applied to the pressure regulator.
2. *True or False?* On today's vehicles, an electric fuel pump runs only when the engine is running.

Multiple Choice

1. Most fuel tank filler caps contain a pressure valve and a ___.
   a. vapor separator
   b. vacuum relief valve
   c. one-way check valve
   d. surge plate
2. If fuel pump pressure or volume is less than specified, which of the following is *not* a likely cause of the problem?
   a. A restricted fuel filter
   b. A faulty fuel pump
   c. Restricted fuel return lines
   d. Restricted fuel supply lines
3. Which of the following statements about a fuel volume test is *not* true?
   a. This test measures the flow rate of the pump and can help isolate fuel system restrictions or weak pumps.
   b. The test is conducted by collecting the fuel dispensed by the certain during a period of time, normally 5 seconds.
   c. The flow of fuel into the container should be smooth and continuous with no signs of air bubbles.
   d. Poor results may indicate a bad pump or restrictions in the delivery system.
4. Low fuel pressure can be caused by all of the following *except*___.
   a. a clogged fuel filter
   b. a restricted fuel line
   c. a fuel pump that draws too high amperage
   d. a dirty filter sock in the tank
5. If a fuel system loses pressure immediately after the ignition is turned off, the possible problems are all of the following *except* ___.
   a. a leaking injector
   b. restricted fuel lines
   c. leaking connectors or hoses
   d. a faulty pressure regulator

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that higher than normal pressure from an electric fuel pump can be caused by a faulty pressure regulator. Technician B says that the typical problem may be an obstructed return line. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. Technician A replaces a damaged steel fuel line with one made of synthetic rubber. Technician B replaces a damaged steel fuel line with one made of steel. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. While discussing electric fuel pumps: Technician A says that some electric fuel pumps are combined in one unit with the gauge sending unit. Technician B says that on an engine with an electric fuel pump, low engine oil pressure may cause the engine to stop running. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. To relieve fuel pressure on an EFI car: Technician A connects a pressure gauge to the fuel rail. Technician B disables the fuel pump and runs the car until it dies. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. While discussing quick-disconnect fuel line fittings: Technician A says that some quick-disconnect fittings may be disconnected with a pair of snapring pliers. Technician B says that some quick-disconnect fittings are hand releasable. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

6. While discussing fuel filters: Technician A says that on some vehicles the fuel filter is not serviceable as a regular maintenance item. Technician B says that some fuel filters are located in the fuel return lines. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. While discussing the various fuel filters used in current automobiles: Technician A says that all systems have a vapor separator that prevents gaseous fuel from being sent to the fuel pump. Technician B says that fuel systems have a strainer located in the fuel tank that prevents large contaminants from entering the fuel system. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. While discussing fuel tank filler pipes and caps: Technician A says that the threaded filler cap should be tightened until it clicks. Technician B says that the vent pipe is connected from the top of the filler pipe to the bottom of the fuel tank. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. While discussing electric fuel pumps: Technician A says that the one-way check valve prevents fuel flow from the underhood fuel system components into the fuel pump and tank when the engine is shut off. Technician B says that the one-way check valve prevents fuel flow from the pump to the fuel filter and fuel system if the engine stalls and the ignition switch is on. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. While discussing electric fuel pumps: Technician A says that some electric fuel pumps in EFI systems are computer controlled. Technician B says that fuel pump pressure is determined by measuring the amount of fuel that the pump will deliver in a specific length of time. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

ELECTRONIC FUEL INJECTION

CHAPTER 30

OBJECTIVES

- Describe the difference between a sequential fuel injection (SFI) system and a multiport fuel injection (MFI) system.
- Explain the design and function of major EFI components.
- Explain how the clear flood mode operates on a fuel injection system.
- Explain why manifold vacuum is connected to the pressure regulator in an MFI system.
- Describe the operation of the pressure regulator in a returnless EFI system.
- Describe the operation of the central injector and poppet nozzles in a central port injection (CPI) system.
- Describe the operation of direct gasoline injection systems.
- Describe the operation of the injection systems used in light- and medium-duty diesel engines.

This chapter discusses the components of electronic fuel injection (EFI) systems and explains how the various designs of EFI work. EFI systems are computer controlled and designed to provide the correct air-fuel ratio for all engine loads, speeds, and temperature conditions. The computer monitors the operating conditions and attempts to provide the engine with the ideal air-fuel ratio. The ideal fuel ratio is often called the **stoichiometric ratio**. A stoichiometric mixture is one that has the air-to-fuel ratio necessary for complete combustion of the fuel **(Figure 30–1)**. This means all of the fuel and the oxygen in the air are completely consumed during combustion. Different fuels have a different stoichiometric ratio **(Figure 30–2)**. The stoichiometric mixture for gasoline is 14.7:1.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2003	**Make:** Honda	**Model:** Accord	**Mileage:** 178,055	**RO:** 19002
Concern:	Towed in, customer states car barely runs, has no power, runs rough, MIL stays on.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

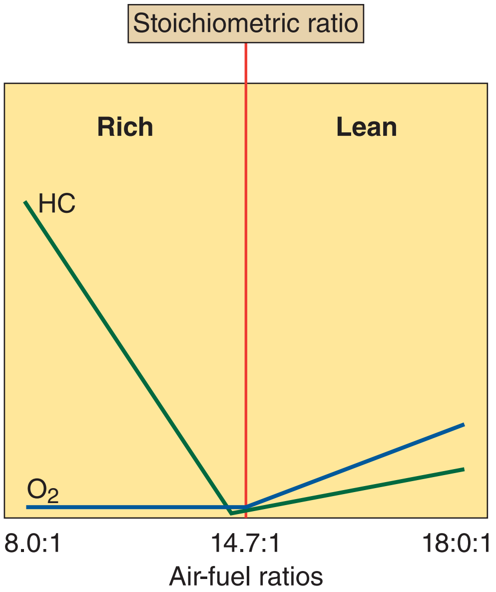


FIGURE 30–1 A graph showing how the amount of raw gasoline (HC) and air (O_2) released in the exhaust changes with a change in the air-fuel ratio.

Fuel Type	Stoichiometric A/F Ratio
Natural gas	17.2:1
Typical gasoline*	14.7:1
Diesel	14.6:1
Ethanol	9.0:1
Methanol	6.4:1

*Gasoline types vary according to the percentage of alcohol added.

FIGURE 30–2 Different fuels have different stoichiometric air-fuel ratios.

A stoichiometric mixture is theoretically the best combination of fuel and air to provide for total combustion. The ratio, however, is based on an ideal environment for combustion. This environment rarely exists and the injection system's controls vary the ratio in response to the inefficiencies. It also responds to changes in conditions that affect the combustion process. The air-fuel ratio also changes for starting, maximum power, and maximum fuel economy. The stoichiometric ratio allows the catalytic converters to work more efficiently.

Basic EFI

In an EFI system **(Figure 30–3)**, the computer must know the amount of air entering the engine so it can supply the correct amount of fuel for that amount of air. In systems with a manifold absolute pressure (MAP) sensor, the computer calculates the amount of intake air based on MAP and rpm input signals. This type of EFI system is referred to as a **speed density** system, because the computer calculates the air intake flow according to engine speed and intake manifold vacuum. Because air density changes with air temperature, an intake air temperature sensor is also used.

Today the most commonly used EFI system is the mass airflow (MAF) system. This system relies on a MAF sensor that directly measures the amount of intake air. The most common type of MAF sensor is the hot wire design. MAF systems are very responsive to changes in operating conditions because they actually measure, rather than compute, airflow.

During closed loop, EFI systems rely on the input from a variety of sensors before adjusting the air-fuel ratio. Based on all of the inputs, the PCM is able to determine the current operating conditions of the engine such as: starting, idle, acceleration, cruise, deceleration, and operating temperature. The PCM gathers the inputs and refers to the look-up tables in its memory to determine the ideal air-fuel ratio for the current conditions. During open loop, fuel is delivered according to predetermined parameters held in the PCM's memory.

When conditions, such as starting or wide-open throttle, demand that the signals from the oxygen sensor be ignored, the system operates in open loop. Pre-OBD II systems may also go into the open-loop mode while idling, or at any time that the oxygen sensor cools off enough to stop sending a good signal, and at wide-open throttle.

Fuel Injectors

Fuel injectors are electromechanical devices that meter and atomize fuel so it can be sprayed into the intake manifold. Injectors used on gasoline direct injection systems are bolted to the cylinder head with the fuel rail and spray fuel directly into the combustion chamber. Fuel injectors resemble a spark plug in size and shape. O-rings are used to seal the injector at the intake manifold, throttle body, and/or fuel rail mounting positions. These O-rings provide thermal insulation to prevent the formation of vapor bubbles and promote good hot start characteristics. They also dampen potentially damaging vibration. When the injector is electrically energized, a fine mist of fuel sprays from the injector tip.

Most injectors consist of a solenoid, a needle valve, and a nozzle **(Figure 30–4)**. The solenoid is attached to the nozzle valve. The PCM controls the injector by controlling its ground circuit through a driver circuit. When the solenoid winding is energized,

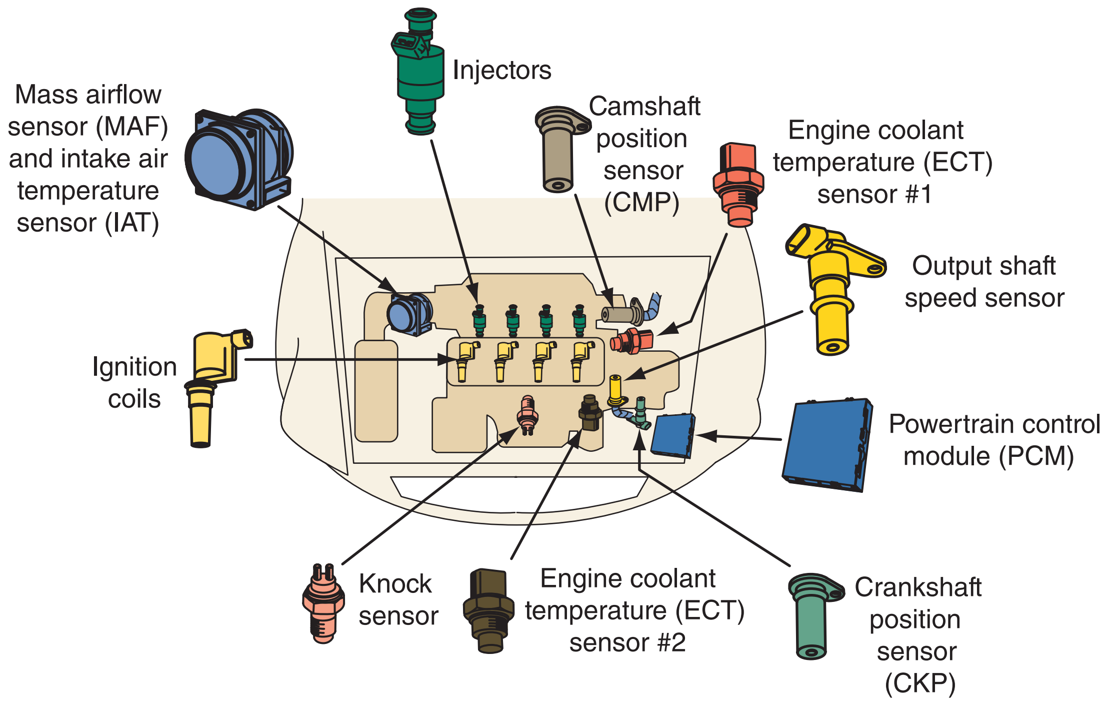


FIGURE 30-3 A typical electronic fuel injection system.

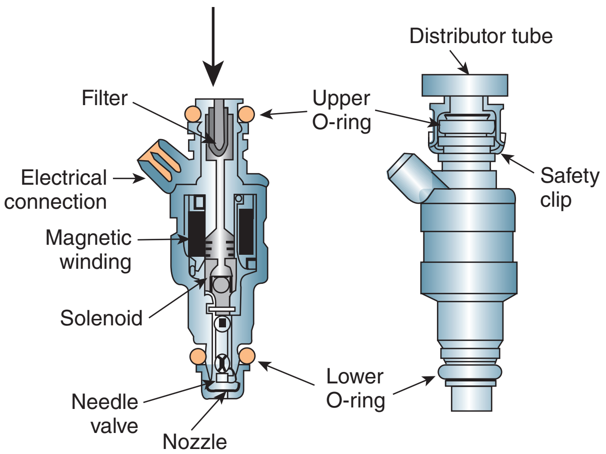


FIGURE 30-4 A typical fuel injector used in multiport fuel injection systems.

it creates a magnetic field that draws the armature back and pulls the needle valve from its seat. Fuel then sprays out of the nozzle. When the solenoid is de-energized, the magnetic field collapses and a helical spring forces the needle valve back on its seat, shutting off fuel flow.

Another injector design uses a ball valve and valve seat. In this case, the magnetic field created by the solenoid coil pulls a plunger upward, lifting the ball valve from its seat. A spring is used to return the valve to its seated or closed position.

Each fuel injector has a two-wire connector. One wire supplies voltage to the injector. This wire may connect directly to the fuse panel or to the PCM, which, in turn, connects to the fuse panel. In a few older systems, a resistor under the hood or in the PCM is used to reduce the current flow through the low-resistance injectors. The second wire is a ground wire. This ground wire is connected to the driver circuit inside the PCM.

The amount of fuel released by an injector depends on fuel pressure, the size of the injector's nozzles, and the length of time the injector is energized. Fuel pressure is mainly controlled by a pressure regulator, and the injector's pulse width or "on time" is controlled by the PCM. Typical pulse widths range from 1 millisecond at idle to 10 milliseconds at full load. The PCM controls the pulse width according to various input sensor signals, operating conditions, and its programming. The primary inputs are related to engine load and engine coolant temperature. Different engines require different injectors. Injectors are designed to pass a specified amount of fuel when opened. In addition, the number of holes at the tip of the injector varies with engines and model years. Fuel injectors can be top fuel feeding, side feeding, or bottom feeding **(Figure 30–5)**. Top- and side-feed injectors are primarily used in port injection systems that operate using high fuel system pressures. Bottom-feed injectors are used in throttle body systems. Bottom-feed injectors are able to use fuel pressures as low as 10 psi.

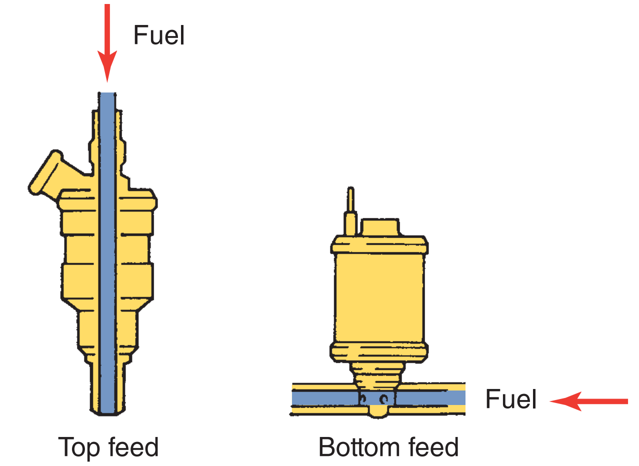


FIGURE 30–5 Examples of top-feed and bottom-feed injectors.

There have been some problems with deposits on injector tips. Because small quantities of gum are present in gasoline, injector deposits usually occur when this gum bakes onto the injector tips after a hot engine is shut off. Most manufacturers use fuel injectors designed to reduce the chance of deposit buildup at the tips. Also, oil companies have added a detergent to their gasoline to help prevent injector tip deposits.

Idle Speed Control

Idle speed control is a function of the PCM. Based on operating conditions and inputs from various sensors, the PCM regulates the idle speed. In throttle body and port EFI systems, engine idle speed is controlled by bypassing a certain amount of airflow past the throttle valve in the throttle body housing. Two types of air by-pass systems are used: auxiliary air valves and idle air control (IAC) valves. IAC valve systems are more common **(Figure 30–6)**. Engines that use electronic throttle control do not use an IAC valve. Instead, the PCM commands the throttle plates open a small amount, approximately 10 percent, to allow airflow into the engine.

The IAC system is a stepper motor or actuator that positions the IAC valve in the air by-pass channel around the throttle valve. The IAC valve is part of the throttle body casting. The PCM calculates the amount of air needed for smooth idling based on input data, such as coolant temperature, engine load, engine speed, and battery voltage.

Performance TIP

Increasing the amount of fuel injected when the engine is in open loop can boost an EFI engine's performance. This normally can be done by installing larger injectors, increasing the fuel pressure, and lengthening the injectors' pulse width. The latter is done by reprograming the PCM. These changes will have little effect on the engine when it is in closed loop. Of course, there will be no increase in power if there is not enough air for the increased fuel.

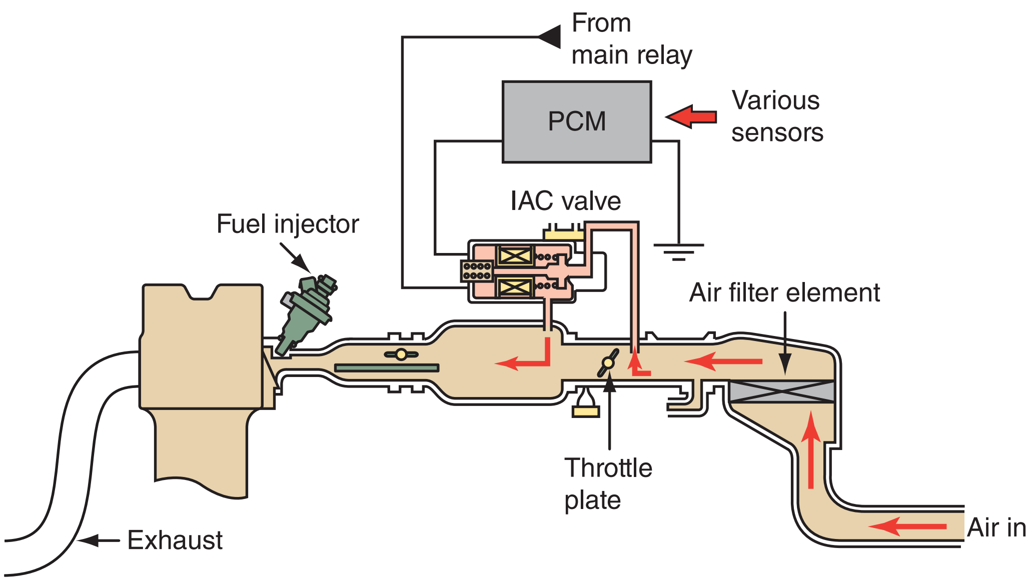


FIGURE 30–6 An idle air control system.

If engine speed is lower than desired, the PCM activates the motor to retract the IAC valve. This opens the channel and diverts more air around the throttle valve. If engine speed is higher than desired, the valve is extended and the by-pass channel is made smaller. Air supply to the engine is reduced and engine speed falls. The PCM typically increases engine speed when generator output is high, such as when the A/C compressor is engaged and the engine cooling fans are operating.

During cold starts idle speed can be as high as 2,100 rpm to quickly raise the temperature of the catalytic converter. The PCM maintains cold idle speed for approximately 40 to 50 seconds. Some older engines are equipped with an auxiliary air valve to aid in the control of idle speed. Unlike the IAC valve, the auxiliary air valve is not controlled by the PCM. Like the IAC system, however, the auxiliary air valve provides additional air during cold engine idling.

Inputs

The ability of the fuel injection system to control the air-fuel ratio depends on its ability to properly time the injector pulses with the compression stroke of each cylinder and its ability to vary the injector "on" time, according to changing engine demands. Both tasks require the use of sensors that monitor the operating conditions of the engine. The PCM receives these signals from the CAN bus and inputs sent directly to the computer **(Figure 30–7)**.

GO TO Chapter 25 for detailed discussions on sensors.

Typical inputs include the following:

- MAF sensors
- MAP sensors
- Air-fuel ratio or oxygen sensors
- IAT sensors
- ECT sensors
- APP/TP sensors
- CKP and CMP sensors

Additional Input Information Sensors Additional sensors are also used to provide the following information on engine conditions:

- Vehicle speed
- Air conditioner operation
- Gearshift lever position
- Battery voltage and generator load
- EGR valve position
- Power-steering pressure

Operational Modes

All fuel injection systems operate in response to inputs. However, the PCM's programming allows it

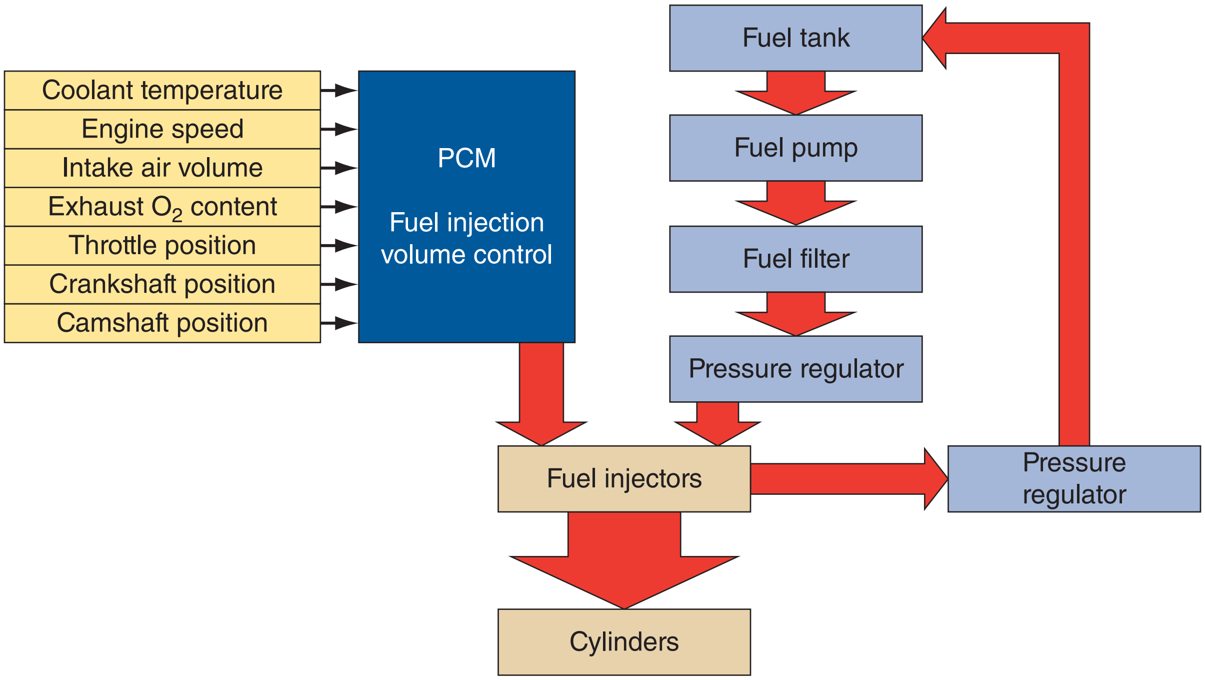


FIGURE 30–7 A basic electronic fuel injection system.

to define the conditions and establish a summary of those conditions. The PCM then controls the delivery of fuel according to that mode of operation. Different EFI systems have different operational modes, but most have starting, run, clear flood, acceleration, and deceleration.

Starting Mode When the ignition switch is initially moved to the start position, the PCM turns on the fuel pump for about 2 seconds. When the PCM receives a good signal from the CKP sensor, it energizes the fuel pump to allow for starting. If a CKP signal is not present, the fuel pump is shut off. With a CKP signal, the PCM controls injector timing and bases the pulse width of the injectors entirely on the engine's coolant temperature and load. Once the engine is cranking, the PCM sets the injectors' pulse width according to inputs from the MAF, IAT, ECT, and TP sensors. In some cases, as the engine is cranking, the injectors may prime the cylinders with a spray of fuel to help get the engine started. The system stays in starting mode until the engine is rotating at a predetermined speed.

Run Mode Once the engine has started and is running above a predetermined speed, the system will operate in open loop. In open loop, the PCM sets injector pulse width according to MAP or MAF, IAT, ECT, and TP sensor signals. The system stays in open loop until the PCM receives good signals from the HO_2S and a predetermined engine temperature has been reached. Once these conditions have been met, the system moves into closed loop. In closed loop, the PCM adjusts the pulse width according to inputs from a variety of sensors, but primarily the HO_2S or A/F ratio sensors **(Figure 30–8)**.

Clear Flood Mode At times the engine will not start because it has received too much fuel; this is called flooding. When an engine floods, the excess fuel must be pumped out of the cylinders. This is done by fully depressing the accelerator pedal and cranking the engine. The clear flood mode is not an automatic process; it is initiated by depressing and holding the accelerator pedal down. When the PCM detects a wide-open throttle, it will go into the acceleration enrichment mode for 3 seconds. If the throttle is held open and the engine's speed is below a predetermined rpm, the system will return to the start mode. In some cases, the PCM will completely turn off the injectors if engine cranking continues for a long period.

Acceleration Mode Based on signals from the TP and MAP or MAF sensors, the PCM can tell when

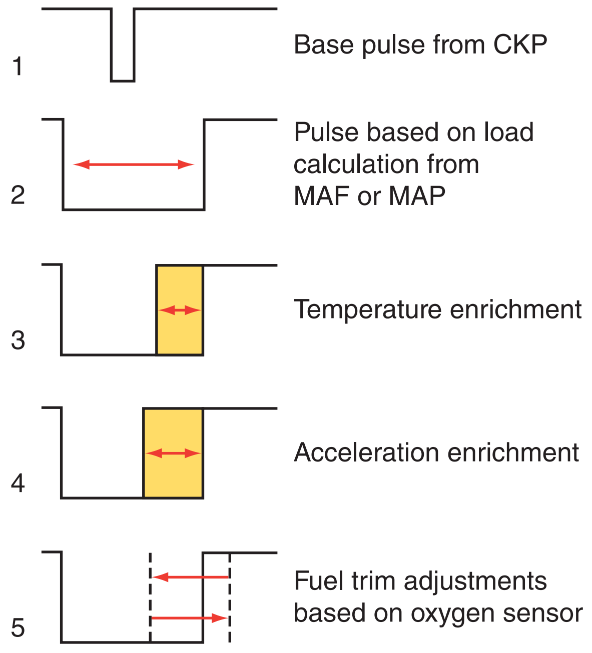


FIGURE 30-8 A graphical representation of how pulse width is calculated.

the vehicle is being accelerated. To compensate for the sudden rush of intake air as the throttle is opened, the PCM increases the injectors' pulse width. The pulse width change is calculated by the PCM according to inputs from the CKP, MAP, ECT, MAF, and TP sensors. Once the PCM determines that the vehicle is no longer accelerating, the EFI system is returned to the run mode.

Deceleration Mode Inputs from the MAP or MAF and TP sensors are also used by the PCM to detect deceleration. During deceleration, the PCM reduces injector pulse width. Some systems will totally shut off the fuel when the vehicle is rapidly decelerating. Some vehicles will totally shut down the fuel system for a brief period during deceleration.

Fuel Trim

OBD II systems constantly monitor the signals from the oxygen or air-fuel ratio sensors while it is operating in closed loop. Based on these inputs and programming instructions, the PCM alters the injectors' pulse width to provide the best possible combination of driveability, fuel economy, and emission control. The adjustments made to the base (programmed) pulse width for operating conditions is called fuel trim. Fuel trim can be monitored for diagnostic purposes. The base pulse width is given a value of 0 percent and all changes are expressed as a negative or positive value. A positive fuel trim value means the PCM

detects a lean mixture and is increasing the pulse width to add more fuel to the mixture. A negative fuel trim value means the PCM is reducing the amount of fuel by decreasing the pulse width to compensate for a rich condition. Some vehicles use equivalence ratio (EQ RAT) instead of fuel trim. If no changes are required to the air-fuel ratio, the EQ ratio is 1.0. If the commanded EQ ratio is 0.95, the air-fuel ratio is commanded rich. Numbers greater than 1.0 indicate a lean command. To determine the air-fuel ratio, multiply the stoichiometric ratio of 14.64:1 by the EQ ratio. For example, an EQ ratio of 0.95 equals an air-fuel ratio command of 13.9:1 ($14.64 \times 0.95 = 13.908$).

The system allows for short-term and long-term fuel trim. Short-term fuel trim (STFT) represents changes made immediately in response to HO_2S signals. Long-term fuel trim (LTFT) represents changes made to set a new base pulse width. LTFT responds to the trends of the STFT. For example, if the STFT is commanded rich and remains at +12 percent for a period of time, the LTFT will increase until STFT returns close to 0 percent correction. The LTFT will then show as a positive number in the scan data. To determine the total fuel correction by the PCM, add the STFT and LTFT numbers together. If STFT is 4 percent and the LTFT is 8 percent, then total fuel correction is 12 percent rich. STFT is erased when the ignition is turned off. LTFT remains in the PCM's memory.

Throttle Body Injection (TBI)

For many auto manufacturers, TBI served as a stepping stone from carburetors to more advanced fuel injection systems. TBI units were used on many engines during the 1980s and 1990s. The throttle body unit is mounted directly to the intake manifold. The injector(s) spray fuel down into a throttle body chamber leading to the intake manifold. The intake manifold feeds the air-fuel mixture to all cylinders.

Four-cylinder engines have a single throttle body assembly with one injector and throttle plate, whereas V6 and V8 engines are usually equipped with dual injectors and two throttle plates on a common throttle shaft **(Figure 30–9)**.

Throttle body systems are not as efficient as port injection systems. Fuel is not distributed equally to all cylinders, the air and fuel from the TBI unit pass through the intake manifold, and the length and shape of the manifold's runners affect distribution. There is also a potential problem of fuel condensing and forming puddles in the manifold when the manifold is cold.

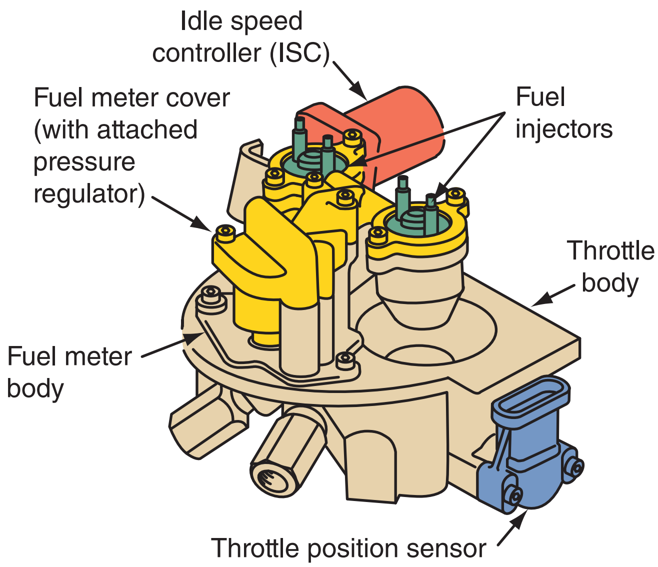


FIGURE 30–9 Dual throttle body assembly used on a six- or an eight-cylinder engine.

Port Fuel Injection (PFI)

PFI systems use at least one injector at each cylinder. They are mounted in the intake manifold near the cylinder head where they can inject a fine, atomized fuel mist as close as possible to the intake valve **(Figure 30–10)**. Delivering the fuel mist right outside the combustion chamber allows the fuel to break down and vaporize a little more before it enters the cylinder. Some port injection systems have a director plate right under the nozzle of the injector. This plate has several small holes that break up the fuel as it is sprayed through the plate.

Through the years, many different PFI systems have been used and although they have things in common, they do not fire the injectors in the same way. PFI systems can be divided into two basic categories: multiport injection (MPI) systems and sequential fuel injection (SFI) systems; each is defined by injector control.

MPI Systems

Due to OBD II regulations, MPI systems are no longer used. In MPI systems, the injectors were grouped together and the injectors in each group or bank fired at the same time. Some MPI systems fired all of the injectors simultaneously. This system offered easy programming and relatively fast adjustments to the air-fuel mixture. The injectors were connected in parallel so they shared one driver circuit and the PCM sent out one signal for all injectors. The amount of fuel required for each four-stroke cycle was divided in

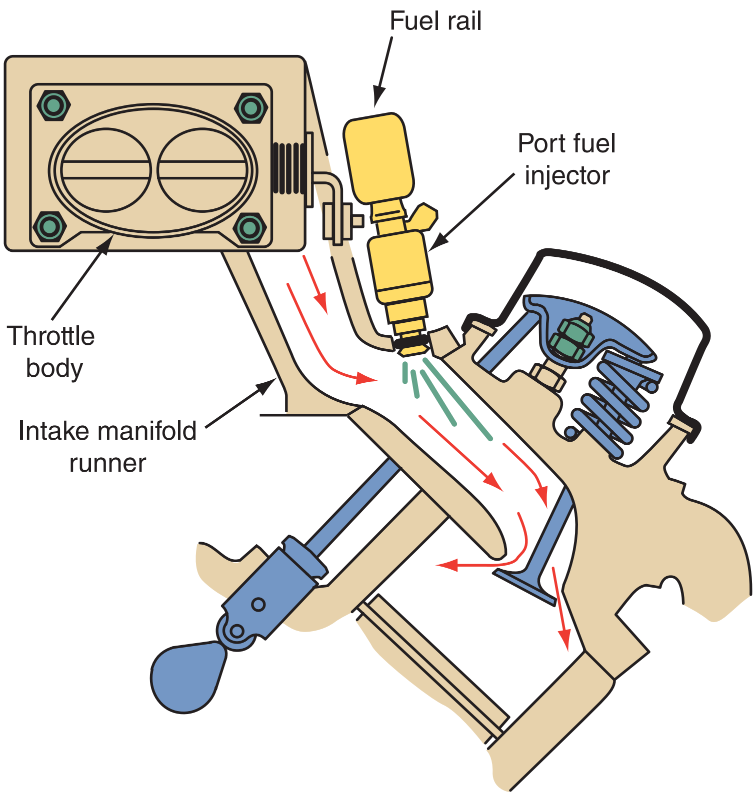


FIGURE 30-10 Port injection sprays fuel into the intake port and fills the port with fuel vapor before the valve opens.

half and delivered in two injections, one for every 360 degrees of crankshaft rotation. The fact that the intake charge had to wait in the manifold for varying periods was the system's major drawback.

In grouped systems, there is a power and ground circuit for each group. When the injectors are split into two equal groups, the groups are fired alternatively, with one group firing each engine revolution.

Because only two injectors can be fired relatively close to the time when the intake valve is about to open, the fuel charge for the remaining cylinders must stand in the intake manifold for varying periods. These periods are very short; therefore, the standing of fuel in the intake manifold was not that great a disadvantage of MPI systems. At idle speeds this wait was about 150 milliseconds, and at higher speeds the time was much less.

Sequential Fuel Injection

SFI systems require a camshaft position sensor to determine when to fire the injectors in addition to a MAF or MAP sensor and other sensors. These systems control each injector separately so that it fires just before the intake valve opens. This means that the mixture is never static in the intake manifold and adjustments to the mixture can be made instantaneously between the firing of one injector and the next. Sequential firing is the most accurate and desirable method of regulating port injection.

To meet OBD II regulations, SFI systems are capable of turning off the injector at a misfiring cylinder. This also allows manufacturers to use cylinder deactivation technology to improve fuel economy under steady cruise and light load conditions.

In SFI systems, each injector is connected individually to the computer, and the computer completes the ground for each injector one at a time. A sequential system has one injector per injector driver.

When the injection system fires according to crankshaft speed, it is called a synchronous system. The action of the injectors is timed to the crankshaft. During starting and acceleration, the PCM may inject extra fuel into all of the cylinders without referring to inputs from the CKP. When the system does this, it is called asynchronous injection.

Throttle Body

The throttle body in a PFI system controls the amount of air that enters the engine as well as the amount of vacuum in the intake manifold. On non-electronic throttle control systems, the throttle body assembly is comprised of an IAC valve assembly, an idle air

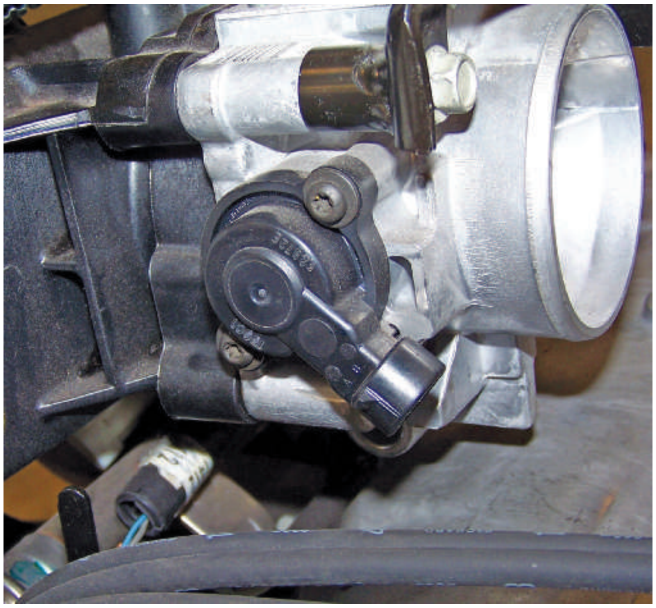


FIGURE 30–11 A TP sensor mounted to a throttle body.

orifice, single or double bores with throttle plates, and a TP sensor **(Figure 30–11)**.

The throttle body housing assembly is a single-piece aluminum or plastic casting. The throttle bore and throttle plates control the amount of intake air that enters the engine. The throttle shaft and plate(s) are controlled by the accelerator pedal, via a linkage comprised of a cam and cable. The TP sensor monitors the movement and position of the plates and sends a signal to the PCM. On some systems, a small amount of coolant is routed through a passage in the throttle body to prevent icing during cold weather.

The throttle bores and plates in many throttle bodies are coated with a special sealant. This sealant has two purposes: It helps seal the plates to the bores when the throttle is closed, and it protects the throttle body from damage caused by contaminants, such as carbon sludge, that may build up in the intake manifold.

The MAF sensor measures the amount of intake air as well as the air used by the idle air orifice and the positive crankcase ventilation (PCV) system. This allows the PCM to know how much air is entering the intake manifold. Some throttle bodies also have a fresh air outlet above the throttle plates for the PCV and IAC systems.

When the engine is at idle and the throttle plates are closed, a small amount of air enters the engine through the idle air orifice. The IAC system allows additional air to enter if the PCM commands it to do so. Most throttle bodies have a base-idle screw, which is adjusted rarely and only as part of an idle speed adjustment procedure. Idle speed is totally controlled by the PCM and there are typically no provisions for adjusting it under normal operating conditions. Some throttle bodies have a throttle stop screw that prevents the throttle plate from seizing in its bore when it is quickly closed.

Throttle bodies also have several vacuum taps or ports located below the throttle plates. These are used to monitor engine vacuum and provide vacuum to the PCV valve, exhaust gas recirculation (EGR) valve, evaporative emission (EVAP) system, and A/C controls.

SHOP TALK

Throttle body assemblies that have this protective coating should not be cleaned, because any cleaning may remove the sealant. Most coated throttle bodies have a warning sticker affixed to them for identification.

Fuel Delivery

The fuel injectors are separately controlled and are mounted to the intake manifold and supply pressurized fuel through fuel lines. These fuel lines run to each cylinder from a fuel manifold, usually referred to as a **fuel rail (Figure 30–12)**. The fuel rail also has a fuel pressure test port, and on returnless fuel systems, a fuel rail pressure (FRP) sensor. The rail is supplied fuel by the fuel pump and distributes the same amount of fuel at the same pressure to each cylinder. Because the fuel is dispensed at each cylinder and

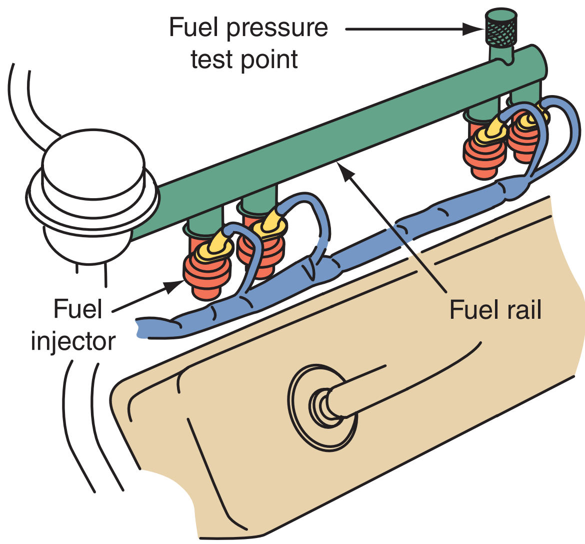


FIGURE 30–12 A typical fuel rail.

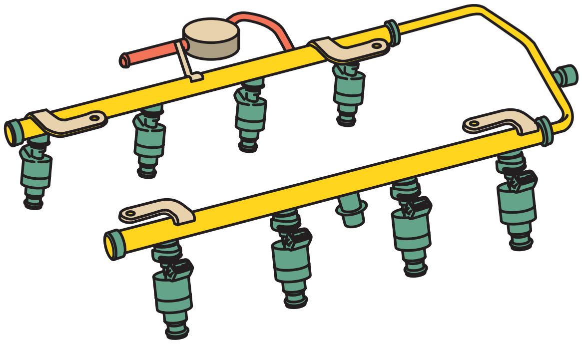


FIGURE 30–13 A one-piece fuel rail for a V8 engine.

not the intake manifold, there is little or no fuel to wet the manifold walls; therefore, there is no need for manifold heat or early fuel evaporation system. Many PFI engines use plastic intake manifolds since the runners are no longer carrying fuel to the cylinders.

The fuel rail assembly on a PFI system of V6 and V8 engines usually consists of a left- and right-hand rail assembly. The two rails can be connected by crossover and return fuel tubes. A typical fuel rail for a V-type engine is shown in **Figure 30–13**.

Some engines are equipped with variable induction intake manifolds that have separate runners for low and high speeds. This technology is only possible with port injection.

Engines that use returnless fuel systems incorporate a fuel pressure sensor that monitors the pressure at the fuel injectors. This sensor may also include a fuel temperature sensor as well. The PCM controls fuel pressure based on this input. The sensor receives a reference voltage of 5 volts, and changes in fuel rail pressure are reflected by the signal back to the PCM. Basically, when fuel pressure is high, the signal has high voltage and when the pressure is low, the signal is low.

Pulsation Damper Some engines have a pulsation damper on their fuel rails. These dampers reduce the pressure pulsations caused by the rapid opening and closing of the fuel injectors. Without control over these fluctuations, the fuel pressure at each injector can be affected. The damper works to control the volume of fuel in the fuel rail. When the pressure in the rail quickly drops, the damper temporarily reduces the volume of fuel in the rail to prevent the fuel pressure from becoming too low. The opposite occurs when the pressure quickly increases. The damper also reduces fuel noise and maintains pressure during engine cool down.

Injector Control

The computer is programmed to ground the injectors well ahead of the actual intake valve openings so the intake ports are filled with fuel vapor before the intake valves open. In both SFI and MFI systems, the computer supplies the correct injector pulse width to provide a stoichiometric air-fuel ratio. The computer increases the injector pulse width to provide air-fuel ratio enrichment while starting a cold engine.

SFI requires inputs from the CKP and CMP sensors in order to determine when to fire each injector. On many systems, once the position of piston number 1 from the CKP is received by the PCM, signals from the CMP are used to synchronize the injectors to the engine's firing order.

Pressure Regulators

PFI systems require an additional control not required by TBI units. In a TBI, the injectors are mounted above the throttle plates and are not affected by fluctuations in manifold vacuum; PFI have their tips located in the manifold where constant changes in vacuum would affect the amount of fuel injected. To compensate for these fluctuations, port injection systems have a fuel pressure regulator that senses manifold vacuum and continually adjusts the fuel pressure to maintain a constant pressure drop across the injector. The pressure regulators respond to changes in manifold pressure due to engine load.

On return PFI systems, a fuel pressure regulator located on or near the fuel rail **(Figure 30–14)**. A diaphragm and valve assembly is positioned in the center of the regulator, and a diaphragm spring seats the valve on the fuel outlet.

When fuel pressure reaches the regulator setting, the diaphragm moves against the spring tension and the valve opens. This allows fuel to flow through the return line to the fuel tank. The fuel pressure drops

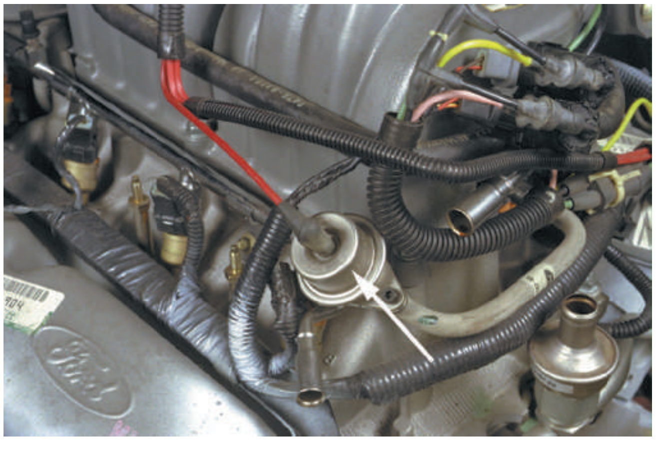


FIGURE 30–14 A typical fuel pressure regulator for a port injection system.

slightly when the regulator valve opens and builds when the spring closes the valve.

A vacuum hose is connected from the intake manifold to the vacuum inlet on the pressure regulator. This hose supplies vacuum to the diaphragm. The vacuum works against fuel pressure to move the diaphragm and open the valve. When the engine is running at idle speed, high manifold vacuum is applied to the pressure regulator. Under this condition, fuel pressure opens the regulator valve.

If the engine is operating at wide-open throttle (WOT), no vacuum (high manifold pressure) is applied to the pressure regulator. This high pressure prevents the regulator valve from opening. This is good because the injectors are discharging fuel into a higher pressure when compared to idle speed conditions. If the fuel pressure remained constant at idle and WOT conditions, the injectors would discharge less fuel into the higher pressure in the intake manifold at WOT. The increase in fuel pressure supplied by the pressure regulator at WOT maintains the same pressure drop across the injectors at idle speed and WOT. When this same pressure drop is maintained, the change in pressure at the injector does not affect the amount of fuel discharged by the injectors.

Returnless Systems Nearly all late-model injection systems are returnless systems. Those systems that have a fuel pressure regulator as part of the fuel sender and pump assembly in the fuel tank **(Figure 30–15)** and are called mechanical returnless systems. The term is applied because the regulator sits inside the fuel tank and there is no designated return fuel line and its action is not related to engine vacuum. With a returnless system, only the fuel needed by the engine is filtered, thus allowing the use of a smaller fuel filter. When the engine is at idle, the fuel pressure should be between 55 and 60 psi (380 and 410 kPa). If the pressure regulator supplies a fuel pressure that is too low or too high, a driveability problem can result. The system also has a switch that shuts off the fuel when a collision has occurred.

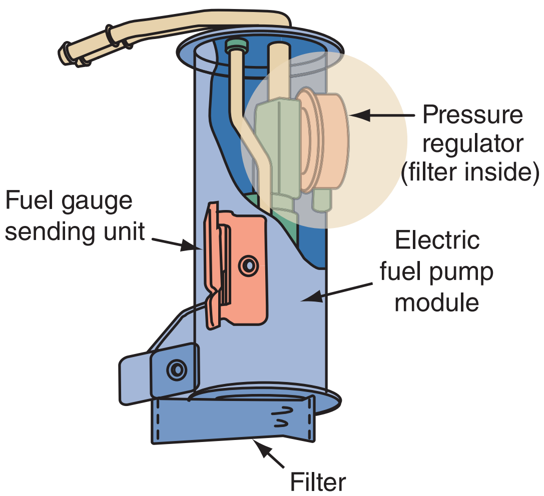


FIGURE 30–15 A returnless fuel system with the pressure regulator and filter mounted in the fuel tank with the fuel pump and fuel gauge sending unit.

Many newer returnless systems are called electronic returnless systems. This is because the PCM controls the speed of the fuel pump to control fuel pressure. These systems may use the PCM to directly control the fuel pump or the PCM may control a second module that actually drives the pump. Regardless of which system is used, the fuel pump speed is controlled using a pulse-width modulated (PWM) signal. As fuel demand increases, the pulse-width is increased and more fuel is supplied.

Throttle-by-Wire Systems

Throttle-by-wire systems eliminate the need for a throttle cable and linkage. They also provide many other benefits over traditional throttle controls, such as improved driveability, increased fuel efficiency, and decreased emissions. Throttle-by-wire systems are used by all manufacturers; each calls their system by a different name, the most common being electronic throttle body (ETB) and electronic throttle control (ETC). There are differences in the programming and hardware used.

Based on inputs from accelerator pedal sensors and its programming, the PCM electronically controls the position of the throttle plate **(Figure 30–16)**. A DC motor that is controlled by the PCM is used to move the plate via gears **(Figure 30–17)**. The motor may be an integral part of the throttle body or a separate unit mounted to the throttle body.

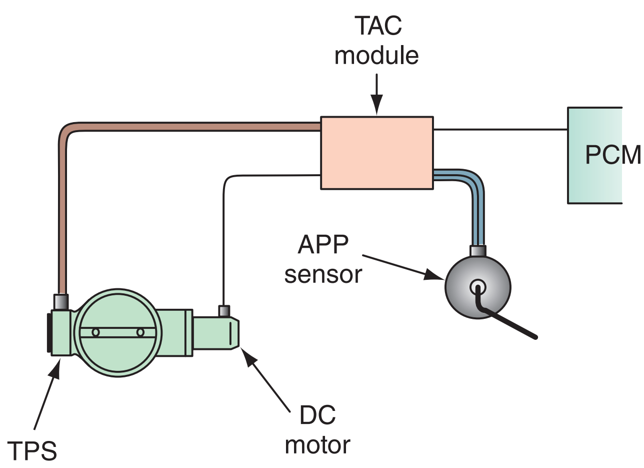


FIGURE 30–16 A simplified diagram for a throttle actuator control (TAC) system.

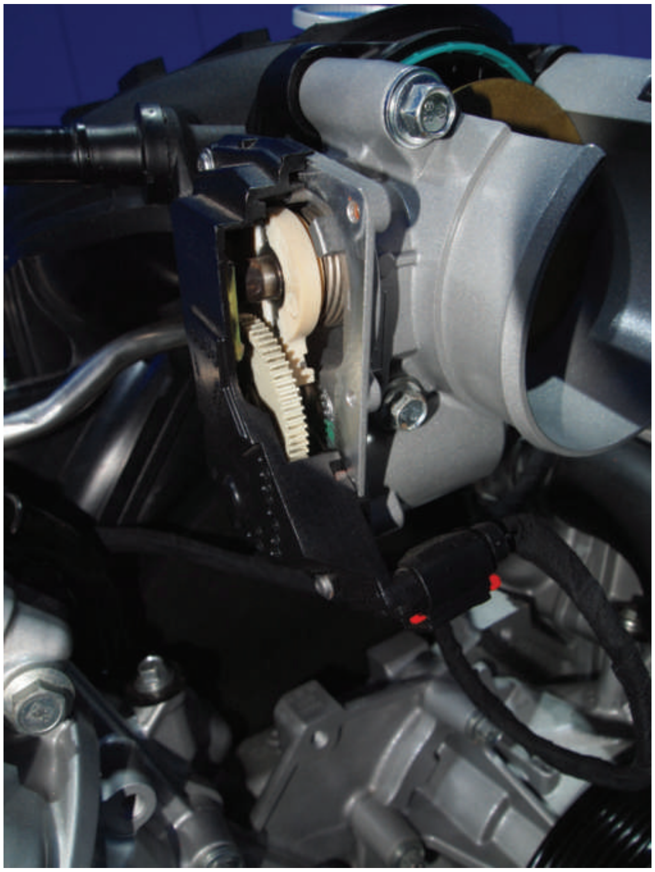


FIGURE 30–17 An electric motor, in response to commands from the PCM, moves the throttle plate.

As a safety feature, two springs are attached to the throttle plate shaft. One, which is the stronger of the two, is used to open the throttle plate slightly if the PCM loses control of engine speed. This allows for limp home operation. The other spring is used to close the throttle. To prevent the throttle plate from closing too much and possibly binding its bore, a hard stop is on the throttle body assembly to limit the closure of the throttle plate.

Driver input to the PCM is delivered by accelerator pedal sensors. A system may have more than one pedal sensor or may use a sensor that sends out more than one signal **(Figure 30–18)**. In either case, the PCM will receive multiple signals regarding accelerator pedal position. This redundancy is important because it allows the PCM to closely monitor the action of the system. The multiple signals ensure that the PCM is receiving correct information.

The TP sensor also provides redundant signals. The multiple signals ensure that the PCM knows where the throttle plate is positioned at all times. These TP sensors are recognizable because they have four electrical leads.

Redundancy also occurs in the processing of the inputs and the controlling of the throttle motor. The throttle system is monitored by two separate processors inside the PCM. Both are looking at the same things and if one determines that something is wrong with the other, it will override the commands of that processor.

In addition to eliminating the throttle linkage, electronic throttle systems also eliminate the need for an IAC valve and idle air orifice. These are not needed because the PCM can control throttle plate opening to meet the air needs of the engine when it is idling.

ETCs are also used with variable valve timing. Because the engine's power changes with a change in valve timing, the desired position of the throttle for those conditions also changes. The PCM can instantly change the throttle position to eliminate any noticeable change in engine power.

ETC also works with electronic-controlled automatic transmissions. The PCM can alter throttle position when the transmission is shifting gears to improve shift quality. This allows the transmission to make quicker gear changes smoothly.

Other advantages include the elimination of cruise control actuators while providing improved speed control and adaptive cruise function. To improve airflow during steady cruise, the PCM may command the throttle plates wide open while using the fuel injectors to control engine speed. ETC also allows the PCM to be more effective when limiting engine and vehicle speeds. ETC is also used in automatic traction control systems.

Central Port Injection (CPI)

In a central port (CPI) or central multiport injection (CMFI) system, a central injector assembly is mounted in the lower half of the intake manifold. The CPI system uses one injector to control the fuel flow to individual **poppet nozzles (Figure 30–19)**. The CPI injector assembly consists of a fuel metering body, a pressure regulator, one fuel injector, poppet nozzles with nylon fuel tubes, and a gasket seal. The injector distributes metered fuel through the lines connected to the nozzles.

To meet OBD II regulations, an updated version of CPI uses individual injectors for each poppet nozzle.

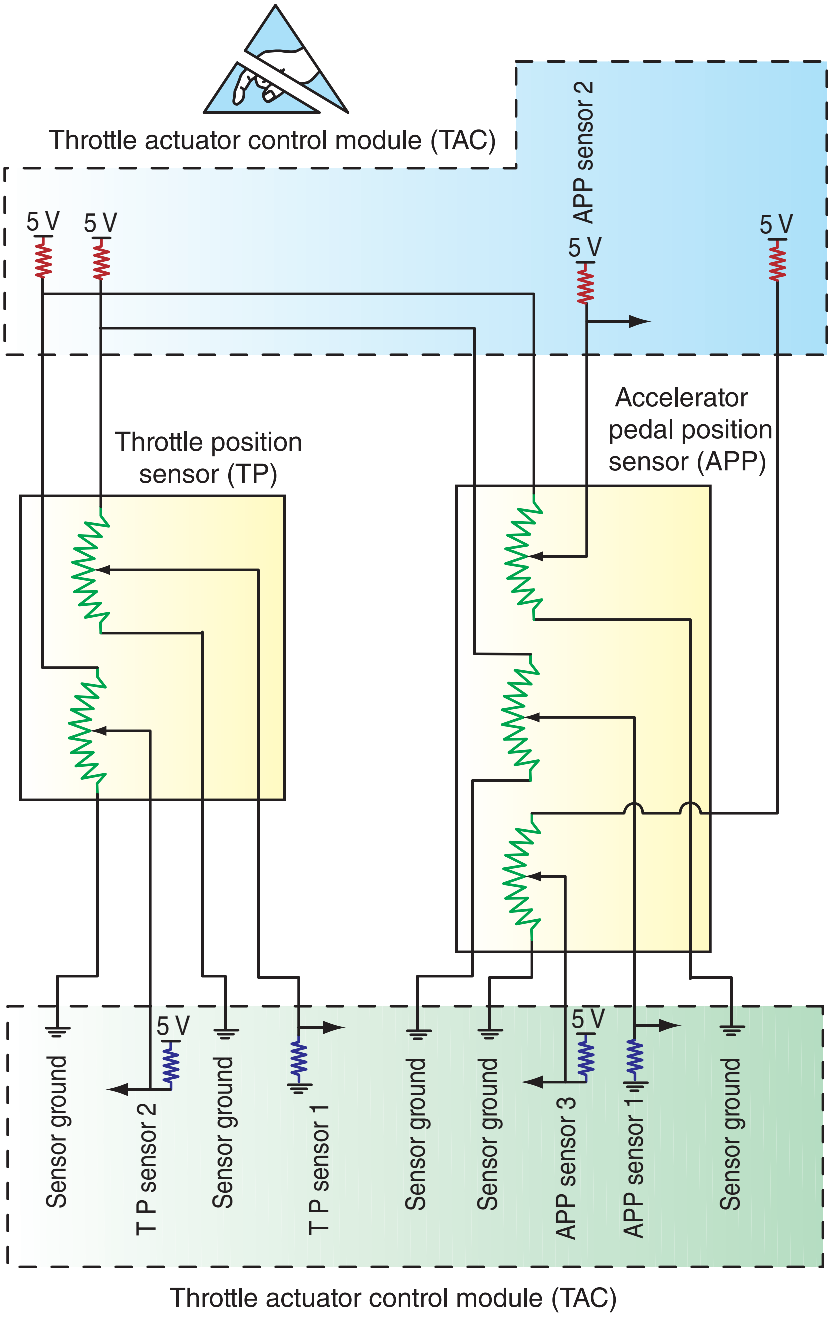


FIGURE 30–18 Redundant position sensors in a throttle-by-wire system.

This system, called central sequential fuel injection (CSFI) allows each injector to be shut off in the event of a misfire.

Pressure Regulator

The pressure regulator is mounted with the central injector. The regulator is inside the intake manifold and intake vacuum is supplied through an opening in the regulator cover. Normally, a regulator spring pushes downward on a diaphragm and closes the valve. Fuel pressure from the fuel pump pushes the diaphragm upward. When the pressure exceeds that of the spring, the valve opens. Pressure is decreased as fuel flows through the valve and a return line to the fuel tank **(Figure 30–20)**.

The pressure regulator maintains fuel pressure at 54 to 64 psi (370 to 440 kPa), which is higher than many PFI systems. Higher pressure is required in the CSFI system to prevent fuel vaporization from the extra heat encountered with the CSFI assembly, poppet nozzles, and lines mounted inside the intake

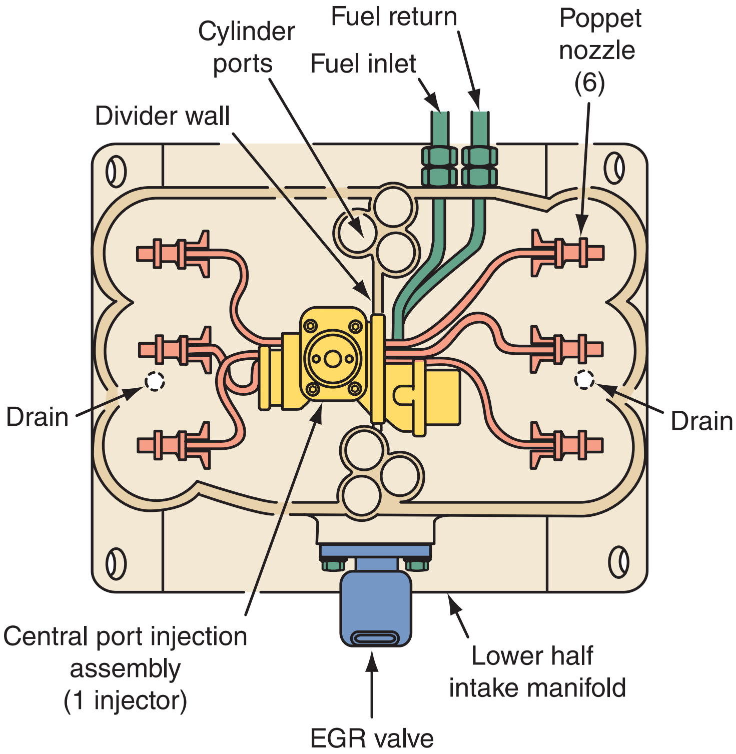


FIGURE 30-19 Central multiport fuel injection components in the lower half of the intake manifold.

manifold. Fuel pressure on the CSFI system is maintained between 60 to 66 psi (415 to 455 kPa).

Injector Design and Operation

CPI systems use one maxi injector which supplies fuel to each of the poppet nozzles. A failure of the injector or of the supply tubes or nozzles requires replacement of the entire CPI unit. Because the CSFI uses individual injectors for each cylinder, each injector and nozzle can be serviced separately.

In both systems, the armature is placed under the injector winding in the injector. The lower side of this armature acts as a valve that covers the outlet ports to the nylon tubes and poppet nozzles. A supply of fuel at a constant pressure surrounds the

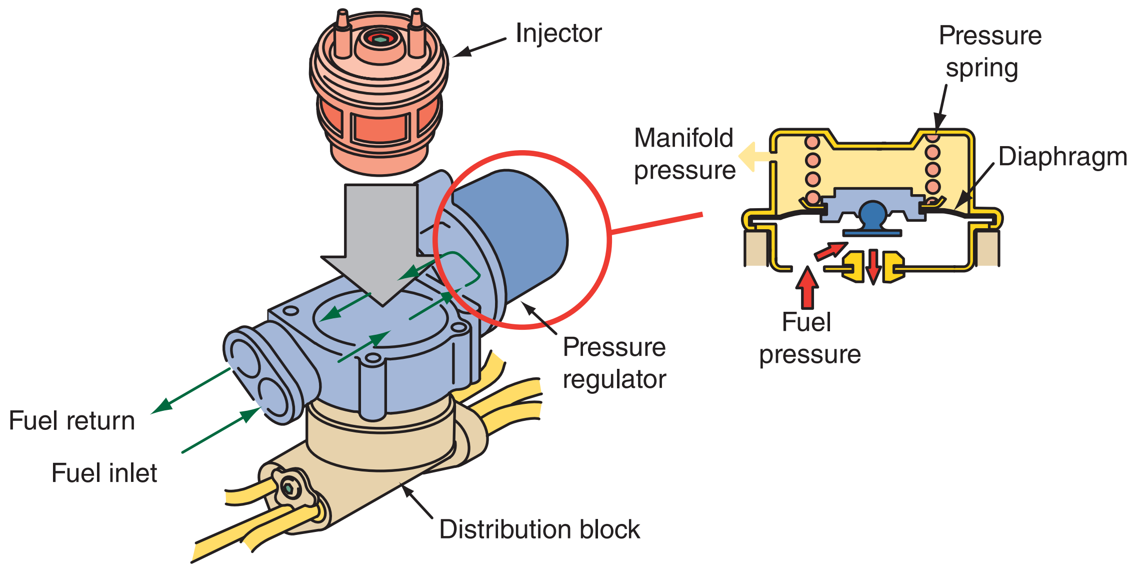


FIGURE 30-20 A pressure regulator for a CSFI system.

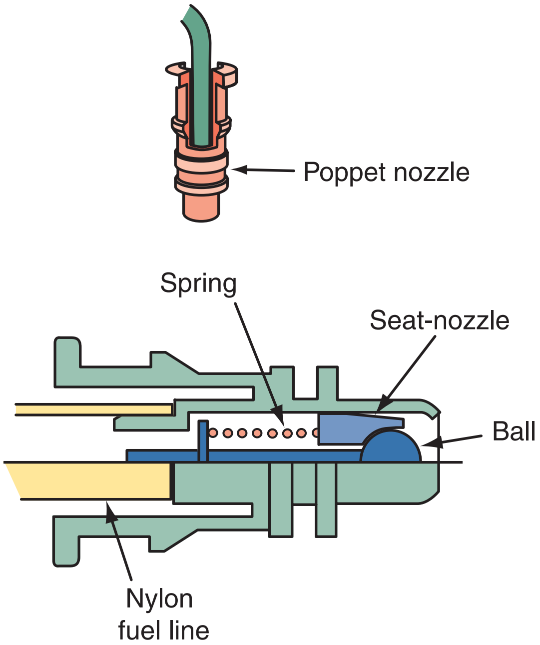


FIGURE 30–21 The internal design of a poppet nozzle.

armature while the ignition switch is on. Each time the PCM grounds the injector, the armature is lifted up, which opens the injector ports. Fuel is then forced to the poppet nozzles **(Figure 30–21)**.

The PCM controls the amount of fuel delivered by the injector(s) by controlling its pulse width. The injector winding has low resistance, and the PCM operates the injector with a peak-and-hold current. When the PCM grounds the injector winding, the current flow in this circuit increases rapidly to 4 amperes. When the current flow reaches this value, a current-limiting circuit in the PCM limits the current flow to 1 ampere for the remainder of the injector pulse width. The peak-and-hold function provides faster injector opening and closing.

Poppet Nozzles

The poppet nozzles are snapped into openings in the lower half of the intake manifold, and the tip of each nozzle directs fuel into an individual intake port. Each poppet nozzle contains a check ball and seat at the tip of the nozzle. A spring holds the check ball in the closed position. When fuel pressure is applied to the nozzles, the pressure forces the check ball to open against spring pressure. The poppet nozzles open when the fuel pressure exceeds 37 to 43 psi (254 to 296 kPa), and the fuel sprays from these nozzles into the intake ports.

When fuel pressure drops below this value, the nozzles close. Under this condition, approximately 40 psi (276 kPa) fuel pressure remains in the nylon lines and poppet nozzles. This pressure prevents fuel vaporization in the lines and nozzles during hot engine operation or hot soak periods. If a leak occurs in a line or other CPI component, fuel drains from the bottom of the intake manifold through two drain holes to the center cylinder intake ports.

Gasoline Direct-Injection Systems

Direct injection has been around for many years on diesel engines. Until recently, this type of injection system has been seldom used with gasoline. With direct injection, highly pressurized fuel is sprayed directly into the cylinders. This type of injection is used by many auto manufacturers and has many different names **(Figure 30–22)**. The most commonly used is gasoline direct injection (GDI); GDI, however, is a registered trademark of Mitsubishi Motors and can only be used by that manufacturer. Therefore, the systems are called gasoline direct injection (GDI), fuel stratified injection (FSI), high precision injection, direct injection (DI), or direct injection spark ignition (DISI). The fuel is highly pressurized when it is sprayed into the cylinders. Under this pressure, the fuel arrives as very fine droplets.

Injectors

With gasoline direct injection, specially designed injectors deliver the fuel into the high pressures and temperatures in the cylinders **(Figure 30–23)**. To prevent the heat from igniting the fuel in the injector, the

FIGURE 30–22 A turbocharged direct-injection-equipped engine from Volkswagen.

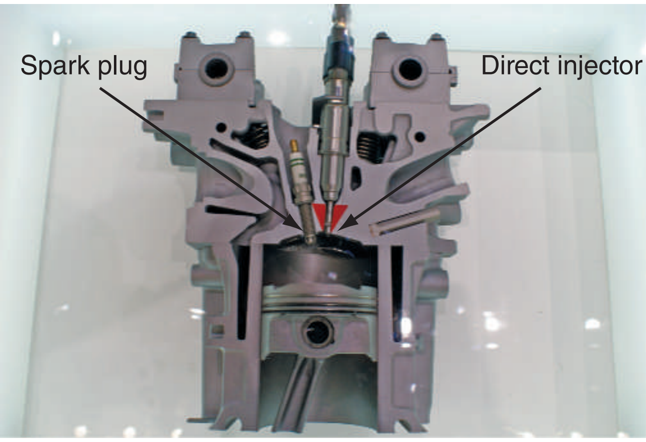


FIGURE 30–23 The direct injector is placed in the combustion chamber so that its spray of fuel is aimed at the spark plug.

injectors are designed to completely seal after the fuel is sprayed. The injectors must also be able to spray the fuel at a much higher pressure than what is in the cylinder. If this did not happen, the fuel would not enter the cylinder; instead the cylinder's pressure would enter the injector. Remember, a high pressure always moves to a point of lower pressure. The injectors need more electrical power to work with the high pressure; therefore, the PCM has separate high voltage and driver circuits for each injector. Voltages for direct injection systems are initially boosted, up to 75 volts, depending on the system. The boosted voltage is to ensure very fast response times and precise control of the injector. The injectors must also be resistant to deposit formations and provide a highly atomized and directed spray of fuel. The fuel injectors are normally made with a small extended tip **(Figure 30–24)**. This allows the injector to quickly move the heat, which is absorbed during combustion, to the cooling jackets in the cylinder head.

FIGURE 30–24 An injector for gasoline direct injection.

The PCM controls the pulse width and timing of each injector and allows the system to operate in very distinctly different modes. Fuel is injected before or after the intake valve is closed, depending on the operational mode. The pulse width also changes with the operational mode, and adjustments are made according to inputs from the MAF and IAT sensors.

Solenoid injectors are used in most direct-injection systems. However, some are piezoelectrically actuated injectors. Piezoelectric injectors rely on stacked crystals. When voltage is applied to the crystals, they change size. The pintle of the injector is attached to the crystals and when the size of the crystals changes, the pintle moves. Piezoelectric injectors have a much faster response time than solenoid injectors.

With GDI, fuel can be injected at any time, not only when the intake valve is open. Also, the injectors can pulse twice during the transition from the compression stroke to combustion. The two pulses promote complete combustion when the PCM senses that operating conditions may prevent a complete burning of the fuel.

High-Pressure Fuel Pump

Gasoline is moved from the fuel tank to the engine in a conventional way, which is by an in-tank electric pump. The fuel is delivered to a mechanical, high-pressure pump driven by an eccentric on the end of a camshaft **(Figure 30–25)**. This pump supplies fuel to a variable-pressure fuel rail. The individual injectors are attached to the rail. A GDI system

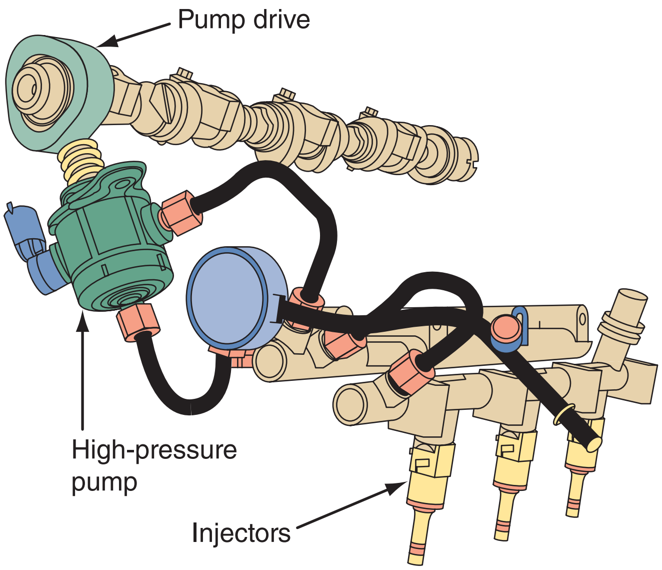


FIGURE 30–25 The high-pressure fuel pump for a GDI system is driven by a camshaft.

can operate with pressures of 435 to 2,900 psi (30 to 200) bar. The pump is a volume-controlled, high-pressure pump. It only moves the required amount of fuel to the injectors.

The PCM regulates the pressure in the fuel rail based on signals from the inputs from the fuel rail pressure regulator that is located on the fuel rail or is part of the high-pressure pump. The pressure is regulated by controlling the amount of fuel that enters the high-pressure pump or by changing the effective pumping stroke of the pump. Controlling the pump inlet is the most common. The PCM controls the power and ground circuits of the regulator. When the regulator is de-energized, the inlet valve is held open by spring pressure. When it is energized, it closes the valve. Through pulse width modulation, the pressure from the pump can be maintained at a value that is best for the operating conditions.

The PCM uses CKP and CMP signals to synchronize the action of the regulator with position and movement of the eccentric on the camshaft.

To protect the system from excessive pressures, there are pressure relief valves in the pump or fuel rail. When pressure reaches a predetermined value, some fuel leaves the relief valve and returns to the fuel tank.

Operational Modes

Most direct-injection systems can operate in three distinct modes: lean burn, stoichiometric, and full power. Each of these modes has different air-fuel ratios, injection timing, and pump pressures. The PCM chooses the mode based on operating conditions. The lean mode relies on a stratified charge for combustion, and the stoichiometric and full-power modes rely on a homogeneous mixture, which means that the air and fuel are well mixed **(Figure 30–26)**. The PCM also must be able to smoothly transition the move from one to another. The systems also have a limp-home mode if the PCM detects a problem with the system. During this time, the PCM will use a fuel strategy that allows the engine to run well enough to drive the vehicle in for service.

It is important to note that not all direct-injection systems have a lean burn mode. These systems use this technology for power gains and emission reduction, not to minimize fuel consumption.

Lean Burn Mode Direct-injected engines are able to run at very lean mixtures, with air-fuel ratios as high as 60:1. This benefit is why GDI engines are capable of drastically reducing fuel consumption. The engines run in the lean mode when the vehicle is cruising with a very light load. In addition to a reduction in fuel consumption, exhaust emissions are also lowered. The lean mixtures are possible because the system allows for a stratified charge.

The placement of the injector tip in the combustion chamber is an important feature of a direct-injection system, especially when it is operating in the lean mode. A small amount of fuel is sprayed near the spark plug when the piston has nearly completed its compression stroke but before ignition occurs. There is enough fuel around the spark plug to cause combustion. This local area of combustion is the stratified charge. The area surrounding that small area has little or no fuel and is mostly air or recirculated exhaust gas. The air surrounding the

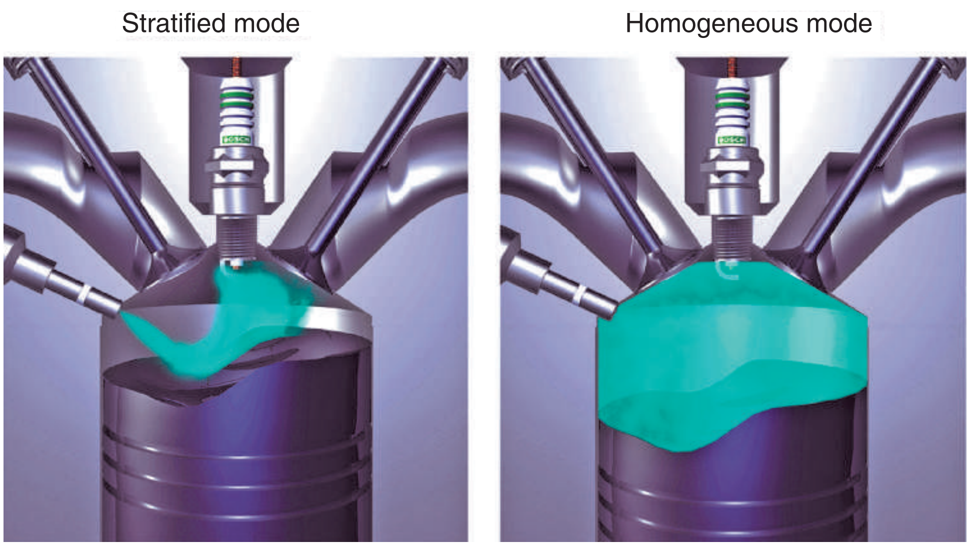


Image courtesy of Robert Bosch GmbH.

FIGURE 30–26 Two of the basic operation modes of a GDI system.

stratified charge forms an insulating cushion to keep fuel away from the cylinder walls.

Stoichiometric Mode During medium-load operation, the system operates in the stoichiometric mode. The air-fuel ratio is near stoichiometric and the fuel is injected during the intake stroke.

Full-Power Mode The full-power mode is used during heavy loads and hard acceleration. The air-fuel mixture is slightly richer than stoichiometric and the fuel is again injected during the intake stroke.

Compression Ratios

The ability of a direct injection to change air-fuel ratios and injection timing over a wide range also allows it to eliminate most conditions that would cause engine knock. This means GDI engines can operate at higher compression ratios without requiring the use of high-octane gasoline. The benefit of high compression is simply higher compression extracts more energy from each droplet of fuel. Therefore, running higher compression ratios provides increased engine horsepower and torque without consuming more fuel.

Higher compression ratios are also possible because the small droplets of fuel injected directly into the cylinder tend to cool the mixture in the cylinder. This cooling makes the mixture denser, means more power can be produced, and makes the mixture less likely to detonate. Because regardless of the operational mode the fuel is sprayed around the spark plug, the mixture burns quickly. This means there is less need for spark advance; this also decreases the chances of detonation.

Advantages of GDI

When compared to other injection systems, direct injection has the following advantages:

- Increases fuel efficiency
- Provides higher power output
- Increases the engine's volumetric efficiency
- Lowers engine thermal losses
- Decreases emissions (NO_x may increase if combustion temperatures go too high.)
- Allows the engine to have high compression without the need to use high-octane fuel
- Reduces most of the turbo lag when used with a turbocharger

GDI Plus SFI

Some engines use a combination of direct and indirect injection. Each cylinder has two injectors: one at the intake port and the other directly in the cylinder **(Figure 30–27)**. Both sets of injectors work in the same way as they would in a normal setup. However, the PCM shuts down the port injection when it is not needed. When the engine is cold or running at low to middle speeds with a light load, both injection systems operate. During high engine speeds and heavy loads, only direct injection is used. During cold starts, the port and direct injectors work together to create a lean stratified charge. Fuel is initially injected into the intake port during the exhaust stroke. Fuel is then injected from the direct injector near the end of the piston's compression stroke. This creates a stratified charge. This charge burns rapidly and therefore quickly heats the chamber; this in turn quickly warms up the catalytic converter.

The PCM controls the injection volume and timing of each injector according to engine load, intake airflow, temperature, and other inputs. This system takes advantage of the benefits of both types of injection systems. A port injection system is more efficient at slight throttle openings, whereas a direct-injection system is best with increased engine speed and load. The goal of the system is improved performance and decreased fuel consumption and emissions during all operating conditions.

Fuel is delivered to both injection systems by the low-pressure fuel pump in the tank. The fuel for the direct-injection system is sent to a high-pressure pump driven by the exhaust camshaft. At the end of the camshaft there is a three-sided lobe that rides on the plunger of the high-pressure pump. The plunger is moved up and down, or stroked, three times for every one complete revolution of the lobe.

The injectors in the direct system have a two slit orifice at the nozzle. This nozzle is designed to provide a fuel spray that fans out toward the spark plug. The injectors are pulsed by an electronic driver unit (EDU) that sends a high-voltage signal to the injectors. The EDU is controlled by the PCM by pulse width modulation. Therefore, the PCM is able to control the timing of the injectors.

The PCM also controls the pressure in the direct-injection system. In doing this, the PCM also is controlling the amount of fuel that is injected into the cylinders. A fuel pressure sensor on the fuel rail monitors the pressure and sends a

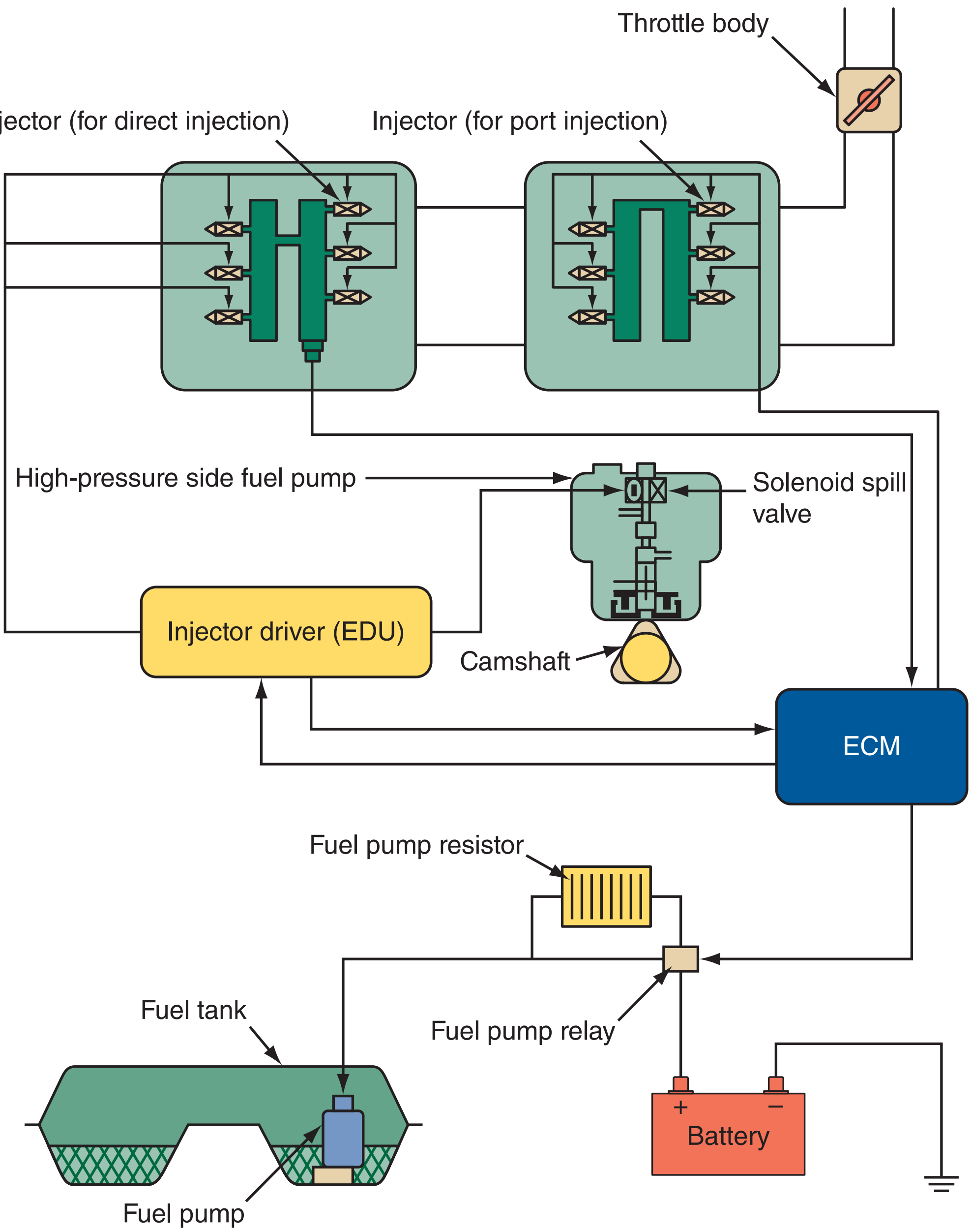


FIGURE 30–27 Toyota's dual system.

signal to the PCM. The PCM calculates the required pressure for the current conditions and orders the EDU to alter the action of a spill control valve, if necessary.

The spill valve is located at the inlet passage of the high-pressure pump and is used to control the pump discharge pressure. It is electrically opened and closed by the EDU. The pressure is regulated by controlling the amount of time the valve is closed.

Fuel is drawn in by the pump when the valve is open and the pump's plunger is moved downward by its spring. The EDU will then close the spill valve and the pump's plunger will move up. The force of the lobe on the plunger will put pressure on the fuel inside the pump. Once the fuel pressure is strong enough to open a check valve at the outlet of the pump, fuel will flow through the fuel rail to the injectors.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2003	**Make:** Honda	**Model:** Accord	**Mileage:** 178,055	**RO:** 19002
Concern:	Towed in, customer states car barely runs, has no power, runs rough, MIL stays on.			
The technician confirms the engine runs very poorly. Checking for codes reveals a P 0172–bank 1 rich. Scan data shows fuel trim number at –25 percent and HO_2S voltages staying very high. He checks fuel pressure and finds it is within a couple psi of the specified pressure. Next, he inspects the air filter and induction system for obstructions. Finding the induction system OK, he next removes the vacuum hose to the fuel pressure regulator and liquid fuel drops from both the hose and regulator.				
Cause:	Found fuel pressure regulator leaking allowing fuel to be pulled back into intake.			
Correction:	Replaced fuel pressure regulator, replaced spark plugs, changed engine oil and filter. Engine runs normally, no DTCs, fuel trims +/− 3 percent.			

KEY TERMS

Fuel rail
Poppet nozzles
Speed density
Stoichiometric ratio

SUMMARY

- EFI systems are computer controlled and designed to provide the correct air-fuel ratio for all engine loads, speeds, and temperature conditions. The ideal fuel ratio is called the stoichiometric ratio, which means the air-to-fuel ratio can allow for complete combustion.
- EFI systems rely on inputs from various sensors; these include airflow, air temperature, mass airflow, manifold absolute pressure, exhaust oxygen context, coolant temperature, and throttle position sensors.
- The volume airflow sensor and mass airflow sensors determine the amount of air entering the engine. The MAP sensor measures changes in the intake manifold pressure that result from changes in engine load and speed.
- The heart of the fuel injection system is the electronic control unit. The PCM receives signals from all the system sensors, processes them, and controls the fuel injectors.
- In an EFI system, the computer supplies the proper air-fuel ratio by controlling injector pulse width.
- Port injection systems use one of four firing systems: grounded single fire, grouped double fire, simultaneous double fire, or sequential fire. All vehicles built after 1996 use SFI.
- Two types of fuel injectors are commonly used: top feed and bottom feed. Top-feed injectors are used in port injection systems. Bottom-feed injectors are used in throttle body injection systems.
- In any EFI system, the fuel pressure must be high enough to prevent fuel boiling.
- Most computers provide a clear flood mode if a cold engine becomes flooded. Pressing the gas pedal to the floor while cranking the engine activates this mode.
- In an SFI system, each injector has an individual ground wire connected to the computer.
- The pressure regulator maintains the specified fuel system pressure and returns excess fuel to the fuel tank.
- In a returnless fuel system, the pressure regulator and filter assembly is mounted with the fuel pump and gauge sending unit assembly on top of the fuel tank. This pressure regulator returns fuel directly into the fuel tank.
- A central multiport injection system has one central injector and a poppet nozzle in each intake port. The central injector is operated by the PCM, and the poppet nozzles are operated by fuel pressure.
- GDI systems inject gasoline directly into the combustion chamber and produces a stratified air-fuel charge that allows for complete combustion with lean air-fuel ratios.
- GDI systems use special injectors that spray the gasoline at very high pressures and seal extremely well when they are not open.
- Most current light- and medium-duty diesel engines use electronically controlled common rail injection systems.

REVIEW QUESTIONS

Short Answer

1. Explain the major differences between port fuel injection and gasoline direct injection systems.
2. What is meant by sequential firing of fuel injectors?
3. Explain how the computer controls the air-fuel ratio on an EFI system.
4. When the throttle plates are closed in a port injection system, where does the air needed for idle speeds come from?
5. If the injector pulse width is increased, the air-fuel ratio becomes ___.
6. When the engine is idling, the pressure regulator in a PFI system provides ___ fuel pressure compared to the fuel pressure at wide-open throttle.
7. Why are special fuel injectors needed for GDI systems?
8. How does a GDI system provide for a stratified charge in the combustion chamber?
9. How does a piezoelectric injector work?
10. Describe clear flood mode and why it is used.
11. Explain the basic operation of a CSFI system.

True or False

1. *True or False?* In GDI systems, the PCM controls fuel pressure through pulse width modulation of the electric high-pressure fuel pump.
2. *True or False?* Diesel engines require higher fuel pressures than comparably sized gasoline engines.

Multiple Choice

1. Which type of fuel injection system has the fuel pressure regulator located in the fuel tank?
   a. Throttle body injection
   b. Mechanical returnless PFI
   c. Electronic returnless PFI
   d. Central multipoint injection
2. Which of the following statements about fuel trim is not true?
   a. A positive fuel trim value means that the PCM detects a lean mixture and is decreasing the pulse width to add more fuel to the mixture.
   b. Short-term fuel trim represents changes made immediately in response to HO_2S signals.
   c. Long-term fuel trim represents changes made to set a new base pulse width.
   d. Long-term fuel trim responds to the trends of the short-term fuel trim.

ASE-STYLE REVIEW QUESTIONS

1. While discussing EFI systems: Technician A says that the PCM provides the proper air-fuel ratio by controlling the fuel pressure. Technician B says that the PCM provides the proper air-fuel ratio by controlling injector pulse width. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. While discussing electronic fuel injection principles: Technician A says that the PCM always adjusts the air-fuel ratio in response to the O_2S signals. Technician B says that STFT is based on the output of the O_2S signals. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. While discussing returnless fuel systems: Technician A says that in a returnless fuel system the pressure regulator is mounted on the fuel rail. Technician B says that in this type of fuel system the pump and pressure regulator are combined in one unit. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

4. While discussing central port injection systems: Technician A says that CPI systems use one injector and several injector nozzles. Technician B says that CPI systems open each injector sequentially. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. While discussing throttle-by-wire systems: Technician A says that a spring on the throttle shaft provides the limp-home feature. Technician B says that most systems have redundant processors and the TP and accelerator pedal sensors send redundant input signals. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. While discussing the compression ratios used with engines equipped with a GDI system: Technician A says that higher ratios can be used because ignition timing is normally very advanced. Technician B says that higher ratios are possible because the small droplets of fuel injected directly into the cylinder tend to cool the mixture in the cylinder. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. While discussing air-fuel ratios: Technician A says that a stoichiometric mixture is theoretically the best combination of fuel and air to provide for total combustion. Technician B says that a stoichiometric mixture always results in complete combustion. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. Technician A says that air-fuel ratios can be regulated by controlling the “on time” of the injectors. Technician B says that the air-fuel ratio can be regulated by controlling the pressure applied to the individual injectors. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. While discussing GDI systems: Technician A says that this type of system allows engines to run at very lean air-fuel ratios and at higher-than-normal compression ratios. Technician B says that GDI systems eliminate the need to have an EGR valve on the engine. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While discussing SFI systems: Technician A says that when the injection system fires according to crankshaft position and speed, it is operating in the synchronous mode. Technician B says that one of the advantages of SFI systems is that they are always in the synchronous mode. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

FUEL INJECTION SYSTEM DIAGNOSIS AND SERVICE

CHAPTER 31

OBJECTIVES

- Perform a preliminary diagnostic procedure on a fuel injection system.
- Remove, clean, inspect, and install throttle body assemblies.
- Explain the results of incorrect fuel pressure.
- Perform an injector balance test and determine the injector condition.
- Perform an injector sound, ohmmeter, noid light, and scope test.
- Service components of the fuel system.
- Check the components of a GDI system.
- Diagnose causes of improper idle speed on vehicles with fuel injection.

Troubleshooting fuel injection systems requires systematic step-by-step test procedures. With so many interrelated components and sensors controlling fuel injection performance **(Figure 31–1)**, a hit-or-miss approach to diagnosing problems can quickly become frustrating, time-consuming, and costly.

Fuel injection systems are integrated into engine control systems **(Figure 31–2)**. The self-test modes of these systems are designed to help in engine diagnosis. Unfortunately, when a problem upsets the smooth operation of the engine, many service technicians automatically assume that the computer (PCM) is at fault. But in the vast majority of cases, complaints about driveability, performance, fuel mileage, roughness, hard starting, or no-starting are due to something other than the computer itself (although many problems are caused by sensor malfunctions that can be traced using the self-test mode).

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2007	**Make:** Nissan	**Model:** Frontier	**Mileage:** 128,145	**RO:** 19077
Concern:	Customer states MIL on, engine runs rough, hesitates, shakes.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

Image courtesy of Robert Bosch GmbH.

FIGURE 31–1 The action of a fuel injector and spark plug to start combustion.

Before condemning sensors as defective, remember that weak or poorly operating engine components can often affect sensor readings and result in poor performance. For example, a sloppy timing chain or bad rings or valves reduce vacuum and cylinder pressure, resulting in a lower exhaust temperature. This can affect the operation of a perfectly good oxygen or lambda sensor, which must heat up to approximately 600 °F (315 °C) before functioning in its closed loop mode.

Preliminary Checks

Before conducting any tests on the injection and engine control systems, be certain of the following:

- The battery is fully charged, with clean terminals and connections.
- The charging and starting systems are operating properly.
- All fuses and fusible links are intact.
- All electrical harnesses are routed properly and their connectors and terminals are free of corrosion and tight **(Figure 31–3)**.
- The MIL is working properly.

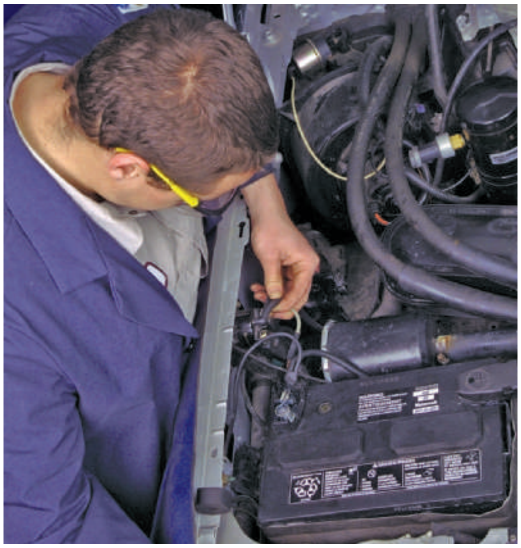


FIGURE 31–3 All underhood wiring should be carefully inspected.

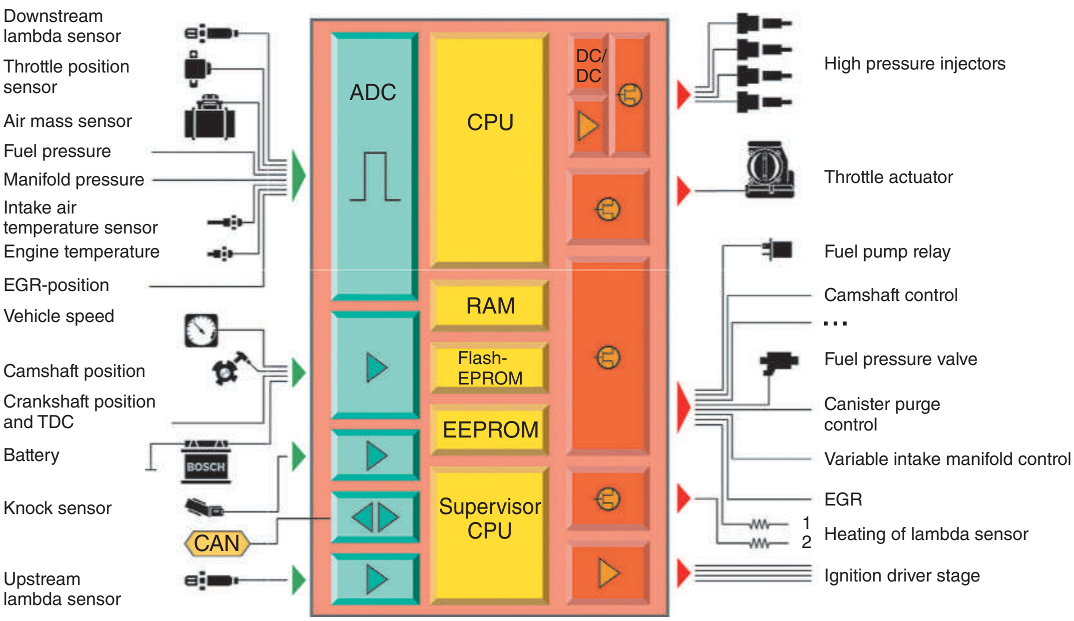


Image courtesy of Robert Bosch GmbH.

FIGURE 31–2 The layout of a late-model EFI system.

- All parts of the air induction system are in good condition and they do not leak.
- All vacuum lines are in good condition, properly routed, and attached.
- The PCV system is working properly.
- All emission control devices are in place, connected, and operating properly.
- The level and condition of the engine's coolant is good.
- The ECT circuit is in good condition.
- The engine is in good mechanical condition.
- The gasoline in the tank is of good quality and has not been substantially cut with alcohol or contaminated with water.
- The exhaust system is not leaking.

Service Precautions

These precautions must be observed when servicing electronic fuel injection systems:

- Always relieve the fuel pressure before disconnecting any component in the fuel system.
- Never turn the ignition switch on while any component of the fuel system is disconnected.
- Use only the test equipment recommended by the vehicle manufacturer.
- When disconnecting the battery, always disconnect the negative cable first.
- Use a grounding strap to prevent static electric discharges when handling computers, modules, and computer chips.
- Isolate or disable all high-voltage systems before testing or servicing the fuel system.

Basic EFI System Checks

Fuel injection problems normally cause no-start or poor driveability problems. The causes of these problems can involve many different sensors and other systems. Of course, the fuel delivery system and the injection system can also cause problems. The EFI system must have good communications with the CAN.

SHOP TALK

The STFT and LTFT should be looked at before beginning any other diagnosis of a driveability problem. Fuel trim allows you to look at what the PCM is doing to control fuel delivery.

SHOP TALK

Prior to OBD II, fuel correction data was given different names. For example, what is now called STFT was called "block integrator" by GM and it called LTFT "block learn." When working on vehicles with OBD I systems, make sure you refer to the service information to identify what you are looking at.

Keep in mind that the PCM constantly adjusts the activity of the fuel injectors to meet the current operating conditions. Therefore, abnormal conditions can cause abnormal operation of the EFI system.

Diagnosis should begin with a check of the MIL; if it stays on or is flashing, the PCM has detected a problem and has set a DTC. A flashing MIL indicates a catalyst-damaging misfire is occurring. The absence of a DTC does not mean that the system is operating normally. A DTC is set only when the PCM sees values that are outside a range or would affect emissions.

Connect a scan tool to the vehicle and retrieve any DTCs. You should also check the conditions of the OBD II monitors. Monitors that have not run or did not pass can provide clues to solving the concern. Use the manufacturer's recommended test sequences for identifying the cause of the DTC. Many fuel injection problems set a fuel trim-related DTC. Fuel trim should be observed whether or not a DTC was set. This is because fuel trim information can show you how the system is responding to various engine operating conditions.

Fuel Trim

The fuel injection system can provide limited corrections for changes in conditions. The fuel system monitor tracks the amount of these corrections. The corrections to base or programmed injection pulse width and timing are called short-term (STFT) and long-term fuel trim (LTFT). Fuel trim may also be displayed as equivalency ration (EQ RAT) or as lambda. The fuel trim monitor is a continuous monitor that looks at the sum of the STFT and LTFT to assess its ability to control the air-fuel ratio. If the PCM detects that it must make an extreme change in fuel strategy, it will set a DTC.

Keep in mind that the actual fuel trim will be the opposite of the DTC. If a system is too lean, DTCs P0171 or P0174 are set because the system is making the mixture richer **(Figure 31–4)**. Likewise, DTCs P0172 and P0175 are set if the system is too rich and the system must reduce the injectors' pulse width to lean the mixture. Also keep in mind that a fuel system DTC does not mean that the fuel system

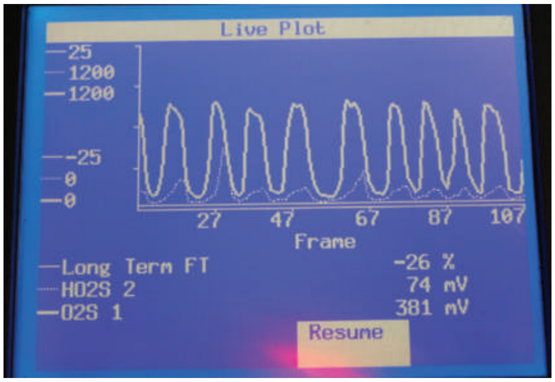


FIGURE 31-4 In this screen, the LTFT on this engine was changed in response to a lean O_2 sensor.

is at fault. Rather, there is a condition that is forcing the PCM to put fuel trim outside a desired range.

Signals from the air-fuel or oxygen sensors cause the PCM to make adjustments to the fuel trim. STFT adjustments are temporary and are not stored in the PCM's memory. LTFT, however, are stored and influences the base timing and duration of the injectors.

While observing fuel trim on a scan tool, zero is the midpoint of the fuel strategy when the PCM is in closed loop. A change in fuel trim is presented as a percentage: Numbers without a minus sign mean fuel is being added, and numbers with a minus sign mean fuel is being subtracted. The constant change or crossing above and below the zero line indicates proper system operation. If the STFT readings are constantly on either side of the zero line, the engine is not operating efficiently.

Instead of displaying STFT and LTFT, some vehicles use equivalence ratio. A displayed equivalence ratio of 1.0 is the same as 0 fuel trim change. However, if the equivalence ratio is less than 1.0, it means the commanded state is rich. If the ratio is above 1.0, it is a lean command. The air-fuel ratio command can be found by multiplying the equivalence ratio times 14.64.

Some intermittent fuel-related driveability problems may be diagnosed by recording the computer's data stream. Before you jump into the data stream, look at the STFT and LTFT.

During open loop, the PCM changes pulse width without feedback from the O_2 sensor, and the short-term adaptive memory value is 1. The number 1 represents a 0 percent change. Once the HO_2S warms up, the PCM moves into closed loop and fuel control is based off of the signals from the HO_2S sensor. The system remains in closed loop until the throttle is fully opened or the engine's temperature drops below a specified limit. In both of these cases, the system goes into open loop.

When the system is in open loop, the injectors operate at a fixed base pulse width. During closed-loop operation, the pulse width is either lengthened or shortened according to the inputs from sensors. As the voltage from the O_2 sensor increases in response to a rich mixture, the STFT decreases, which means the pulse width is shortened. Decreases in STFT are indicated on a scan tool as a number below 1. For example, the short-term adaptive value of 0.75 means the pulse width was shortened by 25 percent and the percent of change on the scan tool will be –25. A short-term adaptive value of 1.25 means the pulse width was lengthened by 25 percent. The latter will be displayed as 25.

STFT will normally toggle in response to the O_2 sensor **(Figure 31–5)**. When the O_2 sensor has a rich signal, the STFT goes lean to adjust the air-fuel ratio. The O_2 sensor will then have a lean signal and the STFT will go rich. This cycling is continuous and normal.

Once the engine reaches a specified temperature (normally 180 °F [82 °C]), the PCM begins to update the LTFT. This setting is based on engine speed, post-catalytic converter O_2 data, and the short fuel trim. If the STFT moves 3 percent and stays there for a period of time, the PCM adjusts the LTFT. The LTFT works to bring the STFT close to a 0 percent correction.

If a lean condition caused by a vacuum leak, restricted injectors, dirty MAF, clogged fuel filter, or bad fuel pump exists, the LTFT will have a + number. If the injectors leak or the fuel pressure regulator is faulty, there will be a rich condition. The rich condition will be evident by—LTFT numbers. If the engine's condition is too far toward either the lean or rich side, the LTFT will not compensate and a DTC will be set.

To diagnose the fuel control system, observe the data stream on the scan tool. Specifically, watch or graph the O_2S or A/F sensors, STFT and LTFT, MAF, and engine load. Operate the engine at idle and then perform a test drive. Include at least one wide-open throttle acceleration and one closed-throttle deceleration. Once back at the shop, examine the collected data. Under acceleration, fuel trims should go positive and the oxygen sensors should go rich. If the oxygen sensors show lean and the engine has a MAF sensor, a misreporting MAF will show a low engine load. If engine load and MAF data look correct, compare the fuel trim and oxygen sensor data. High fuel trim num-

Condition	Exhaust Oxygen Content	Fuel Trim Correction	Result
Lean	High	FT % increases	Adds fuel
Rich	Low	FT % decreases	Subtracts fuel

FIGURE 31-5 STFT will normally toggle in response to the oxygen content in the exhaust.

bers and low oxygen sensor output indicate a lean condition, possibly a vacuum leak or fuel supply problem. On V-type engines, look for fuel trim numbers to be close to the same for each bank. A major variation between banks can indicate a fuel delivery problem, vacuum leak, or a leaking or restricted exhaust.

Other systems can cause the fuel trim to be out of range. They include the following:

- Air induction system leaks allowing unmetered air into the engine
- A faulty PCV valve or leak in the PCV system
- A misreporting engine coolant temperature sensor
- Ignition system misfires
- Exhaust system leaks before the oxygen sensors
- Faulty or contaminated O_2 or A/F sensors (check these after all other systems have been determined to be working properly)

GO TO Chapter 25 for basic diagnostics of computer systems and detailed testing of sensors.

Oxygen Sensor Diagnosis

Carefully check the wiring and connectors to the O_2 sensors for damage and evidence of unwanted resistance. Also, check for intake and exhaust system leaks. These conditions would tend to create more oxygen in the exhaust and the PCM will respond by adding fuel to the mixture. A misfiring spark plug allows unburned fuel and oxygen in the exhaust, which also causes the sensor to give a false lean reading.

Before testing an O_2 sensor, refer to the correct wiring diagram to identify the terminals at the sensor. Most late-model engines use heated oxygen sensors (HO_2S). These sensors have an internal heater that helps to stabilize the output signals. Most HO_2S have four wires connected to them. Two are for the heater and the other two are for the sensor.

On an older vehicle that does not supply serial data, an O_2 sensor can be checked with a voltmeter. Connect it between the O_2 sensor wire and ground. The sensor's voltage should cycle from low to high. The signal from most O_2 sensors varies between 0 and 1 volt. If the voltage is continually high, the air-fuel ratio may be rich or the sensor may be contaminated. When the O_2 sensor voltage is continually low, the air-fuel ratio may be lean, the sensor may be defective, an exhaust leak before the sensor may be pulling in outside air, or the wire between the sensor and the PCM may have a high resistance. If the O_2 sensor signal remains in a mid-range position, the computer may be in open loop or the sensor may be defective.

If the O_2 sensor signal sits at or is close to zero, unplug the sensor. If the voltage increases while the sensor is being unplugged, the sensor is probably shorted to ground. If O_2 sensor voltage sits at or is close to 1 volt, check the wiring at the sensor to see if the heater power feed wire or connector is shorted to the sensor's output signal wire.

The activity of an O_2 sensor can also be monitored with a lab scope. The scope is connected to the sensor in the same way as a voltmeter. The switching of the sensor should be seen as the sensor signal goes to lean to rich to lean continuously **(Figure 31–6)**. If the pattern toggles at high voltages, there is a rich condition **(Figure 31–7)**. With a lean mixture, the pattern will toggle at low voltages.

The activity of the sensor can typically be monitored on a scan tool. If the scan tool has the ability to graph data, this is especially useful for watching oxygen sensor and fuel trim data together **(Figure 31–8)**. When watching the voltage while the engine is running, it should move to nearly 1 volt then drop back to close to 0 volt. Immediately after it drops, the voltage should move back up. This immediate cycling is an important function of an O_2 sensor. If the response is

SHOP TALK

On some older engines, O_2 sensor heater problems (and faulty O_2 sensor signals) can result from a poorly grounded exhaust system. A poor ground adds resistance to the circuit, which prevents the heater from heating the sensor sufficiently. This can cause faulty sensor output signals. Often the problem can be corrected by tightening the exhaust manifold-to-engine bolts.

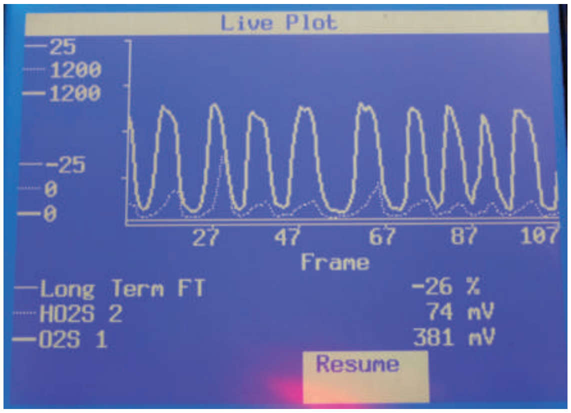


FIGURE 31–6 A good O_2 sensor waveform.

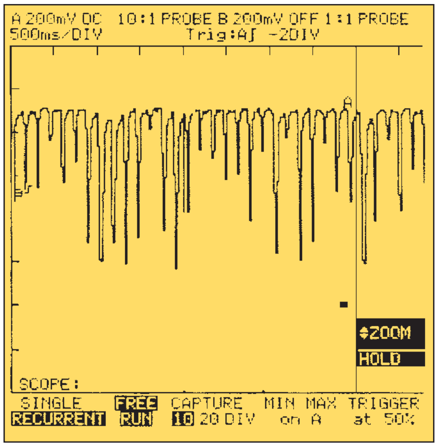


FIGURE 31–7 An O_2 sensor signal caused by a leaking injector.

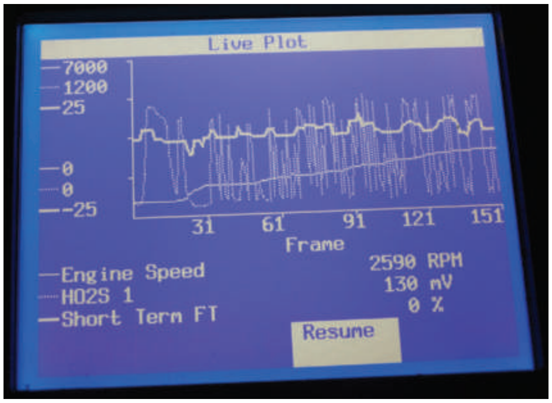


FIGURE 31–8 Note how the fuel trim responded to the O_2 signal and engine speed.

slow, the sensor is lazy and should be replaced. With the engine at about 2,500 rpm, the O_2 sensor should cycle ten to forty times in 10 seconds. When testing the O_2 sensor, make sure the sensor is heated and the system is in closed loop. Some OBD II systems have a very low data transfer rate, which will cause the results of this test to be inaccurate. Check the service information before coming to conclusions.

A/F Sensors

The signals from air-fuel ratio sensors are different from those of a conventional O_2 sensor. This is because A/F sensors produce a current that is interpreted by the PCM. Reading A/F sensor data may be possible using generic OBD II data or you may need to use EOBD data depending on the scan tool being used. When some of these sensors are looked at with an OBD II generic scan tool, the voltage range will appear the same as a conventional O_2 sensor, 0 to 1 volt. However, because an A/F sensor operates differently, the normal toggling of the voltage does not appear. The voltage tends to stay around 0.66 volt.

Exhaust Oxygen Content	Direction of Current Flow	Voltage Signal	A/F Mixture Is:
Low	Negative	Below 3.3	Rich
Stoichiometric	Zero	3.3	14.7:1
High	Positive	Above 3.3	Lean

FIGURE 31–9 A table showing the action of an air-fuel ratio sensor.

When a lean condition is created with a vacuum leak, the voltage will increase to about 0.8 volt and return to 0.66 volt when the vacuum line is reconnected. A normal O_2 sensor would have dropped to a low voltage and risen to a higher voltage after the vacuum line was reconnected. If a technician does not know that the engine has an A/F sensor, an assumption would be made that the sensor or PCM is bad.

Scan tools designed for A/F sensors will display the voltage signals within a range of 2.4 to 4 volts. The 0.66 volt on the generic scan tool would read as 3.2 volts on the enhanced scan tool. The voltage increases with a lean mixture and drops with a rich mixture **(Figure 31–9)**. This is opposite of a conventional O_2 sensor.

An A/F sensor can be tested by manually causing a lean or rich mixture. The voltage signal should quickly respond to those changes. If the voltage does not change or changes very slowly, check the sensor's heater circuit. To check sensor response, use a scan tool that can graph the A/F sensor PID. Run the engine at about 2,500 rpm and then let off of the throttle. As the engine decelerates, snap the throttle open to about 4,000 rpm and then let it return to idle. The sensor should show a lean to rich to lean transition during the test.

A/F sensors need to be hot before they will work correctly. The PCM controls the heater circuit by duty cycling the heater through the groundside of the heater. The power feed to the heater should have battery voltage. If it does not, diagnose that circuit. The circuit can also be checked with a current probe or lab scope. When looking at the heater circuit's current flow, changes in amperage should be evident. Pay attention to the peak amperage; normally this should not exceed 6 amps. Refer to the service information for specific values. In many cases, Mode $06 will provide heater current values.

Air Induction System Checks

In a fuel injection system (particularly designs that rely on airflow meters or mass airflow sensors), all the air entering the engine must be accounted for by

FIGURE 31–10 Carefully inspect the ductwork and hoses of the air induction system.

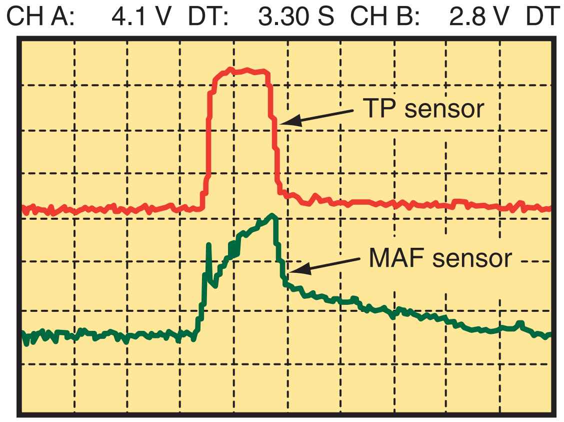


FIGURE 31–11 Waveforms of TP and MAF sensors showing how they simultaneously change with acceleration and deceleration.

the air measuring device. If it is not, the air-fuel ratio becomes overly lean. For this reason, cracks or tears in the plumbing between the airflow sensor and throttle body are potential air leak sources that can affect the air-fuel ratio.

During a visual inspection of the air control system, pay close attention to these areas, looking for cracked or deteriorated ductwork **(Figure 31–10)**. Check in between the ribs of induction hoses for cracks. Small cracks in these areas may only cause a problem as the engine moves during operation. Also make sure that all induction hose clamps are tight and properly sealed. Look for possible air leaks in the crankcase, for example, around the dipstick tube and oil filter cap. Any extra air entering the intake manifold through the PCV system is also not measured and can upset the delicately balanced air-fuel mixture at idle.

It is important to note that vacuum leaks may not affect the operation of engines fitted with a speed density (MAP sensor based) fuel injection system. This does not mean that vacuum leaks are okay, it just means that the operating system may be capable of adjustments that allow the engine to run well in spite of the vacuum leak. This is true for vacuum leaks that are common to all cylinders. If the vacuum leak affects one or two cylinders, the computer cannot compensate for the unmetered air and those two cylinders will not operate efficiently.

Airflow Sensors

When diagnosing poor fuel economy, erratic performance, hesitation, or hard-starting problems, make the following checks to determine if the airflow sensor is at fault.

Mass Airflow Sensors MAF sensors measure intake air before it reaches the throttle plate. If any air bypasses the sensor and enters the combustion chambers without being measured, the engine will run lean. A vacuum leak or a leak between the MAF and throttle plate will also reduce fuel delivery. The resulting lean mixture will cause the PCM to store DTCs indicating excessive fuel corrections and/or lean misfires.

The action of a MAF can be observed on a lab scope **(Figure 31–11)**. As the throttle is opened, the MAF signal should increase due to the increase in airflow. Graph the MAF signal output from idle to a WOT snap acceleration and back to idle. The sensor should produce a spike as the throttle is snapped open and rpms increase.

When using scan data to test the MAF, compare the MAF output with engine load, fuel trims, and oxygen sensor data. A misreporting MAF may show normal at idle speeds but as rpm increases, the unreported air will cause the O_2S voltage to be low and fuel trims to go positive.

If a MAF is suspected as causing a lean condition, remove it and inspect the hot wire for signs of debris. A contaminated MAF should be replaced and the induction system and air filter closely inspected.

Manifold Absolute Pressure (MAP) Sensors Speed density systems rely on MAP signals. Increased manifold pressure (lower vacuum) causes the injectors' pulse width to increase regardless of the cause of the pressure change (open throttle, vacuum leak, recirculated exhaust gas, or exhaust pressure).

MAP sensors respond in the opposite way as MAFs and VAFs. Vacuum leaks in speed density systems can be verified by watching the IAC counts on a scan tool. Low vacuum will result in low IAC counts. In response, the PCM will increase the amount of fuel, which will cause the idle speed to increase.

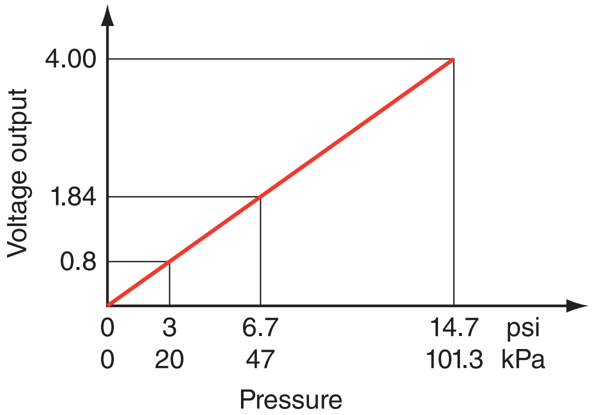


FIGURE 31–12 A chart showing how a typical MAP sensor's signal changes with a change in pressure.

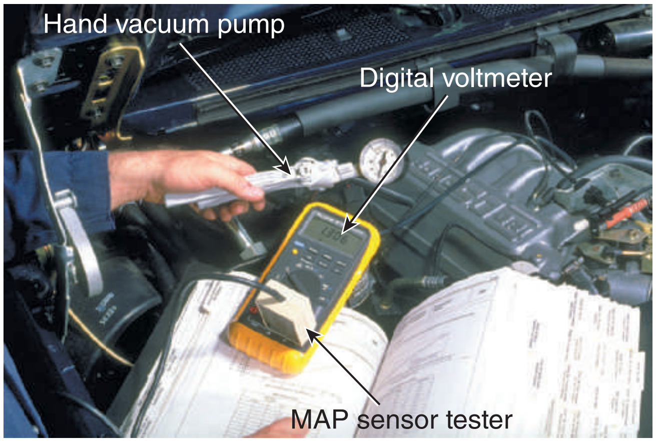


FIGURE 31–13 This adapter changes the frequency signal from a MAP to an analog signal that can be monitored with a DMM.

To correct this, the PCM will attempt to reduce the idle speed by closing the IAC. MAP sensors respond directly to changes in pressure **(Figure 31–12)**. Special MAP transducers are available to allow a DMM to monitor MAP signals **(Figure 31–13)**.

Throttle Body

The throttle body **(Figure 31–14)** allows the driver to control the amount of air that enters the engine, thereby controlling the speed of the engine. Each type of throttle body assembly is designed to allow a certain amount of air to pass through it at a particular amount of throttle opening. If anything accumulates on the throttle plates or in the throttle bore, the amount of air that can pass through is reduced. This normally causes an idle problem.

These deposits can be cleaned off the throttle assembly and the airflow through them restored. Begin by removing the air duct from the throttle assembly; that will give access to the plate and bore. The deposits can be cleaned with a spray cleaner or wiped off with a cloth. If either of these cleaning methods does not remove the deposits, the throttle body should be removed, disassembled, and placed in an approved cleaning solution.

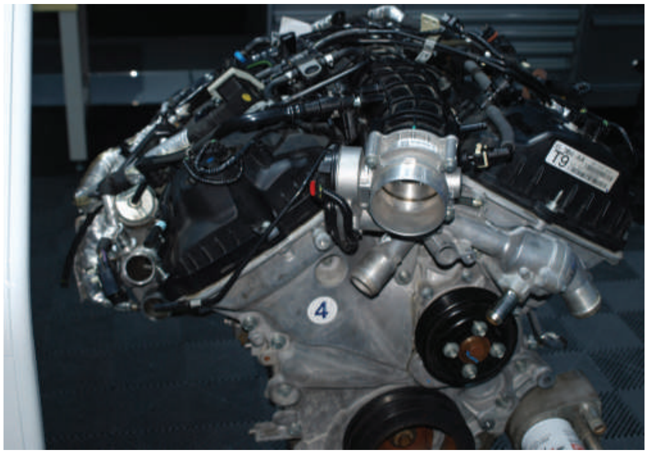


FIGURE 31–14 A throttle body positioned between the banks of the V8 engine.

A pressurized can of throttle body cleaner may be used to spray around the throttle area without removing and disassembling the throttle body. The throttle assembly can also be cleaned by soaking a cloth in carburetor solvent and wiping the bore and throttle plate to remove light to moderate amounts of carbon residue. Also, clean the backside of the throttle plate. Then, remove the idle air control valve from the throttle body (if so equipped) and clean any carbon deposits from the pintle tip and the IAC air passage.

If the intake manifold setup has diaphragms or solenoids that control the selection of manifold runners, make sure you allow some of the cleaning solution to be drawn in by the engine while it is running in order to clean the valves, sometimes called *butterflies*, controlled by the solenoids or diaphragms. Dirty switchover valves can cause hard starting, poor performance, increased oil consumption, and DTCs.

Throttle Body Inspection—Non-Electronic Throttle Control Throttle body inspection and service procedures vary widely depending on the year and make of the vehicle. However, some components such as the TP sensor are found on nearly all throttle bodies. Since throttle bodies have some common components, inspection procedures often involve checking common components.

Throttle Body Removal and Cleaning Whenever it is necessary to remove the throttle body assembly for replacement or cleaning, make sure you follow

PROCEDURE

Throttle Body Inspection

STEP 1 Check for smooth movement of the throttle linkage from idle position to the wide-open position.

STEP 2 Check the throttle linkage and cable for wear and looseness.

STEP 3 Check the vacuum at each vacuum port on the throttle body while the engine is idling and while it is running at a higher speed.

STEP 4 Connect a smoke machine to a manifold vacuum port and inject smoke into the engine. Look for signs of smoke around the throttle body and vacuum hoses.

STEP 5 Operate the engine until it reaches normal operating temperature and check the idle speed on a tachometer. The idle speed should be 700 to 800 rpm. Refer to the manufacturer's idle speed specifications.

the procedures outlined by the manufacturer. Throttle bodies often have coolant circulating through them so it may be necessary to drain coolant from the radiator before removing the throttle body. Once the assembly has been removed, remove all nonmetallic parts such as the TP sensor, IAC valve, throttle opener, and the throttle body gasket from the throttle body. Now it is safe to clean the throttle body assembly in the recommended throttle body cleaner and blow dry with compressed air. Blow out all passages in the throttle body assembly.

Before reinstalling the throttle body assembly, make sure all metal mating surfaces are clean and free from metal burrs and scratches. Make sure you have new gaskets and seals for all sealing surfaces before you begin to reinstall the assembly. After everything that was disconnected is reconnected, start the engine and verify there are no leaks and that the engine idle speed is correct.

Caution! Dispose of fuel-soaked rags or towels by placing them in a fireproof container.

Fuel System Checks

GO TO Chapter 29 for a detailed discussion on fuel delivery systems and how to test and service them.

Checking for fuel delivery is a simple task on throttle body injection systems. Remove the air cleaner, crank the engine, and the injector should be spraying some fuel. It is impossible to visually check the spray pattern and volume of port system injectors. However, performing simple fuel pressure and fuel volume tests will give an accurate evaluation of the fuel delivery system. Keep in mind that fuel pressure affects the output of a fuel injector: If an injector has the same pulse rate but receives low pressure there is less fuel; if the pressure is high, the amount of fuel increased.

Low fuel pressure can cause a no-start or poor-running condition. It can be caused by a faulty fuel pump, a fault in the fuel pump electrical circuit, a clogged fuel filter, a faulty pressure regulator, or a restricted fuel line anywhere from the fuel tank to the fuel filter connection.

High fuel pressure readings will result in a rich-running engine. A restricted fuel return line to the tank or a bad fuel regulator may be the problem. To isolate the cause of high pressure, relieve system pressure and connect a tap hose to the fuel return line. Direct the hose into a container and energize the fuel pump. If fuel pressure is now within specifications, the fuel return line is blocked. If pressure is still high, the pressure regulator is faulty.

If fuel pressure is within specs but the pressure bleeds down, there may be a leak in the fuel pressure regulator, the fuel pump check valve, or the injectors themselves. Hard starting is a common symptom of internal system leaks. Also, fuel starvation and lean conditions can occur when the injectors drain the fuel rail faster than the fuel pump can fill it. This could be caused by low fuel pressure or inadequate delivery volume.

Connect the fuel pressure gauge and run the engine until it reaches normal operating temperature. Turn off the engine and immediately pinch off the fuel return line between the fuel regulator and the tank. If pressure holds with the return line pinched, the leak is in the return line. If the pressure still drops quickly, remove the clamp from the line. Now run the fuel pump to restore normal pressure and then immediately pinch off the supply hose between the fuel pump and the inlet on the fuel rail. If the system

now maintains pressure, it is probable that the fuel pump check valve is leaking. If the pressure still drops, there is an external leak in the rail, a leaking pressure regulator, or the injectors are leaking.

Returnless Systems Nearly all late-model vehicles use a returnless fuel system. In mechanical returnless systems, the pressure regulator is part of the fuel pump assembly in the fuel tank. Electronic returnless systems have a pressure sensor on the fuel rail and modulate the pulse width of the fuel pump to control pressure. The pulse width is controlled by the PCM. High pressures in these systems can be caused by a faulty pressure regulator, pressure sensor, fuel pump, PCM, or electrical circuits.

Injector Checks

A fuel injector is nothing more than a solenoid-actuated fuel valve. Its operation is quite basic in that as long as it is held open and the fuel pressure remains steady, it delivers fuel until it is told to stop.

Because all fuel injectors, except piezo injectors, operate in a similar manner, fuel injector problems tend to exhibit the same failure characteristics. The main difference is that, in a TBI design, generally all cylinders will suffer if an injector malfunctions, whereas in port systems the loss of one injector will only affect one cylinder.

An injector that does not open causes hard starts on port-type systems and an obvious no-start on single-point TBI designs. An injector that is stuck partially open causes loss of fuel pressure (most noticeably after the engine is stopped and restarted within a short time period) and flooding due to raw fuel dribbling into the engine. Buildups of gum and other deposits on the tip of an injector can reduce the amount of fuel sprayed by the injector or they can prevent the injector from totally sealing, allowing it to leak. Since injectors on MFI and SFI systems are subject to more heat than TBI injectors, port injectors have more problems with tip deposits.

Because an injector adds the fuel part to the air-fuel mixture, any defect in the fuel injection system will cause the mixture to go rich or lean. If the mixture is too rich and the PCM is in control of the air-fuel ratio, a common cause is that one or more injectors are leaking. An easy way to verify this on port-injected engines is to use an exhaust gas analyzer.

With the engine warmed up, but not running, remove the air duct from the airflow sensor. Then insert the gas analyzer's probe into the intake plenum area. Be careful not to damage the airflow sensor or throttle plates while doing this. Look at the HC readings on the analyzer. They should be low and drop as time passes. If an injector is leaking, the HC reading will be high and will not drop. This test does not locate the bad injector, but does verify that one or more are leaking.

Another cause of a rich mixture is a leaking fuel pressure regulator. If the diaphragm of the regulator is ruptured, fuel will move into the intake manifold through the diaphragm, causing a rich mixture. The regulator can be checked by using two simple tests. After the engine has been run, disconnect the vacuum line to the fuel pressure regulator **(Figure 31–15)**. If there are signs of fuel inside the hose or if fuel comes out of the hose, the regulator's diaphragm is leaking. The regulator can also be tested with a hand-operated vacuum pump. Apply 5 in. Hg (127 mm Hg) to the regulator. A good regulator diaphragm will hold that vacuum.

Checking Voltage Signals When an injector is suspected as the cause of a lean problem, the first step is to determine if the injector is receiving a signal (from the PCM) to fire.

> **Warning!** When performing this test, make sure to keep off the accelerator pedal. On some models, fully depressing the accelerator pedal activates the clear flood mode, in which the voltage signal to the injectors is automatically cut off. Technicians unaware of this waste time tracing a phantom problem.

FIGURE 31–15 A fuel pressure regulator.

Once the injector's electrical connector has been removed, check for voltage at the injector using a noid light that plugs into the connector. After making the test connections, crank the engine. The noid light flashes if the computer is cycling the injector on and off. If the light is not flashing, the power supply circuit to the injectors is open, or the computer or connecting wires are defective. If sufficient voltage is present after checking each injector, check the electrical integrity of the wiring between the computer and the injectors themselves.

An ohmmeter can be used to test an injector. Connect the ohmmeter across the injector terminals **(Figure 31–16)** after the wires to the injector have been disconnected. If the meter reading is infinite, the injector winding is open. If the meter shows more resistance than the specifications call for, there is high resistance in the winding. A reading that is lower than the specifications indicates that the winding is shorted. If the injector is even a little bit out of specifications, it must be replaced. If using an ohmmeter to test injectors, check the injector when cold and at operating temperature. An injector winding may test within specifications at room temperature but fail when hot. It is also important to remember that a resistance test does not prove a component is good as the part being tested is not under load at the time of the test.

Injector Balance Test If the injectors are electrically sound, perform an injector pressure balance test. This test will help isolate a clogged or dirty injector. Photo Sequence 29 shows a typical procedure for testing injector balance. Depending on the vehicle, the on-board computer system may have an injector test mode accessible through a scan tool. If the vehicle does not have an injector test mode, an electronic injector pulse tester is used for this test. As each injector is energized, a fuel pressure gauge is observed to monitor the drop in fuel pressure. The tester is designed to safely pulse each injector for a controlled length of time. The tester is connected to one injector at a time. The ignition is turned on until a maximum reading is on the pressure gauge. That reading is recorded and the ignition turned off. With the tester, activate the injector and record the pressure reading after the needle has stopped pulsing. This same test is performed on each injector. Start the engine and let it run briefly between each injector test to allow the fuel to burn out of the cylinders.

FIGURE 31–16 Checking an injector with an ohmmeter.

The difference between the maximum and minimum reading is the pressure drop. Ideally, each injector should drop the same amount when opened. Typically a variation of 1.5 to 3 psi (20 kPa) after each injector is energized is cause for concern. If there is no pressure drop or a low-pressure drop, suspect a restricted injector orifice or tip. A higher-than-average pressure drop indicates a rich condition. When an injector plunger is sticking in the open position, the fuel pressure drop is excessive. If there are inconsistent readings, the nonconforming injectors either have to be cleaned or replaced.

If the injector's orifice is dirty or otherwise restricted, there will not be much pressure decrease when the injector is energized. Stumbles during acceleration, engine stalling, and erratic idle are all caused by restricted injector orifices.

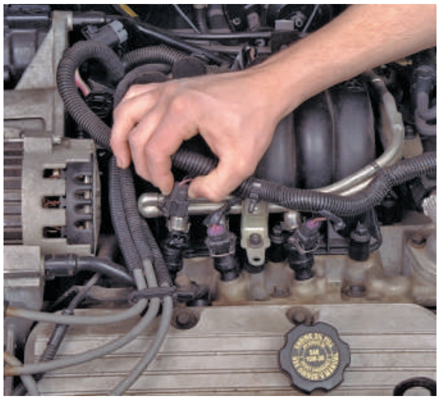
If an excessive amount of pressure drop is observed, it is likely that an injector's plunger is sticking open. A sticking injector may result in a rich air-fuel mixture.

Injector Sound Test If the injector's electrical leads are difficult to access, an injector power balance test may be hard to perform. As an alternative, start the engine and use a technician's stethoscope to listen for correct injector operation. A good injector makes a rhythmic clicking sound as the solenoid is energized and de-energized several times each second. If a clunk-clunk instead of a steady click-click is heard, chances are the problem injector has been found. Cleaning or replacement is in order. If an injector does not produce a clicking noise, the injector, connecting wires, or PCM may be defective. When the injector clicking noise is erratic, the injector plunger may be sticking. If there is no injector clicking noise, proceed with the injector resistance test and noid light test to locate the cause of the problem. If a stethoscope is not handy, use a thin steel rod, wooden dowel, or fingers to feel for a steady on/off pulsing of the injector solenoid.

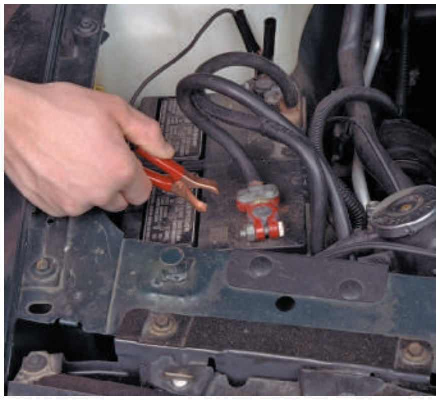
PHOTO SEQUENCE 29

Typical Procedure for Testing Injector Balance

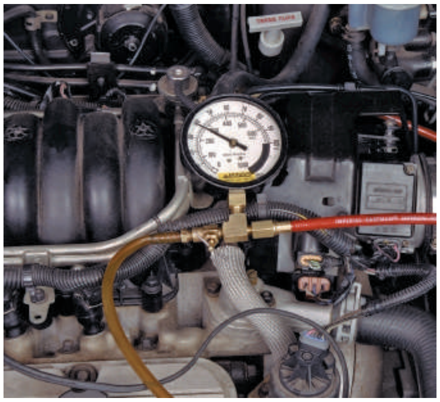
P29-1 Connect the fuel pressure gauge to the Schrader valve on the fuel rail, and then relieve the pressure in the system.



P29-2 Disconnect the number 1 injector and connect the injector pulse tester to the injector's terminals.

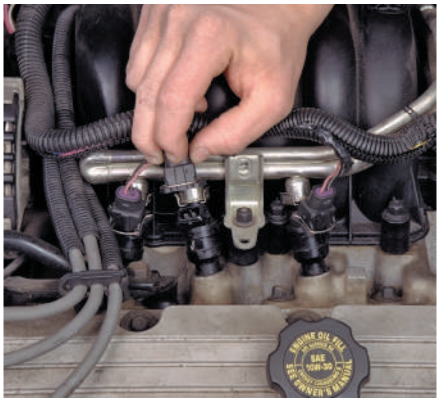


P29-3 Connect the injector pulse tester's power supply leads to the battery.

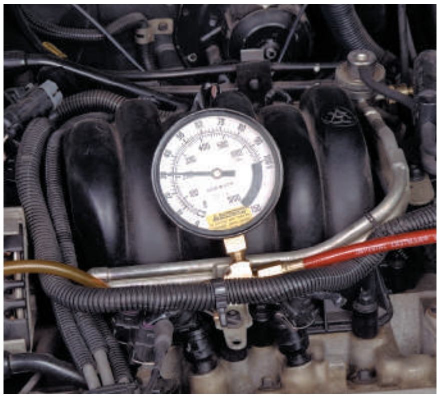


P29-4 Cycle the ignition switch several times until the system pressure is at the specified level.

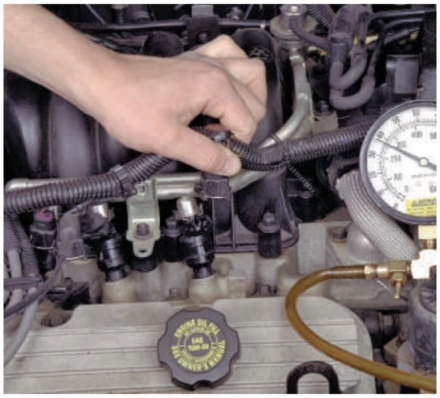
P29-5 Push the injector pulse tester switch and record the pressure on the pressure gauge. Subtract this reading from the measured system pressure. The answer is the pressure drop across that injector.



P92-6 Move the injector tester to the number 2 injector and cycle the ignition switch several times to restore system fuel pressure.



P29-7 Depress the injector pulse tester's switch and observe the fuel pressure. Again the difference between the system pressure and the pressure when an injector is activated is the pressure drop across the injector.



P29-8 Move the injector tester's leads to the number 3 injector and cycle the ignition switch to restore system pressure.

P29-9 Depress the switch on the tester to activate that injector and record the pressure drop. Continue the procedure for all injectors, then compare the results of each to specifications and to each other.

Oscilloscope Checks An oscilloscope can be used to monitor the injector's pulse width and duty cycle when an injector-related problem is suspected. The pulse width is the time in milliseconds that the injector is energized. The duty cycle is the percentage of on-time to total cycle time.

To check the injector's firing voltage on the scope, a typical hookup involves connecting the scope's positive lead to the injector supply wire and the scope's negative lead to an engine ground.

Fuel injection signals vary in frequency and pulse width. The pulse width is controlled by the PCM, which varies it to control the air-fuel ratio. The frequency varies depending on engine speed. The higher the speed, the more pulses per second there are. Most often the injector's ground circuit is completed by a driver circuit in the PCM. All of these factors are important to remember when setting a lab scope to look at fuel injector activity. Set the scope to read at least 50 volts, then set the sweep and trigger to allow you to clearly see the on signal on the left and the off signal on the right. Make sure the entire waveform is clearly seen. Also remember the setting may need to be changed as engine speed increases or decreases.

Fuel injectors are fired either individually or in groups. When the injectors are fired in groups, a driver circuit controls two or more injectors. On some V-type engines, one driver fires the injectors on one side of the engine, while another fires the other side. Bank-fired systems were common prior to OBD II standards. Each fuel injector has its own driver transistor in sequential and throttle body injection. It is extremely important, while troubleshooting, that you recognize how the injectors are fired. When the injectors are fired in groups, there can be a common or noncommon cause of the problem. For example, a defective driver circuit in the PCM would affect all of the injectors in a group, not just one. Conversely, if one injector in the group is not firing, the problem cannot be the driver.

In sequential fuel injection systems, each injector has its own driver circuit and wiring. To check an individual injector, the scope must be connected to that injector. This is great for locating a faulty injector. If the scope has a memory feature, a good injector waveform can be stored and recalled for comparison to the suspected bad fuel injector pattern. To determine if a problem is the injector itself or the PCM and/or wiring, simply swap the injector wires from an injector that had a good waveform to the suspect injector. If the waveform cleans up, the wiring harness or the PCM is the cause of the problem. If the waveform is still not normal, the injector is to blame.

There are three different types of fuel injector circuits. In the conventional circuit, the driver constantly applies voltage to the injector. The circuit is turned on when a ground is provided. The waveform for this type of injector circuit is shown in **Figure 31–17**. Notice that there is a single voltage spike at the point where the injector is turned off. The total on-time of the injector is measured from the point where the trace drops (on the left) to the point where it rises up (next to the voltage spike).

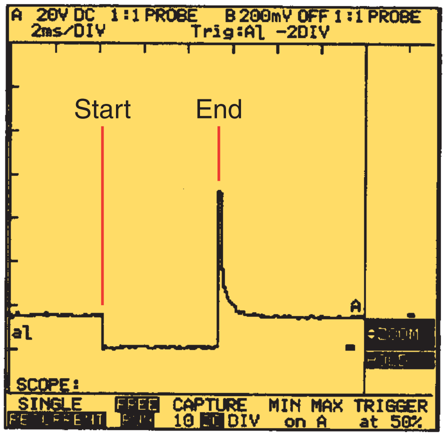


FIGURE 31–17 The waveform for a conventional fuel injector driver circuit.

Peak and hold injector circuits use two driver circuits to control injector action. Both driver circuits complete the circuit to open the injector. This allows for high current at the injector, which forces the injector to open quickly. After the injector is open, one of the circuits turns off. The second circuit remains on to hold the injector open. This is the circuit that controls the pulse width of the injector. This circuit also contains a resistor to limit current flow during on-time. When this circuit turns off, the injector closes. When looking at the waveform for this type of circuit **(Figure 31–18)**, there will be two voltage spikes. One is produced when each circuit

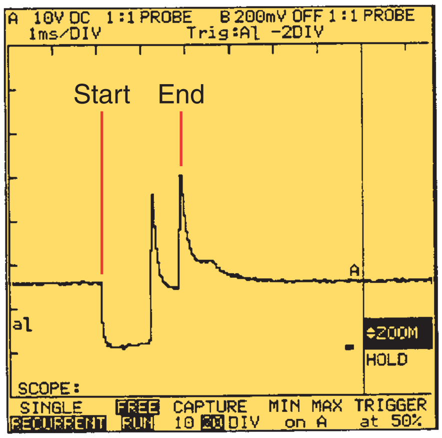


FIGURE 31–18 The waveform for a peak and hold fuel injector driver circuit.

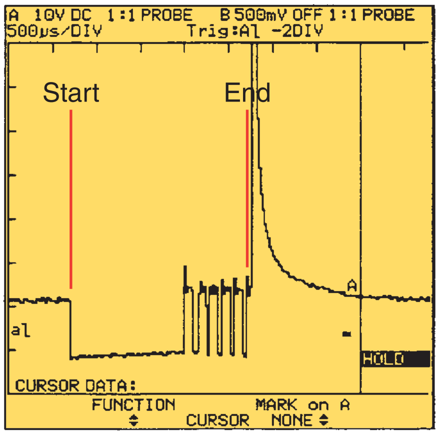


FIGURE 31–19 The waveform for a pulse-modulated fuel injector driver circuit.

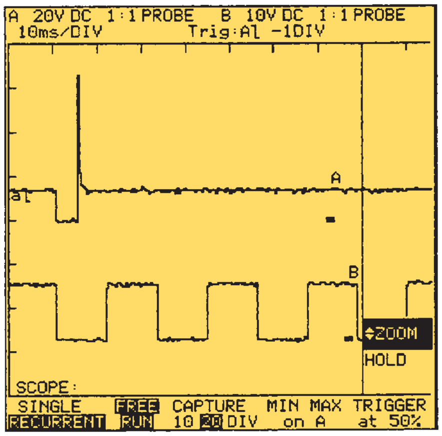


FIGURE 31–20 On a dual trace scope, you can compare the ignition reference signal to the injector's ON signal.

opens. To measure the on-time of this type injector, measure from the drop on the left to the point where the second voltage spike is starting to move upward.

A **pulse-modulated injector** circuit uses high current to open the injector. Again this allows for quick injector firing. Once the injector is open, the circuit ground is pulsed on and off to allow for a long on-time without allowing high current flow through the circuit. To measure the pulse width of this type of injector **(Figure 31–19)**, measure from the drop on the left to the beginning of the large voltage spike, which should be at the end of the pulses.

For all types of injectors, the waveform should have a clean, sudden drop in voltage when it is turned on. This drop should be close to 0 volts. Typically, the maximum allowable voltage during the injector's on-time is 600 millivolts. If the drop is not perfectly vertical, either the injector is shorted or the driver circuit in the PCM is bad. If the voltage does not drop to below 600 millivolts, there is resistance in the ground circuit or the injector is shorted. When comparing one injector's waveform to another, check the height of the voltage spikes. The voltage spike of all injectors in the same engine should have approximately the same height. If there is a variance, the injector is either shorted or the winding has high resistance. Other causes include the power feed wire to the injector with the variance or the PCM's driver for that injector is faulty.

While checking the injectors with a lab scope, make sure the injectors are firing at the correct time. To do this, use a dual trace scope and monitor the ignition reference signal and a fuel injector signal at the same time. The two signals should have some sort of rhythm between them. For example, there can be one injector firing for every four ignition reference signals **(Figure 31–20)**. This rhythm is dependent on the synchronization of the CKP and CMP sensors. Most sequential systems use the CMP signal for injector timing. If the injector's waveform is fine but timing is wrong, the ignition reference circuit is not allowing the injector to fire at the correct time. This is usually caused by incorrect camshaft timing. If the ignition signal is lost because of a faulty sensor, the injection system will also shut down. If the injector circuit and the ignition reference circuit shut down at the same time, the cause of the problem is probably the ignition reference sensor. If the injector circuit shuts off before the ignition circuit, the problem is the injector circuit or the PCM.

Current Ramping When using a DSO or GMM, the ramping current should be compared to the voltage **(Figure 31–21)**. When the injector is grounded, current flows to it. The current trace should show a steady build until the current limiter injector's driver

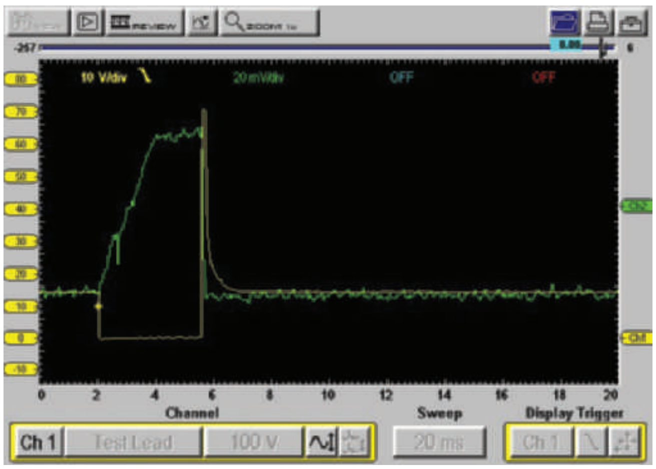


FIGURE 31–21 Comparing injector current ramping (green) to the voltage signals (yellow).

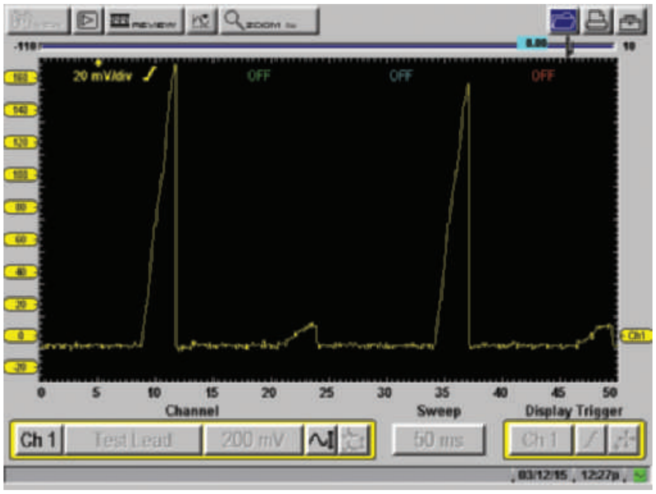


FIGURE 31–22 This injector is shorted, it is drawing too much current.

circuit activates. At that point, the current should level out until the injector is turned off. When the circuit is turned off, current should drop sharply. When one looks at the build of current, any unwanted resistance in the injector's coil will show up as decrease in current flow during its ramp. Although the injector may be firing in spite of the resistance, the injector is bad or will be soon. If the current flow rises too quickly, this indicates a shorted injector that is drawing too much current **(Figure 31–22)**.

It is important to understand the stages of voltage at the injector to understand what the current should be doing. Before the injector fires, there is system voltage to it but no current flow. Once the PCM grounds the injector, current begins to flow. When there is enough current to turn on the injector, the injector opens. At this point, if the voltage does not drop close to zero, there could be ground problems or a weak driver circuit. Also, the current may have a rough time building. After the injector is fired, current stops and the voltage should move high. Immediately after the injector is turned off, the magnetic field in the coil collapses, causing another voltage spike. If the magnetic field in the coil is weak, this secondary spike will not be very high. This can be caused by high resistance or a short in the injector's windings. It can also be caused by low current to the injector.

Injector Service

Because a single injector can cost up to several hundred dollars, arbitrarily replacing injectors when they are not functioning properly, especially on multiport systems, can be an expensive proposition. If injectors are electrically defective, replacement is the only alternative. However, if the injector balance test indicated that some injectors were restricted or if the vehicle is exhibiting rough idle, stalling, or slow or uneven acceleration, the injectors may just be dirty and require a good cleaning.

Injector Cleaning

Before discussing the typical cleaning systems available and how they are used, several cleaning precautions are in order. First, never soak an injector in cleaning solvent. Not only is this an ineffective way to clean injectors, but it most likely will destroy the injector in the process. Also, never use a wire brush, pipe cleaner, toothpick, or other cleaning utensil to unblock a plugged injector. The metering holes in injectors are drilled to precise tolerances. Scraping or reaming the opening may result in a clean injector but it may also be one that is no longer an accurate fuel-metering device.

The basic premise of all injection cleaning systems is similar in that some type of cleaning chemical is run through the injector in an attempt to dissolve deposits that have formed on the injector's tip. The methods of applying the cleaner can range from single-shot, premixed, pressurized spray cans to self-mix, self-pressurized chemical tanks resembling bug sprayers. The premixed, pressurized spray can systems are fairly simple and straightforward to use since the technician does not need to mix, measure, or otherwise handle the cleaning agent.

Automotive parts stores usually sell pressurized containers of injector cleaner with a hose for Schrader valve attachment. During the cleaning process, the engine runs on the pressurized container of propane and injector cleaner. Fuel pump operation must be stopped to prevent the pump from forcing fuel up to the fuel rail. Disconnect the wires from the in-tank fuel pump or the fuel pump relay to disable the fuel pump. Plug the fuel return line from the fuel rail to the tank. Connect a can of injector cleaner to the Schrader valve on the fuel rail and run the engine for about 20 minutes on the injector solution.

Other systems require the technician to assume the role of chemist and mix up a desired batch of cleaning solution for each application. The chemical solution then is placed in a holding container and pressurized by hand pump or shop air to a specified operating pressure. The injector cleaning solution is poured into a canister on some injector cleaners and shop air supply is used to pressurize the canister to the specified pressure. The injector cleaning solution contains unleaded fuel mixed with injector cleaner.

Courtesy of SPX Service Solutions.

FIGURE 31–23 An injector cleaner connected to a fuel rail.

The container hose is connected to the Schrader valve on the fuel rail **(Figure 31–23)**. Disable the fuel pump according to the car manufacturer's instructions (e.g., pull the fuel pump fuse, disconnect a lead at pump). Clamp off the fuel pump return line at the flex connection to prevent the cleaner from seeping into the fuel tank. Set and connect the cleaning system so it can circulate the cleaning solution through the fuel rail with the engine off. To do this, adjust the machine's delivery pressure to a pressure higher than normal delivery pressure. To flush the entire fuel rail, including the injector inlet screens and regulator, adjust the machine's delivery pressure higher than the fuel pressure regulator's normal pressure setting.

Readjust the machine to a pressure slightly lower than the normal regulated pressure and then open the cleaner's control valve one-half turn or so to prime the injectors, and then start the engine. If available, set and adjust the cleaner's pressure gauge to approximately 5 psi (34.47 kPa) below the operating pressure of the injection system and let the engine run at 1,000 rpm for 10 to 15 minutes or until the cleaning mix has run out. If the engine stalls during cleaning, simply restart it. Run the engine until the recommended amount of fluid is exhausted and the engine stalls. Shut off the ignition, remove the cleaning setup, and reconnect the fuel pump.

After removing the clamping devices from around the fuel lines, start the car. Let it idle for 5 minutes or so to remove any leftover cleaner from the fuel lines. In the more severely clogged cases, the idle improvement should be noticeable almost immediately. With more subtle performance improvements, an injector balance test verifies the cleaning results. Once the injectors are clean, recommend the use of an in-tank cleaning additive or a detergent-laced fuel.

The more advanced units feature electrically operated pumps neatly packaged in roll-around cabinets that are quite similar in design to an A/C charging station **(Figure 31–24)**.

After the injectors are cleaned or replaced, rough engine idle may still be present. This problem occurs because the adaptive memory in the computer has learned previously about the restricted injectors. If the injectors were supplying a lean air-fuel ratio, the computer increased the pulse width to try to bring the

FIGURE 31–24 A fuel injector cleaner cart.

air-fuel ratio back to stoichiometric. With the cleaned or replaced injectors, the adaptive computer memory is still supplying the increased pulse width. This action makes the air-fuel ratio too rich now that the restricted injector problem does not exist. With the engine at normal operating temperature, drive the vehicle for at least 5 minutes to allow the adaptive computer memory to learn about the cleaned or replaced injectors. Afterward, the computer should supply the correct injector pulse width and the engine should run smoothly. This same problem may occur when any defective computer system component is replaced.

Fuel Rail, Injector, and Regulator Service

There are service operations that will require removing the fuel injection fuel rail, pressure regulator, and/or injectors. Most of these are not related to fuel system repair. However, when it is necessary to remove and refit them, it is important that it be done carefully and according to the manufacturer's recommended procedures.

Injector Replacement

Photo Sequence 30 outlines a typical procedure for removing and installing an injector. Consult the vehicle's service information for instructions on removing and installing injectors. Before installing the new one, always check to make sure the sealing O-ring is in place. Also, prior to installation, lightly lubricate the sealing ring with engine oil or automatic transmission fluid (avoid using silicone grease, which tends to destroy an O_2S and clog the injectors) to prevent seal distortion or damage.

Warning! Cap injector openings in the intake manifold to prevent the entry of dirt and other particles. Also, after the injectors and pressure regulator are removed from the fuel rail, cap all fuel rail openings to keep dirt out of the fuel rail.

Fuel Rail, Injector, and Pressure Regulator Removal

The procedure for removing and replacing the fuel rail, injectors, and pressure regulator varies depending on the vehicle. On some applications, certain components must be removed to gain access to these components. Many GDI systems use special fuel lines and fittings that cannot be reused if loosened. Before opening a GDI fuel rail or line, determine if the part requires replacement. Reusing a component can cause fuel leaks and damage to the vehicle. The system must be relieved of any and all pressure before the fuel lines are opened to remove any of the components. Before removing the fuel rail, use compressed air to blow dirt and debris from around where the injectors pass through the intake and wipe off any dirt from the fuel rail with a shop towel. Then loosen the fuel line clamps on the fuel rail, if so equipped. If these lines have quick-disconnect fittings, grasp the larger collar on the connector and twist in either direction while pulling on the line to remove the fuel supply and return lines **(Figure 31–25)**. Now, remove the vacuum line from the pressure regulator and disconnect the electrical connectors from the injectors. The fuel rail is now ready to be removed. On some engines, the fuel rail is held in place by bolts; they need to be removed before pulling the fuel rail free. When pulling the fuel rail away from the engine, pull with equal force on each side of the fuel rail to remove the rail and injectors.

Warning! Do not use compressed air to flush or clean the fuel rail. Compressed air contains water, which may contaminate the fuel rail.

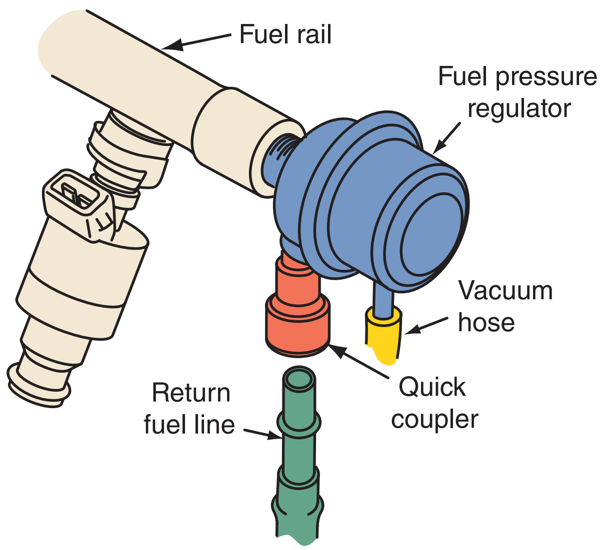
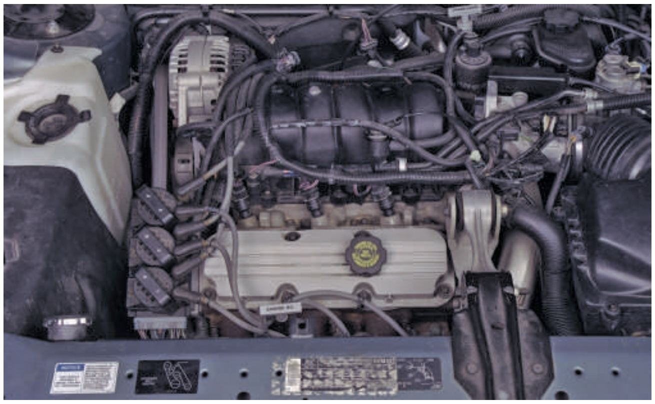


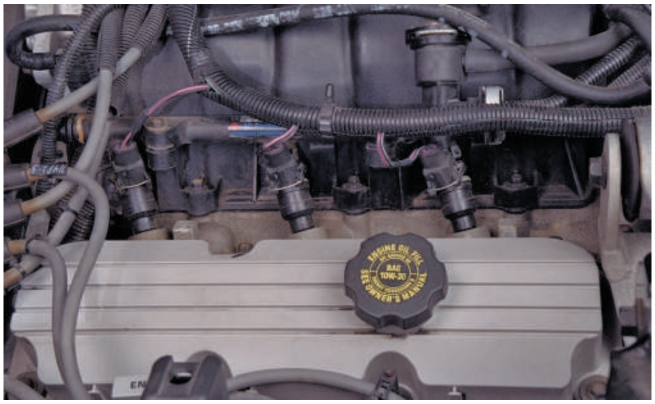
FIGURE 31-25 Fuel supply and return lines connected to the fuel rail.

PHOTO SEQUENCE 30

Removing and Replacing a Fuel Injector on a PFI System



P30-1 Often an individual injector needs to be replaced. Random disassembly of the components and improper procedures can result in damage to one of the various systems located near the injectors.

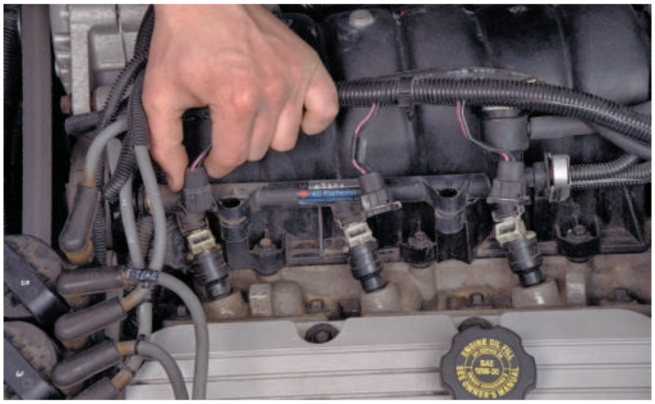


P30-2 The injectors are normally attached directly to a fuel rail and inserted into the intake manifold or cylinder head. They must be positively sealed because high-pressure fuel leaks can cause a serious safety hazard.

P30-3 Prior to loosening any fitting in the fuel system, the fuel pump fuse should be removed.

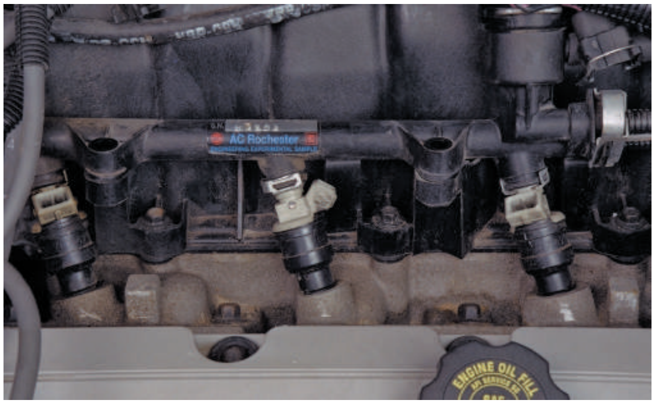
P30-4 As an extra precaution, many technicians disconnect the negative cable at the battery.

P30-5 To remove an injector, the fuel rail must be able to move away from the engine. The rail-holding brackets should be unbolted and the vacuum line to the pressure regulator disconnected.

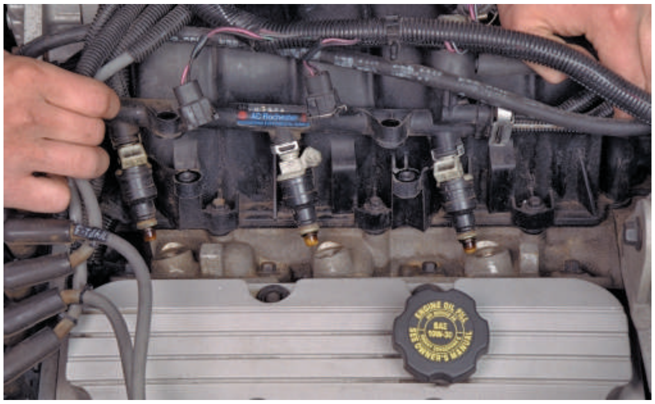


P30-6 Disconnect the wiring harness to the injectors by depressing the center of the attaching wire clip.

Removing and Replacing a Fuel Injector on a PFI System *(continued)*

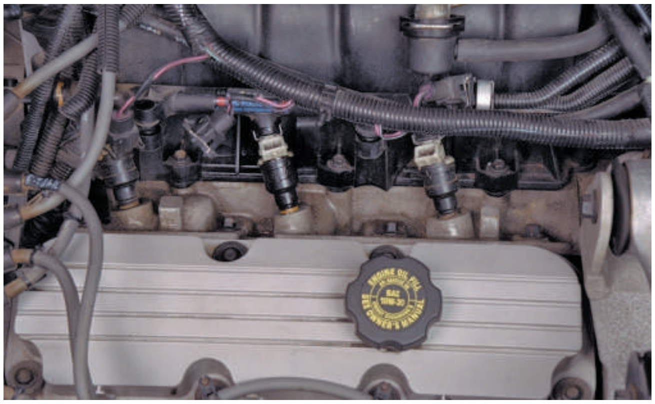


P30-7 The injectors are held to the fuel rail by a clip that fits over the top of the injector. O-rings at the top and at the bottom of the injector seal the injector.



P30-8 Pull up on the fuel rail assembly. The bottoms of the injectors will pull out of the manifold while the tops are secured to the rail by clips.

P30-9 Remove the clip from the top of the injector and remove the injector unit. Install new O-rings onto the new injector. Be careful not to damage the seals while installing them, and make sure they are in their proper locations.



P30-10 Install the injector into the fuel rail and set the rail assembly into place.

P30-11 Tighten the fuel rail holddown bolts according to manufacturer's specifications.

P30-12 Reconnect all parts that were disconnected. Install the fuel pump fuse and reconnect the battery. Turn the ignition switch to the run position and check the entire system for leaks. After a visual inspection has been completed, conduct a fuel pressure test on the system.

Prior to removing the injectors and pressure regulator, the fuel rail should be cleaned with a spray-type engine cleaner. Normally the approved cleaners are listed in the service information. After the rail is cleaned, the injectors can be pulled from the fuel rail. Use snapring pliers to remove the snapring from the pressure regulator cavity. Note the original direction of the vacuum fitting on the pressure regulator and pull the pressure regulator from the fuel rail. Clean all components with a clean shop towel. Be careful not to damage fuel rail openings and injector tips. Check all injector and pressure regulator openings in the fuel rail for metal burrs and damage.

Warning! Do not immerse the fuel rail, injectors, or pressure regulator in any type of cleaning solvent. This action may damage and contaminate these components.

When reassembling the fuel rail with the injectors and pressure regulator, make sure all O-rings are replaced and lightly coated with engine oil. Assemble the fuel rail in the reverse order as that used for disassembly. After the rail and injectors are in place and everything connected to them, reconnect the negative battery terminal and disconnect the 12-volt power supply from the cigarette lighter. Then start the engine and check for fuel leaks at the rail and be sure the engine operation is normal.

FIGURE 31–26 A GDI injector.

Special GDI Checks

The injectors in a GDI system **(Figure 31–26)** are best checked with an ohmmeter. Resistance checks can identify if the injector has an open or a short. If an injector does not have the specified resistance, it should be replaced. Of course, there are also designated DTCs that may lead you to suspect a problem with an injector. Those DTCs are related to particular injectors, unless the malfunction is something that affects many of them.

Because GDI operates under very high pressures, a typical fuel volume check on the high-pressure pump should not be done. However, fuel pressure and volume tests can be performed on the supply pump. The fuel pressure of the high-pressure pump is tested with a scan tool. If the pressure displayed on the scan tool is not within the specified range, first confirm the fuel pressure sensor is operating correctly. If the fuel pressure sensor is reading correctly, check the high-pressure pump. Some engines have experienced increased wear on the pump drive, which reduces fuel pressure. The fuel injector **(Figure 31–27)** and pump control can be checked with an ohmmeter **(Figure 31–28)**. Connect the meter across the terminals at the connector. Compare your readings to specifications. If the reading does not match specs, replace the injector or pump. The fuel pressure sensor can also be checked with a voltmeter. With the engine running and a fuel pressure gauge connected, backprobe the sensor's output signal and compare the pressure gauge reading and voltage to specifications.

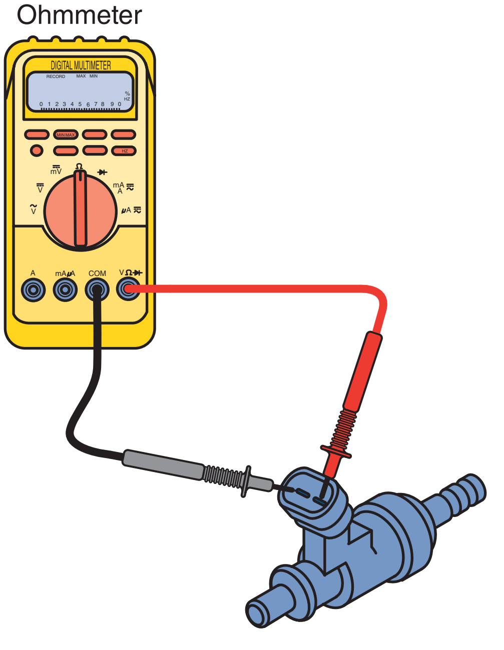


FIGURE 31–27 A GDI injector can be checked with an ohmmeter.

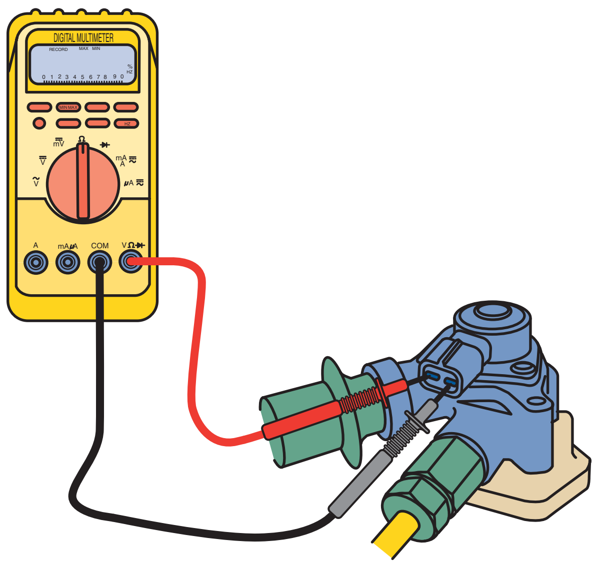


FIGURE 31–28 The control unit for the high-pressure fuel pump in a GDI system can be checked with an ohmmeter.

Electronic Throttle Controls

An electronic throttle control (ETC) system **(Figure 31–29)** normally includes a throttle actuator or motor, TP sensors, accelerator pedal position (APP) sensors, an electronic throttle control module, and a relay. The control module may be part of the PCM or may be a separate unit. The actuator responds to commands from the PCM **(Figure 31–30)**.

The ETC system relies on redundant inputs and processors. Two accelerator pedal position signals are sent to the PCM, each having a different voltage range. The PCM processes these signals along with other inputs to set the throttle plate at the required position. The throttle plate is controlled by a DC motor that is controlled by the PCM. The PCM has two driver circuits for the motor; one causes the plate to open and the other closes it. The exact position of the throttle plate is monitored by two TP sensors; the signal range of these also differs. It also has redundant monitors that track the system's effectiveness. When the PCM detects a fault, the monitor will set a DTC and/or put the system into a limp-home mode **(Figure 31–31)**.

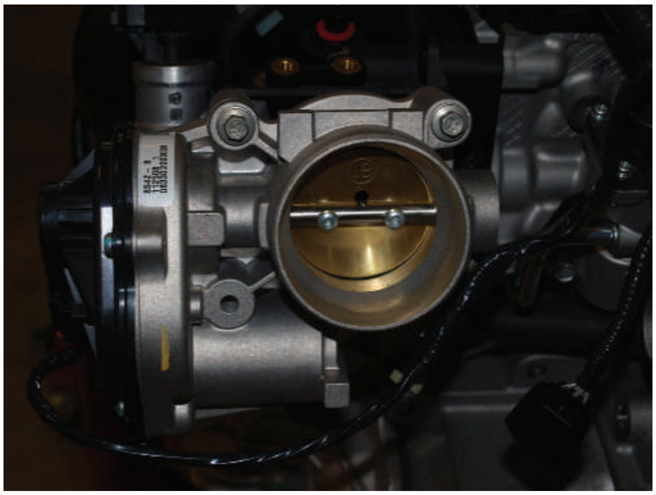


FIGURE 31–29 An electronically controlled throttle assembly.

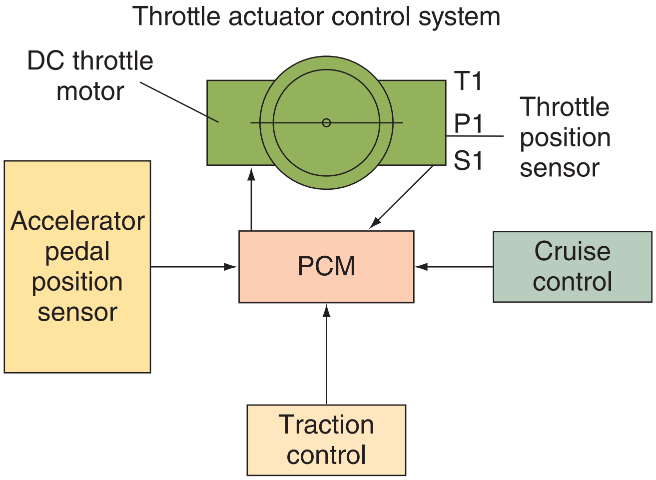


FIGURE 31–30 A simplistic look at an electronic throttle control system.

Diagnostic Monitors

The PCM monitors the voltage levels of the APP sensors, TP sensors, and the throttle motor circuit. It also monitors the return rate of the two return springs. The APP sensors are potentiometers mounted at the accelerator pedal. Depending on the vehicle, there can be two separate APP sensors or one sensor capable of sending two separate signals. One signal is used to define the position of the pedal. The signal varies between 0 and 5 volts according to the pedal's position. The other signal is used to monitor the sensor itself. The PCM compares the two signals and if there is a difference in the reported pedal position, the PCM determines that the sensor is bad and will illuminate the MIL and set a DTC.

The TP sensor (there may be two separate sensors or one capable of providing two separate signals) is mounted to the throttle body. This sensor sends a signal noting the position of the throttle. The PCM uses one of the signals as feedback. This is done by adding the TP voltage to the APP voltage. This sum must equal 5 volts. If the sum is greater or

DTC	Description	Probable Causes	MIL
P0120	Throttle / Pedal Position Sensor / Switch "A" Circuit Malfunction	1. TP sensor 2. ECM	ON
P0121	Throttle / Pedal Position Sensor / Switch "A" Circuit Range / Performance Problem	1. TP sensor	ON
P0122	Throttle / Pedal Position Sensor / Switch "A" Circuit Low Input	1. TP sensor 2. Short in APP circuit 3. Open in TP circuit 4. ECM	ON
P0123	Throttle / Pedal Position Sensor / Switch "A" Circuit High Input	1. TP sensor 2. Open in APP circuit 3. Open in ETC circuit 4. Short between TP and APP circuits 5. ECM	ON
P0220	Throttle / Pedal Position Sensor / Switch "B" Circuit	1. TP sensor 2. ECM	ON
P0222	Throttle / Pedal Position Sensor / Switch "B" Circuit Low Input	1. TP sensor 2. Short in APP circuit 3. Open in TP circuit 4. ECM	ON
P0223	Throttle / Pedal Position Sensor / Switch "B" Circuit High Input	1. TP sensor 2. Open in APP circuit 3. Open in ETC circuit 4. Short between TP and APP circuits 5. ECM	ON
P0505	Idle Control System Malfunction	1. ETC 2. Air induction system 3. PCV hose connection 4. ECM	ON
P050A	Cold Start Idle Air Control System Performance	1. Throttle body assembly 2. MAF sensor 3. Air induction system 4. PCV hose connections 5. VVT system 6. Air cleaner element 7. ECM	ON
P050B	Cold Start Ignition Timing Performance	1. Throttle body assembly 2. MAF sensor 3. Intake system 4. PCV hose connection 5. VVT system 6. Air filter element 7. ECM	ON

FIGURE 31–31 Some examples of generic DTCs related to the electronic throttle control system. *(continued)*

DTC	Description	Probable Causes	MIL
P060A	Internal Control Module Monitoring Processor Performance	ECM	ON
P060D	Internal Control Module Accelerator Pedal Position Performance	ECM	ON
P060E	Internal Control Module Throttle Position Performance	ECM	ON
P0657	Actuator Supply Voltage Circuit / Open	ECM	ON

FIGURE 31-31 *(continued)*

less than this, the PCM will illuminate the MIL and set a DTC.

The PCM also looks at the voltages to the control unit and the actuator assembly, in addition to the amount of current required to move the throttle plate. If it detects lower-than-normal voltage to the control unit or actuator, it will disable the throttle control system and set it into the limp-home mode. It will also illuminate the MIL and set the DTC. The PCM continuously monitors the current flow through the actuator. If the current is too high or low, the PCM recognizes this as a problem. The PCM also looks at the position of the throttle and the current flowing to it. If the position does not change when it is commanded to do so, the MIL will be illuminated and a DTC set.

Fail-Safe Mode When DTCs relating to the ETC system are set, the PCM will enter into a fail-safe or limp-home mode. During this time the actuator is no longer controlled by the PCM. However, the throttle plate is held slightly open by a spring. This limited throttle opening restricts the ability of the engine to provide power. If the accelerator pedal is depressed, the PCM will control engine output by controlling the fuel injection and ignition systems. This will allow the vehicle to be driven slowly.

Idle Speed

Although there is no adjustment for idle speed, idle speed checks can give an indication of the condition of the electronic throttle system. The best way to monitor idle speed is with a scan tool. Before checking the speed, make sure that the MIL is not illuminated and that there are no DTCs set. Also make sure that the ignition, air induction, and PCV systems are okay.

Set the parking brake and disconnect the connector to the evaporative emission (EVAP) canister purge valve. Connect the scan tool to the DLC and make sure there is communication between the tool and the vehicle. Start the engine and make sure all accessories are turned off. Increase the speed to about 3,000 rpm and hold it there until the cooling fan turns on. Allow the engine to idle; check the idle speed and compare it to specs. Then turn on some heavy load accessories, such as MAX air conditioning with the blower on high and the high-beam headlights. Check the idle speed. If the idle speed does not match specifications, conduct the idle learn procedure. If the speed is still wrong, further diagnostics of the system and fuel injection system are necessary. Once the idle speed matches the specifications, reconnect the EVAP canister purge valve.

Idle Learn All throttle positions reported to the PCM reflect a change from a base reading. It is extremely important that the PCM knows that base. Manufacturers have prescribed procedures for teaching the PCM this base. Those procedures must be followed exactly as stated. The learn or relearn procedure should be completed anytime the PCM has been replaced or updated, and after the throttle body has been cleaned or replaced. Often no-DTC idle speed problems are solved by completing the idle learn or relearn procedure. It is important to note that the system does not need to relearn if the battery has been disconnected. The system will automatically go through the procedure when the engine is restarted.

Idle learn is normally done by running the engine at idle for a prescribed time after it has reached normal operating temperature and the PCM has been reset by a scan tool. The idle learn process can be monitored and verified with a scan tool.

General Diagnostics

There are several DTCs assigned to problems with the ETC system. All of the major components have several DTCs assigned to them. There are also pinpoint tests for each component. Most of the components can be checked with a voltmeter, ohmmeter, or scope. The parts should be inspected prior to testing. This is especially true of the throttle body assembly.

It should be checked for any buildup of dirt on the plate and in the bores. If needed, clean the assembly. Also make sure that the plate moves freely in the bore.

Ohmmeter checks are made across specific terminals at the throttle body. On most units, the connection is made across the positive (M+) feed to the motor and the negative (M–) terminals. This setup measures the resistance of the windings in the actuator's motor. Some throttle bodies have the TP sensor built into the assembly. In these cases, the TP sensor is checked at different terminals in the same connector. Always refer to the service information to identify the test terminals and resistance specifications.

A voltmeter can be used to check the operation of the TP and APP sensors. This is done in the same way as when checking typical sensors, except that with ETC systems there are two output signals to monitor. The sensors can also be checked with a lab scope.

Idle Speed Checks

The idle speed of fuel-injected engines without an electronic throttle is regulated by controlling the amount of air that bypasses the airflow sensor or throttle plates. When one of these vehicles has an idling problem, check the linkage and vacuum lines before going any further with your diagnosis. Although idle speed is not typically adjustable, some engines do have provisions for setting the speed. Always refer to the decal in the engine compartment to identify the conditions that must be present before adjusting the speed. Also, refer to the service information before making any adjustments. The idle speed and quality for most engines are controlled by the PCM through the IAC.

IAC Checks

If the idle speed is not within specifications, the system should be looked at with a scan tool. Make sure there is proper communications between the scan tool and the vehicle. Also make sure that all CAN communications are good.

Many different inputs will affect the performance of the IAC as well as cause other driveability problems. Following are examples:

- With higher-than-normal TP signals at idle, the PCM interprets this as the throttle being opened and will close the IAC to decrease idle speed.
- If the resistance of the ECT is too high, a higher-than-normal voltage signal is sent to the PCM, which interprets this as a cold engine. The PCM will then open the IAC to increase speed.

SHOP TALK

On most vehicles, the scan tool will indicate the status of input switches as closed or open, or high or low. Most input switches provide a high-voltage signal to the PCM when they are open and a low-voltage signal if they are closed.

- If the resistance of the ECT is too low, a lower-than-normal voltage signal is sent to the PCM, which interprets this as a hot engine. The PCM will then open the IAC to increase speed.
- A stuck closed A/C switch will signal to the PCM that the A/C is always on and the PCM will always order an increased idle speed.
- If battery voltage is low, the PCM may command higher-than-normal idle speed to increase charging system output.

If the sensors and circuits seem to be fine, check the IAC. The IAC can be monitored with a scan tool. Most will have a test mode that allows for manual control of the IAC. To test the IAC motor, use the scan tool to command the IAC motor top open and close while watching engine speed. As the IAC opens, engine speed should increase and as the IAC closes engine speed should decrease. If the scan tool data shows the IAC commanded to move but the engine speed does not change, suspect a faulty IAC motor. Remember that the IAC counts PID is a command by the PCM. Just because the IAC is commanded does not mean the motor actually performed the command.

Some vehicles have an active IAC test mode. When the IAC is operated in its low range, the PCM will move the IAC in approximately 16 steps **(Figure 31–32)**. When operated in its high range,

FIGURE 31–32 When the IAC is operated in its low range, the PCM will move the IAC in approximately 16 steps.

FIGURE 31–33 When operated in its high range, the IAC should move approximately 112 steps or counts.

there should be approximately 112 steps or counts **(Figure 31–33)**. The normal range of counts is given in the appropriate service information.

Most technicians look for consistent idle counts on a warm engine to verify that the IAC is not sticking or malfunctioning. During the check, devices such as the A/C system can be operated and the scan tool watched. If the counts and idle speed change when the A/C is turned on and off, the IAC, connecting wires, and PCM are working fine. If the counts change but engine speed does not, or if the counts do not change, further diagnosis is required. Always follow the diagnostic procedures given by the manufacturer.

IAC problems on OBD II vehicles will set one or more DTCs. Although there are DTCs designated for the IAC system, keep in mind that the operation of the entire engine performance system can affect idle speed and quality. Therefore, all DTCs could be the cause of an idle problem.

It is important to note that the PCM cannot effectively control idle if it does not know when the throttle is closed. This is also important for all other engine speeds. The PCM sets the closed throttle reference according to the lowest TP voltage signal since the engine was started. The PCM does this each time the engine is started. This reference voltage is called the TPREL PID on most systems. When looking at this PID with the throttle closed, the value should be C/T (closed throttle). If any other value is noted, the engine will have a higher-than-normal idle speed. Abnormal readings are typically caused by a bad TP sensor, loose or worn throttle plates, or excessive noise in the TP or related circuits.

Most late-model vehicles have a feature that adjusts the calibration of the IAC according to the wear of system components; this is called idle air trim. The system constantly monitors the engine and its systems and determines the ideal idle speed. The idle speed is based on look-up tables. If the corrections exceed predetermined levels, the PCM will set a DTC. Once the problem is solved and corrected, the system must relearn its base idle trim values. This process is completed with a scan tool and should be done whenever a part of the IAC system is replaced or a repair is made to something that affects idle speed.

SHOP TALK

If the IAC motor counts are below 12 on the scan tool, look for a vacuum leak. The PCM will run the valve all the way down to compensate for the leak. If no leak is found, then check the circuit between the PCM and the motor. The circuit is likely open between the PCM and the motor. Wiggle the wires on the motor. Wiggle the wires on the IAC motor and observe the reading on the scan tool. If the count reading changes while wiggling the wires, you have found the problem.

Servicing the IAC Motor

On some vehicles, there is a provision to manually move the IAC plunger through the scan tool. When this test mode is selected, the PCM is ordered to extend and retract the IAC motor plunger every 2.8 seconds. When this plunger extends and retracts properly, the motor, connecting wires, and PCM are in normal condition. If the plunger does not extend and retract, further diagnosis is necessary to locate the cause of the problem. On other vehicles, this same test can be conducted with a jumper wire connecting two terminals of the DLC together.

Carbon deposits in the IAC motor air passage in the throttle body or on the IAC motor's pintle can cause erratic idling and engine stalling. Remove the motor from the throttle body, and inspect the throttle body air passage for carbon deposits. If there are heavy carbon deposits, remove the complete throttle body for cleaning. Clean the IAC air passage, motor sealing surface, pintle valve, and pintle seat with throttle body cleaner.

Warning! Be careful while cleaning the assembly; the IAC motor can be damaged if throttle body cleaner is allowed to get inside the motor.

The motor can be checked with an ohmmeter. If the ohmmeter readings are not within specifications, replace the motor. If a new IAC motor is installed, make sure that the part number, pintle shape, and diameter are the same as those on the original motor. Measure the distance from the end of the pintle to the shoulder of the motor casting **(Figure 31–34)**. Move the pintle until it is at the specified distance. If the pintle is extended too far, the motor can be damaged during installation.

Install a new gasket or O-ring on the motor. If the motor is sealed with an O-ring, lubricate the ring with transmission fluid. If the motor is threaded into the throttle body, tighten the motor to the specified torque. When the motor is bolted to the throttle body, tighten the mounting bolts to the specified torque.

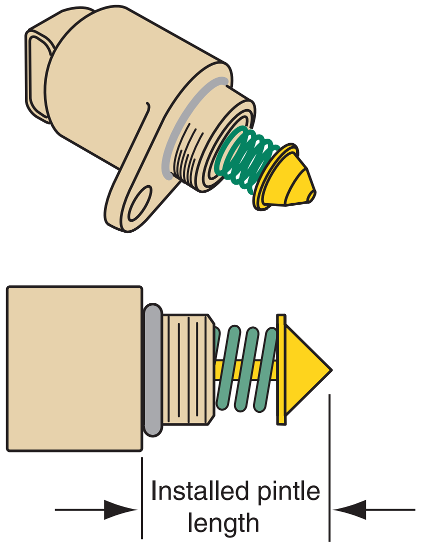


FIGURE 31–34 Measure the distance the pintle of an IAC motor is extended before installing the motor.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2007	**Make:** Nissan	**Model:** Frontier	**Mileage:** 128,145	**RO:** 19077
Concern:	Customer states MIL on, engine runs rough, hesitates, shakes.			
The technician confirms the engine runs poorly. Checking for codes reveals a P0171– bank 1 lean. Scan data shows fuel trim number at +18 percent for bank 1 but normal for bank 2. Bank 1 HO_2S voltages indicate a lean exhaust and bank 2 cycle rich and lean. He checks fuel pressure and finds it is at the specified pressure. Since it seems only one-half of the engine is affected, he believes the problem to be either an ignition or fuel problem on bank 1. Performing an injector balance test, he finds there is no rpm drop when injector number 1 is disabled. Testing determines the ignition coil and spark plug are good and spark is being delivered to the cylinder. The technician then performs an injector flow test, measuring the fuel pressure drop when activating the injector. This test reveals no drop in fuel pressure with the injector activated.				
Cause:	Found number 1 fuel injector faulty, no fuel flow through injector.			
Correction:	Replaced fuel injector and confirmed no DTCs, fuel trims +/– 3 percent. Engine operating normally.			

KEY TERMS

Peak and hold injector
Pulse-modulated injector

SUMMARY

- Always relieve the fuel pressure before disconnecting any component in the fuel system.
- Always turn off the ignition switch before connecting or disconnecting any system component or test equipment.
- An O_2 sensor can be checked with a voltmeter connected between the sensor wire and ground. The sensor's voltage should be cycling from low voltage to high voltage.
- The signal from most O_2 sensors varies between 0 and 1 volt. If the voltage is continually high, the air-fuel ratio may be rich or the sensor may be contaminated.
- When the O_2 sensor voltage is continually low, the air-fuel ratio may be lean, the sensor may be defective, or the wire between the sensor and the computer may have high resistance.
- If the O_2 sensor voltage signal remains in a mid-range position, the computer may be in open loop or the sensor may be defective.
- A/F ratio sensors respond to oxygen in the opposite way as O_2 sensors.
- The activity of the sensor can be monitored on a scan tool or lab scope.

- An injector that does not open causes hard starts on port-type systems and an obvious no-start on single-point TBI designs.
- An injector that is stuck partially open causes a loss of fuel pressure and flooding due to raw fuel dribbling into the engine.
- Buildups of gum and other deposits on the tip of an injector can reduce the amount of fuel sprayed by the injector and can prevent it from totally sealing, allowing it to leak.
- A rich mixture can be caused by a leaking fuel pressure regulator. If the regulator's diaphragm is ruptured, fuel will flow into the intake manifold, causing a rich mixture.
- When an injector is suspected as the cause of a lean problem, determine if the injector is receiving a signal to fire. Check for voltage at the injector using a high-impedance testlight or noid light.
- An ohmmeter can be used to test an injector.
- An injector pressure balance test will help isolate a clogged injector.
- An oscilloscope can be used to monitor the injector's pulse width and duty cycle.
- For all types of injectors, the waveform on a scope should have a clean, sudden drop in voltage when it is turned on.
- Never soak an injector in cleaning solvent or use a wire brush, pipe cleaner, toothpick, or other cleaning utensil to unblock a plugged injector.
- In a fuel injection system, idle speed is regulated by controlling the amount of air that is allowed to bypass the airflow sensor or throttle plates. When a car tends to stall or idles too fast, look for obvious problems like binding linkage and vacuum leaks first. Then check the minimum idle checking/setting procedure described on the underhood decal.

REVIEW QUESTIONS

Short Answer

1. List four service precautions for working on the fuel injection system.
2. What is indicated by a LTFT reading of 24 percent?
3. Describe how testing GDI fuel systems differs from non-GDI systems.
4. What is the difference between the pulse width and the duty cycle of an injector?
5. How can you use a dual trace scope to make sure that the injectors are firing at the correct time?
6. What are three possible problems that can allow fuel pressure to rapidly bleed down once the engine is shut off?
7. What is the purpose of having two accelerator pedal signals in an electronic throttle control system?
8. What is indicated by a negative LTFT value?
9. What problem may result from dirt buildup on an engine's throttle plates?
10. What is the difference between STFT and LTFT?

True or False

1. *True or False?* The signals from an air-fuel ratio sensor are identical to those from a conventional oxygen sensor.
2. *True or False?* Oxygen sensor condition can be checked using an ohmmeter.

Multiple Choice

1. Which of the following is the most likely cause of a lean condition during acceleration and cruising speeds?
   a. A defective oxygen sensor
   b. A defective PCM
   c. A defective ECT sensor
   d. A defective MAF sensor
2. The PCM checks for a closed throttle plate each time the engine starts. This becomes the base for all throttle settings and can be viewed by looking at the PID with the throttle closed. Which of the following would not cause an abnormal reading and a higher-than-normal idle speed?
   a. A bad TP sensor
   b. A bad IAC valve
   c. Loose or worn throttle plates
   d. Excessive noise in the TP or related circuits
3. Which of the following would *not* cause a hard-to-start problem on a PFI engine?
   a. A defective IAC valve
   b. A defective oxygen sensor
   c. A leaking fuel pressure regulator
   d. Dirty injectors

ASE-STYLE REVIEW QUESTIONS

1. While discussing the causes of higher-than-specified fuel pressure: Technician A says that a leaking fuel pressure regulator on a PFI system may cause high fuel pressure. Technician B says that if the fuel return line is restricted, fuel pressure may be higher than normal. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

2. While discussing IAC valve diagnosis: Technician A says that on some vehicles, a jumper wire may be connected to specific DLC terminals to check the IAC valve operation. Technician B says that if the scan tester indicates zero IAC valve counts, there may be an open circuit between the PCM and the IAC valve. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. While discussing IAC motor removal, service, and replacement: Technician A says that throttle body cleaner may be used to clean the IAC motor internal components. Technician B says that on some vehicles, IAC motor damage occurs if the pintle is extended more than specified during installation. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. While discussing injector testing: Technician A says that a defective injector may cause cylinder misfiring at idle speed. Technician B says that restricted injector tips may result in acceleration stumbles. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. While discussing airflow sensors: Technician A says that with mass airflow and volume airflow sensor systems, if any air bypasses the sensors, the engine will run lean. Technician B says that vacuum leaks in a speed density system will decrease injector pulse width. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. While discussing scan tool diagnosis of fuel injection systems: Technician A says that the scan tool may allow for control over some systems and components on many systems. Technician B says that many scan tools will store sensor readings during a road test and then play back the results in a snapshot test mode. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. While discussing a high idle speed problem: Technician A says that higher-than-normal idle speed may be caused by low electrical system voltage. Technician B says that higher-than-normal idle speed may be caused by a defective coolant temperature sensor. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. While discussing the causes of a rich air-fuel ratio: Technician A says that a rich air-fuel ratio may be caused by a faulty fuel rail pressure sensor. Technician B says that a rich air-fuel ratio may be caused by a defective coolant temperature sensor. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. While diagnosing an idle speed problem: Technician A says that higher-than-normal TP signals at idle will cause the IAC to close, which will decrease idle speed. Technician B says that if the resistance of the ECT is too low, a lower-than-normal voltage signal is sent to the PCM, which interprets this as a hot engine and will close the IAC to decrease speed. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While looking at fuel trim values: Technician A says that restricted or dirty injectors may be evident by a negative LTFT. Technician B says that a faulty fuel pressure regulator may result in a negative LTFT. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER 32

INTAKE AND EXHAUST SYSTEMS

OBJECTIVES

- Explain the operation of the components in the air induction system, including ductwork, air cleaner/filters, and intake manifolds.
- Inspect and troubleshoot vacuum and air induction systems.
- Explain the purpose and operation of a turbocharger.
- Inspect a turbocharger and describe some common turbocharger problems.
- Explain supercharger operation and identify common supercharger problems.
- Explain the operation of exhaust system components, including the exhaust manifold, gaskets, exhaust pipe and seal, catalytic converter, muffler, resonator, tailpipe, clamps, brackets, and hangers.
- Properly perform an exhaust system inspection, and service and replace exhaust system components.

An internal combustion engine needs air for combustion. It also needs to allow spent gases to leave the cylinder after combustion. The focus of this chapter is on the intake and exhaust systems. Both of these are often overlooked but are very important.

The reason air enters a cylinder is simply a basic law of physics—high pressure always moves toward an area of low pressure. Therefore, outside air moves into the cylinders because of the vacuum formed on the intake stroke.

Vacuum Systems

The vacuum in the intake manifold not only draws air into the cylinders; it also is used to operate or control many systems, such as emission controls, power brake boosters, parking brake releases, ventilation system components, and cruise control on older vehicles **(Figure 32–1)**. Vacuum is applied to these systems through a network of hoses, tubes, and control valves.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2011	**Make:** Ford	**Model:** F-150	**Mileage:** 78,852	**RO:** 19127
Concern:	Customer states MIL on, engine lacks power.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

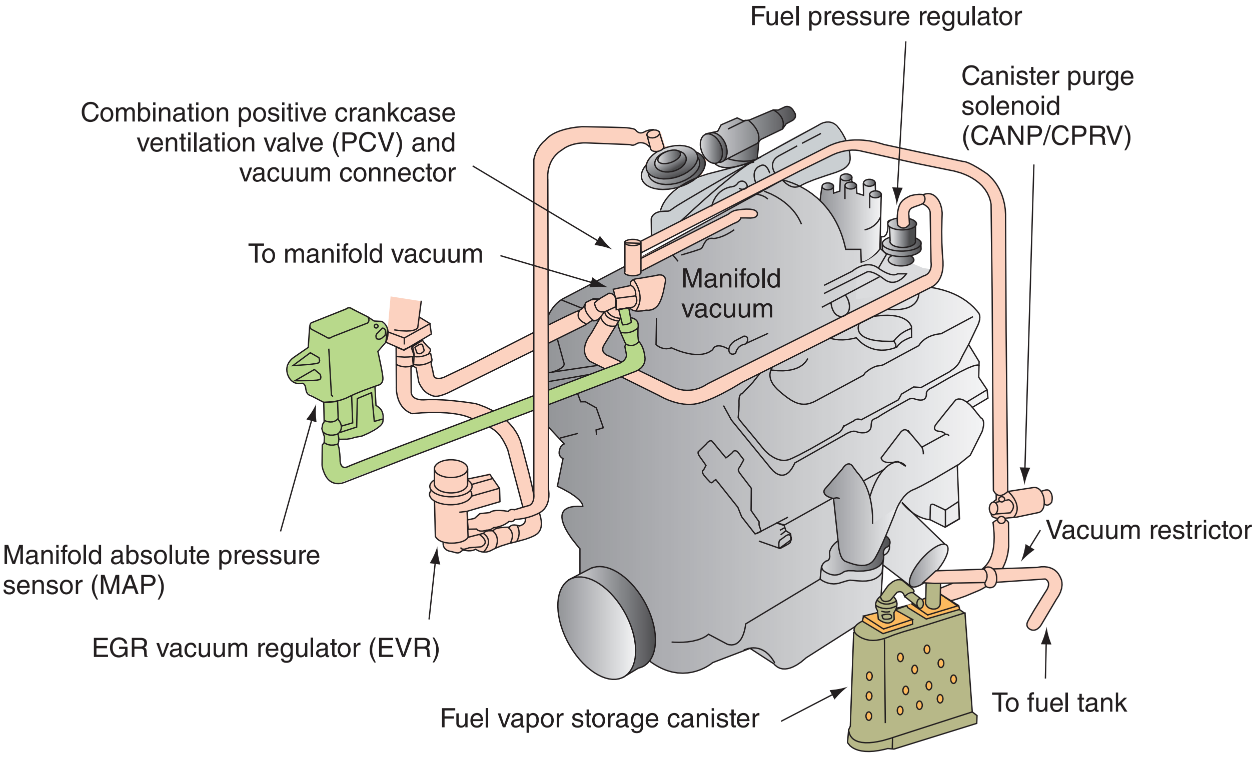


FIGURE 32-1 Typical vacuum devices and controls.

Vacuum Basics

The term *vacuum* refers to any pressure that is lower than the earth's atmospheric pressure at any given altitude. The higher the altitude, the lower the atmospheric pressure.

GO TO Chapter 3 for a detailed explanation of atmospheric pressure and vacuum.

Vacuum is measured in relation to atmospheric pressure. At sea level, atmospheric pressure is 14.7 psi and will appear as zero on most pressure gauges. This does not mean that there is no pressure; rather, it means the gauge is designed to read pressures greater than atmospheric pressure. Measurements taken on this type of gauge are given in pounds per square inch and should be referred to as psig (pounds per square inch gauge). Some gauges read in bar, kP, or inches of mercury. Gauges and other measuring devices that include atmospheric pressure in their readings also display their measurements in psi. However, the measurements on these gauges should be referred to as psia (pounds per square inch absolute). There is a big difference between 12 psia and 12 psig—12 psia is less than atmospheric pressure and therefore would represent a vacuum, whereas 12 psig would be approximately 26.7 psia. Vacuum, therefore, is any pressure less than 0 psig or 14.7 psia **(Figure 32–2)**. Normally a measure of vacuum is given in inches of mercury (in. Hg). Vacuum may also be expressed in units of kilopascals and bar. Normal atmospheric pressure at sea level is about 1 bar or 100 kilopascals.

Engine vacuum is created by the downward movement of the piston during the intake stroke. With the intake valve open and the piston moving downward, a partial vacuum is created within the cylinder and intake manifold. The air passing the

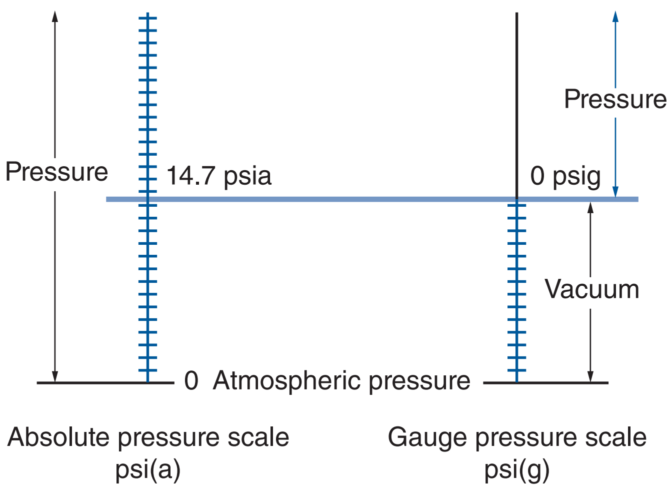


FIGURE 32-2 A comparison of psia and psig.

intake valve does not move fast enough to fill the cylinder, thereby causing the lower pressure. This partial vacuum is continuous in a multicylinder engine, because at least one cylinder is always at some stage of its intake stroke.

Diagnosis and Troubleshooting

Vacuum problems can produce or contribute to the following driveability symptoms:

- Stalling
- Poor starting
- Backfiring
- Rough idle
- Poor acceleration
- Rich or lean stumble
- Overheating
- Detonation, or knock or pinging
- Rotten eggs exhaust odor
- Poor fuel economy

Whenever there is a driveability problem, do the following:

- Inspect vacuum hoses for improper routing or disconnections.
- Look for cut or disconnected hoses that will allow more air into the intake manifold than the engine is calibrated for.
- Look for kinks in the lines and hoses that can cut off vacuum to a component, thereby disabling it.
- Check for vacuum hose routing and wear near hot spots, such as the exhaust manifold or EGR tubes.
- Make sure there is no evidence of gasoline, oil, or transmission fluid in vacuum hose connections. (Valves can become contaminated by oil getting inside.)
- Inspect vacuum system devices for damage (dents in cans; by-pass valves; broken nipples on valves; broken "tees" in vacuum lines, and so on).

Any defective hoses should be replaced one at a time to avoid misrouting. OEM vacuum lines may be installed in a harness consisting of $^{1}/_{8}$-inch or larger outer diameter and $^{1}/_{16}$-inch inner diameter nylon hose with bonded nylon or rubber connectors. Occasionally, a rubber hose might be connected to the harness. The nylon connectors have rubber inserts to provide a seal between the nylon connector and the connection (nipple). In recent years, many manufacturers have been using ganged steel vacuum lines.

SHOP TALK

A smoke machine can be used for locating vacuum, induction, and exhaust leaks.

Vacuum Test Equipment

GO TO Chapter 9 for details on conducting an engine vacuum test and interpreting the results.

With a vacuum gauge connected to the intake manifold and the engine warm and idling, watch the action of the gauge's needle. A healthy engine will give a steady, constant vacuum reading between 17 and 22 in. Hg. Some four- and six-cylinder engines, however, may have a normal reading of 15 in. Hg, and many high-performance engines will have an unsteady but consistent reading.

An emissions vacuum schematic is given on an underhood decal. This shows the vacuum hose routings and vacuum source for all emissions-related equipment. The vacuum schematic in **Figure 32–3** shows the relationship and position of components as they are mounted on the engine. It is important to remember that these schematics only show the vacuum-controlled parts of the emission system. The location and hose routing for other vacuum devices can be found in the service information.

Many technicians use smoke machines to locate vacuum leaks. Smoke machines inject smoke into the vacuum system or into the engine. If there are no leaks, smoke will not escape from the engine. However, if a vacuum leak is present, the smoke will show the location of the leak.

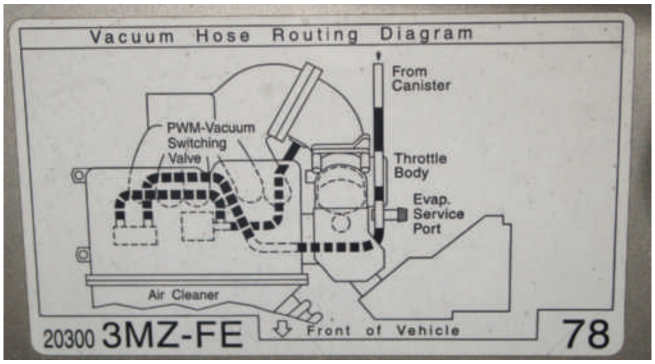


FIGURE 32-3 An underhood vacuum hose routing diagram.

Air Induction System

The air induction system directs outside air to the engine's cylinders. The induction system is comprised of ductwork that channels outside air to an air cleaner that removes dirt from the air, ductwork that connects the filter to the throttle body, and an intake manifold that distributes the air to the engine's cylinders **(Figure 32–4)**. Within the induction system are sensors that measure intake air temperature and airflow.

An inspection of the air induction system should be part of diagnosing a driveability problem. Make sure that the intake ductwork is properly installed and that all connections are airtight—especially those between an airflow sensor or remote air cleaner and the throttle body.

Air Cleaner/Filter

The primary purpose of the air filter is to prevent airborne contaminants and abrasives from entering the cylinders. These contaminants can cause serious damage and appreciably shorten engine life. Therefore, all intake air should pass through the filter before entering the engine.

The air filter is inside a sealed air cleaner assembly. This assembly is also used to direct the airflow and reduce the noise caused by the movement of intake air **(Figure 32–5)**. The air cleaner also provides filtered air to the PCV system and provides engine compartment fire protection in the event of backfire.

If the air filter becomes very dirty, the dirt can block the flow of air into the engine. Restricted airflow to the engine can cause poor fuel economy, poor performance, and high emissions.

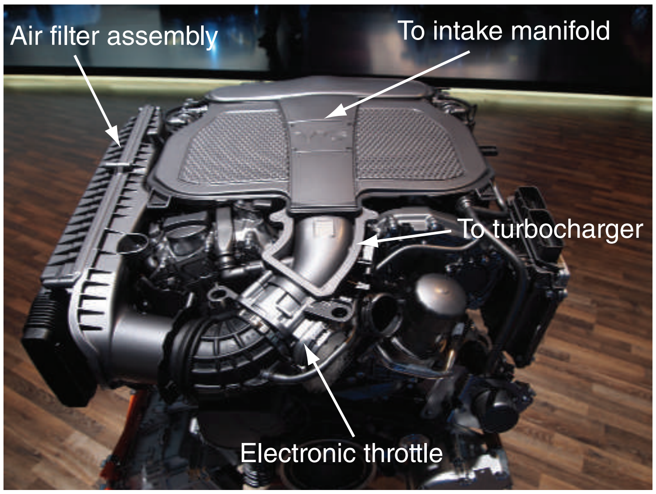


FIGURE 32–4 The air induction system for a late-model turbocharged engine.

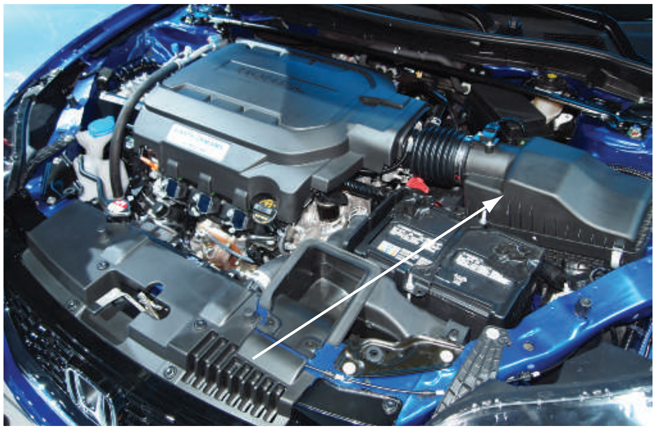


FIGURE 32–5 An example of an air cleaner used on current engines.

GO TO Chapter 8 for information on servicing and replacing an air filter.

Induction Hoses

To route air into the engine, a network of induction hoses and pipes are used. Air enters through the fresh air inlet and passes through induction hoses and pipes. Induction hoses are typically flexible rubber hoses to allow for movement between the engine and other induction components. Some vehicles use rigid plastic pipes to move air that may also have a Helmholtz chamber or resonator. A Helmholtz resonator looks like an additional chamber sticking out of a section of induction pipe. The purpose of the chamber is to reduce noises generated by air moving through the induction system and intake manifold.

Some vehicles use sound enhancing systems that route hoses from the induction system to the passenger compartment. These systems provide additional engine noise to offset the added sound proofing used in modern cars **(Figure 32–6)**.

FIGURE 32–6 Sound-enhancing tubes on a Camaro.

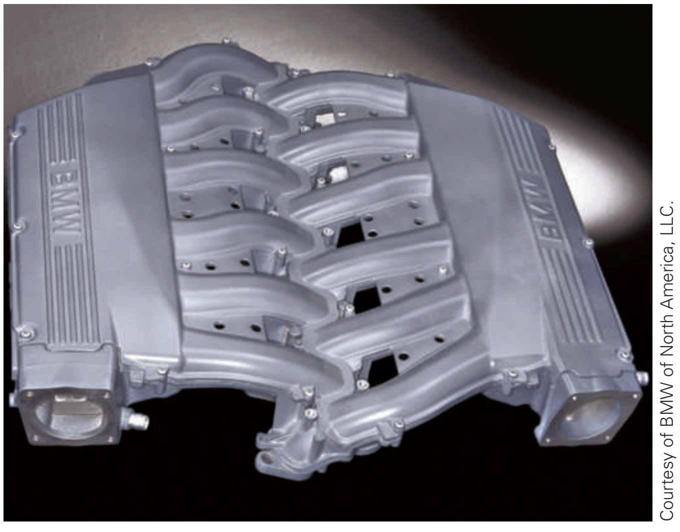
Intake Manifolds

An intake manifold distributes the clean air or air-fuel ratio as evenly as possible to each cylinder of the engine.

Older engines had cast-iron intake manifolds. The manifold delivered air and fuel to the cylinders and had short runners. These manifolds were either wet or dry. Wet manifolds had coolant passages cast directly in them. Dry manifolds did not have coolant passages but had exhaust passages through the manifold to heat the floor of the manifold. This helped to vaporize the fuel before it arrived in the cylinders. Other dry manifold designs used some sort of electric heater unit or grid to warm the bottom of the manifold. Heating the floor of the manifold stopped fuel from condensing in the plenum area. Good fuel vaporization and the prevention of condensation allowed for delivery of a more uniform air-fuel mixture to the individual cylinders.

Intake manifolds also serve as the mounting point for many intake-related accessories (such as the fuel injectors, fuel rail, and throttle body) and sensors **(Figure 32–7)**. Some include a provision for mounting the thermostat and thermostat housing. In addition, connections to the intake manifold provide a vacuum source for the exhaust gas recirculation (EGR) system, power brakes, and/or heater and air-conditioning airflow control doors.

Intake manifolds for today's engines are typically made of die-cast aluminum **(Figure 32–8)** or plastic **(Figure 32–9)**. These materials are used to reduce weight. Because these intake manifolds only deliver air to the cylinders, fuel vaporization and condensation are not of any concern. The primary goal of their design is the capability to deliver equal amounts of air to each cylinder.



Courtesy of BMW of North America, LLC.

FIGURE 32–8 A die-cast aluminum intake manifold.

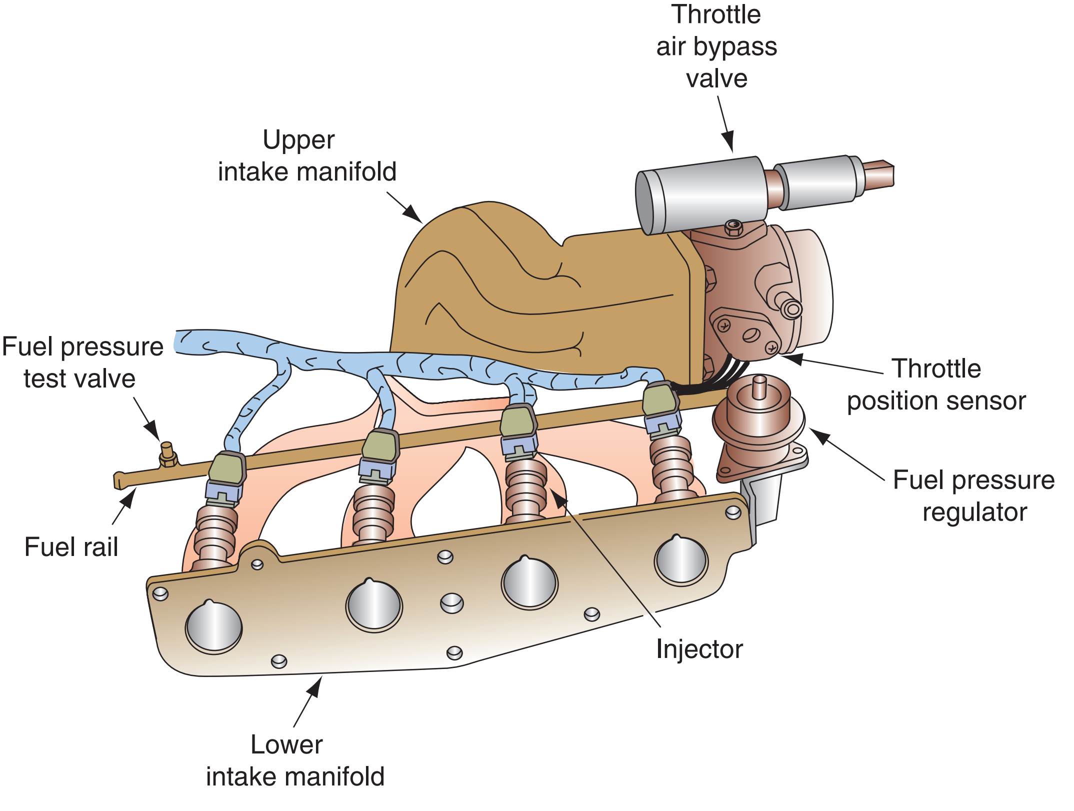


FIGURE 32–7 A late-model intake manifold for a four-cylinder engine.

Courtesy of BMW of North America, LLC.

FIGURE 32–9 A plastic intake manifold for an inline five-cylinder engine.

FIGURE 32–10 A throttle body assembly.

Attached to the inlet of the intake manifold is the throttle body. The throttle body **(Figure 32–10)** controls the amount of air entering the engine. Inside of the throttle body is the throttle plate. At idle the throttle plate is closed or very nearly closed and little air enters the engine. At wide-open throttle (WOT) the throttle plate is horizontal to allow maximum airflow into the engine. On older vehicles, the throttle plate is controlled by the throttle cable, which is attached to the accelerator or gas pedal. Modern vehicles use electronic throttle control (ETC) systems.

Design Variations

Basic manifold design varies with the different types of engine. For example, the intake manifold for a four-cylinder engine has either four runners or two runners that break into four near the cylinder head. Inline six-cylinder engines have six runners or three that branch off into six near the cylinder head. On V-type engines, there are individual runners for each cylinder.

An intake manifold has two basic components: a plenum area and runners. As air first enters the intake manifold, it moves into the plenum. The air then moves from the plenum through the runners to the cylinders. The size and shape of the plenum and runners are designed for a specific engine and application.

The plenum serves as a reservoir for the air and is used to distribute the intake charge evenly and to enhance engine breathing. The shape of the runners is different for PFI and GDI engines than other engines. An intake manifold that delivers both air and fuel is designed to cause turbulence so that the air and fuel mix while they are being delivered to the cylinders. When the intake manifold only delivers air, there is no need for turbulence and the runners provide a smooth direct flow of the air. Air-only runners have smooth finishes and a minimum number of bends. The length of the runners is designed to achieve the best performance during a particular range of engine speeds.

An engine is most volumetrically efficient when a maximum amount of air enters the cylinders. Peak engine torque occurs when the engine is most efficient. Generally, an engine designed for maximum torque and horsepower at high speeds has shorter runners than one that provides high torque at lower speeds. The length of the runners changes when the engine develops its peak torque.

One of the things that most do not think about is the behavior of air when it enters a runner. A simple thought is the air arrives and stays there until the intake valve opens. It then flows past the valve into the cylinder. Actually, the air is moving at a pretty good speed when it is pulled into the cylinder and must come to a halt when the valve closes. The air does not sit there until the valve opens again; rather, it bounces off the closed valve and heads toward the plenum area. When the air reaches the plenum, it meets a rush of incoming air and bounces back toward the intake valve. The air, however, bounces back quicker than it did when it left the intake valve. This is due to a push given by the intake air.

A runner is designed to take this bouncing air and send it back to the intake valve in time for the next opening. This timing determines the length of the runner and results in a stronger intake charge

because the air is under pressure. In most manifolds, this air wave bounces several times before the intake valve opens again. The bouncing effect and resultant pressure of the air is called acoustic supercharging.

The inside diameter of the runners also affects the delivery of air. When a small diameter runner is used, the air will move into the cylinders faster. This increases volumetric efficiency at low engine speeds. When the engine is running at higher speeds, it needs a lot of air. Small diameter runners would restrict the airflow and hurt the engine's efficiency. Therefore, larger diameter runners are needed at high engine speeds.

Variable Intake Manifolds

Many engines have variable intake manifolds, which are controlled by the PCM. These manifolds change the size of the plenum area and/or change the length and effective diameter of the runners according to engine speed and load. The use of these manifolds allows the engine to experience high volumetric efficiency with more than one range of engine speeds.

The operation and design of these manifolds vary with manufacturer and engine. Systems that alter the plenum area have two small plenums. Depending on the system, only one of the plenums is used during low speeds. In other systems, the plenums are divided and are used for specific cylinders. In both cases, when the engine reaches a particular speed, the plenums are opened and work together to create a larger plenum area. These systems are commonly referred to as intake manifold tuning (IMT) systems.

IMT systems have a motor connected to a butterfly valve in the center of the manifold **(Figure 32–11)**. The valve is closed during low speeds, keeping the two plenum areas separated. When commanded by the PCM, the valve opens and allows the two plenums to become one large plenum. The PCM receives feedback on the position of the valve through a position sensor on the motor.

Warning! The butterfly valve is moved with great force. Always keep your fingers away from the valve when the system is energized. Failure to do this may result in a serious injury.

The most common variable intake manifold designs change the path of air between long and short runners or between small-diameter and large-diameter runners according to engine speed. These systems are typically called intake manifold

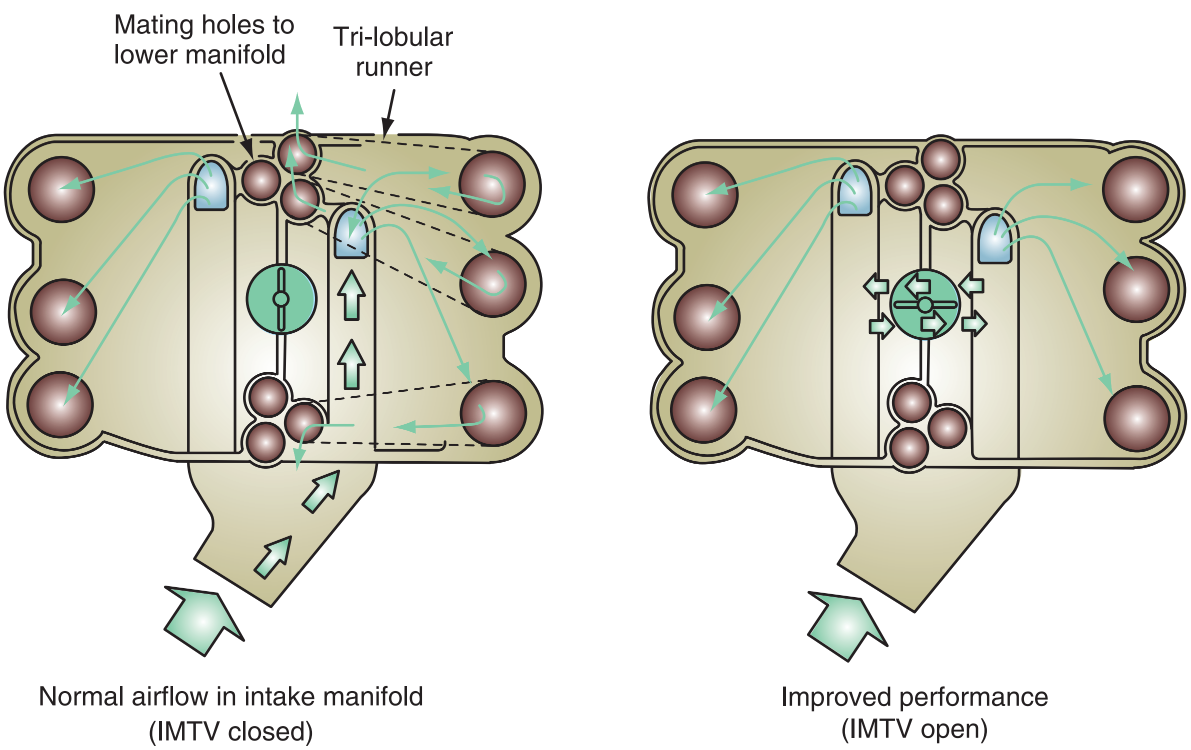


FIGURE 32–11 The action of an intake manifold tuning control valve (IMTV).

runner control (IMRC) systems. Intake air passes through long- or small-diameter runners at low speeds and is routed through short- or large-diameter runners at high speeds. The switching of runners is mostly done by controlling a butterfly valve that opens and closes the short- or large-diameter runners. Ultimately, the overall volume of air is controlled by the throttle plate; the butterfly valve in the manifold merely controls the routing of the air.

Changing the runners for different speeds allows for the benefits of acoustic supercharging as well as providing increased airflow at high speeds. It is important to realize that too much airflow at low speeds can actually hurt engine performance because the engine does not need it and the resultant air waves are hard to time to intake valve opening. All IMRC systems must have a feedback system, according to OBD II standards. If the IMRC system is not working correctly, a DTC is set.

The butterfly valve in IMRC systems is vacuum or electrically controlled. In vacuum systems, a vacuum actuator is mounted on the manifold **(Figure 32–12)**. Vacuum to the actuator is controlled by a PCM-regulated solenoid. Linkage connects the actuator to the butterfly valve. The PCM relies mainly on inputs from the TP, ECT, and CKP sensors to determine when to open or close the butterfly valve. At low speeds, the solenoid is energized. This allows manifold vacuum to hold the valve closed. Once engine speed and other conditions are met, the solenoid is turned off and springs on the butterfly valve force the valve open.

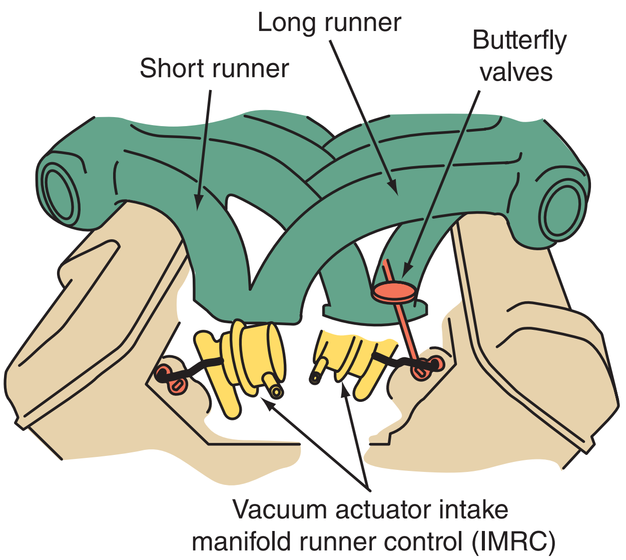


FIGURE 32–12 The vacuum controls and butterflies used to switch between the long and short intake runners.

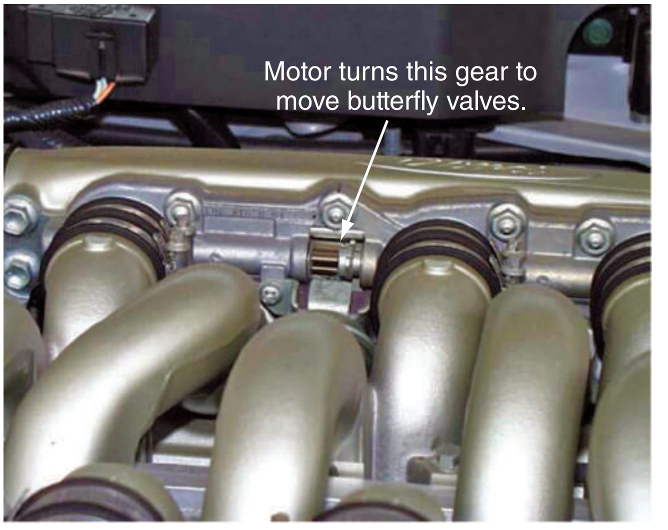


FIGURE 32–13 An electric motor meshes with this gear to rotate the shaft for the butterfly valves in this variable intake manifold.

In electrical systems, a motor is used to move the butterfly valve. There can be one valve per cylinder or one valve per bank of runners **(Figure 32–13)**. The valve can be normally open and remain open, or it is closed by the solenoid when the valve for the other runner is opened. Often there is a butterfly valve common to the high-speed runners. This valve is located in the plenum area and switches the routing of the air inside the plenum. The action of the motor is controlled by the PCM and can be duty cycled to be able to respond to current engine speeds.

Water Injection Systems

To extract even more power and efficiency from an engine, the twin-turbocharged six-cylinder engine that powers the BMW M4 GTS is fitted with a water injection system that sprays a cooling mist into the intake air. This reduces the temperature in the cylinder, which improves combustion and allows the engine to run at higher boost levels by reducing knocking and heat-related stresses. A water injection ECM monitors and controls systems operation.

Once injected into the cylinders, the water quickly evaporates, lowering the temperature of incoming air. The system lowers the air temperature more than an intercooler can (by as much as 80 °F or 26.7 °C). Therefore, the turbos can provide higher boost levels without causing engine knocking. Water injection decreases cylinder temperature and allows advanced ignition timing and higher compression ratios. BMW claims a 5 percent power increase and up to a 13 percent increase in fuel economy.

In this engine, three injectors are installed in the intake plenum of the inline-six-cylinder motor, each supplying two cylinders with fine droplets of water. The injectors are placed in the intake runner just ahead of the intake valve and shoot a very fine mist of water into the intake air stream during high load engine operation. The injectors are fed water from a dedicated water pump, similar to an electric fuel pump.

The source of distilled water is a 5.0 liter (1.3 gallon) tank installed in the rear of the car. If the tank runs out of water, the control module will reduce maximum engine power until the tank is refilled.

Servicing an Intake Manifold

There are few reasons why an intake manifold would need to be replaced or repaired. If the manifold is cracked or the sealing surfaces are severely damaged, it should be replaced. When the manifold is removed or there is evidence of a leak between the manifold and the cylinder head, the sealing surfaces should be checked for flatness. This check should include coolant and oil passages. Minor imperfections on the surface can be filed smooth; however, never try to repair any serious damage.

A leaking manifold gasket is one of the most common causes of internal coolant leaks. A bad gasket can also cause vacuum leaks. When installing an intake manifold, use new gaskets and seals. Also, make sure you are installing the most recent gasket designs. Make sure that the manifold and gasket are aligned properly. On V-type engines, the use of guide bolts helps to ensure proper alignment. Make sure that all of the attaching bolts are tightened to specifications and in the correct order.

Many engines have two-piece intake manifolds, an upper and a lower manifold. To replace spark plugs or perform valve lash adjustments on many V-6 engines, the upper intake must be removed. The two parts are sealed together with gaskets and seals. These should be replaced when the manifold is separated, and bolts should be tightened to specifications.

Forced Induction Systems

Engines cannot produce the amount of power they are capable of at high speeds because they do not receive enough air. This is the reason why many "race cars" have hood scoops. Hood scoops deliver cool air under pressure to the intake manifold and provide an open source for the air. With today's body styles, hood scoops are not particularly desired because they increase air drag. Therefore, other methods are used to increase the volume of intake air and compression. Variable intake manifolds and valve timing certainly help with this. Some manufacturers are exploring variable compression engines but none are yet in production.

Performance gains have been made through air filter designs **(Figure 32–14)**. The shape of the filter and its direct exposure to the air allow for increased intake flow. Although these filters can increase horsepower and decrease fuel consumption, manufacturers do not use these filters on normal cars. With the filter exposed, there is nothing to reduce intake noise and owners may find the noise offensive.

Keep in mind that the power generated by the internal combustion engine is directly related to the amount of air that is compressed in the cylinders. In other words, the greater the compression (within reason), the greater the output of the engine. Two approaches can be used to increase an engine's effective compression. One is to modify the engine to increase its compression ratio. This can be done in many ways, including the use of domes or high-top pistons, altered crankshaft strokes, or changes in the shape and structure of the combustion chamber.

Another, less expensive way to increase compression (and engine power) without physically changing the shape of the combustion chamber is to simply increase the intake charge. By pressurizing the intake mixture before it enters the cylinder, more air and fuel molecules can be packed into the combustion chamber. The two ways to artificially increase

FIGURE 32–14 A specialty cone air filter can increase the power output of an engine.

the amount of airflow into the engine are known as turbocharging and supercharging.

Both of these systems force more air into the intake manifold by compressing the air before it reaches the manifold. Turbocharging uses exhaust gases and supercharging relies on the rotation of the engine to compress the air. Both systems offer benefits but have some limitations. The biggest disadvantage of using either system is related to the compression of air. When air is compressed, its heat increases. High-temperature air is less dense, meaning there is less oxygen in the air. Most turbocharged or supercharged systems use an intercooler to increase the density of the air.

Intercoolers

The **intercooler** cools the turbocharged or supercharged air before it reaches the combustion chamber **(Figure 32–15)**. The removal of heat from the pressurized air going into the intercooler increases the density of the air, which improves efficiency, engine horsepower, and torque.

Intercoolers are actually radiators for the intake air. The heat from the compressed air that passes through it is removed and dissipated to the atmosphere. An intercooler system may consist of an added radiator in the grill area **(Figure 32–16)** or above the engine **(Figure 32–17)**, a coolant reservoir (separate from the reservoir of the engine's cooling system), a pump, and hoses and tubes to connect the components **(Figure 32–18)**. An intercooler is always located after the turbocharger or supercharger and before the intake manifold. As the heated air flows through the intercooler, heat is transferred to the coolant circulating through the intercooler. The coolant is cooled by the air passing through the intercooler. The amount of coolant moving through the intercooler is normally controlled by the PCM. Therefore, the PCM controls the temperature of the incoming air.

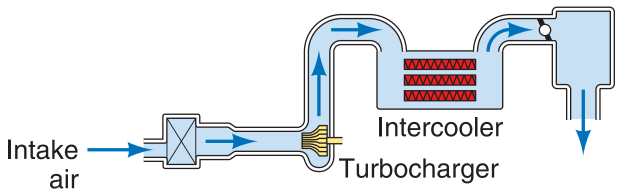


FIGURE 32–15 Routing of the boosted air in and out of an intercooler.

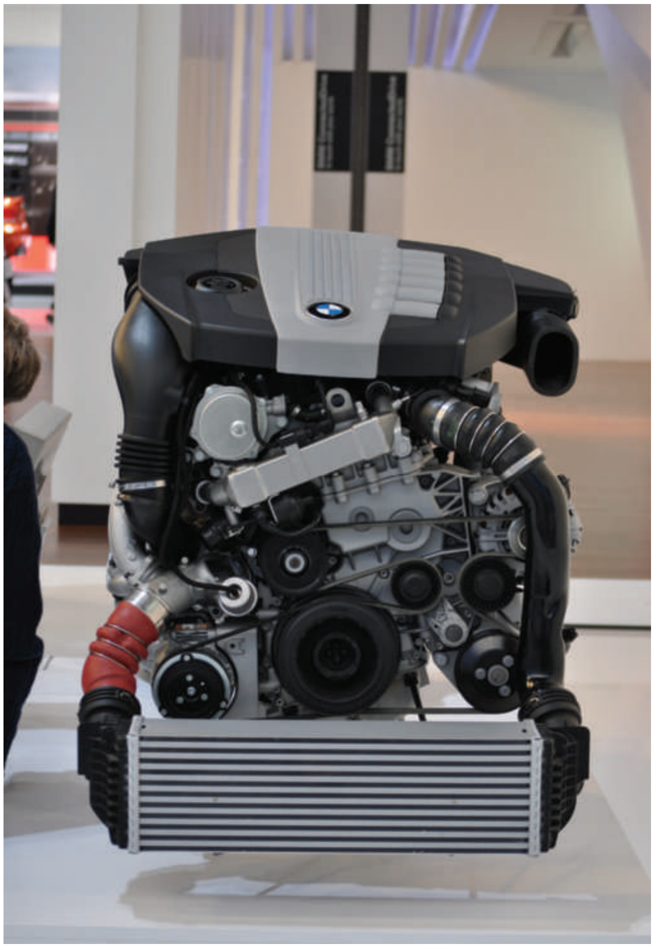


FIGURE 32–16 A twin turbocharged engine with an intercooler located in front of the engine.

FIGURE 32–17 The intercooler for this supercharged engine is located on top of the engine.

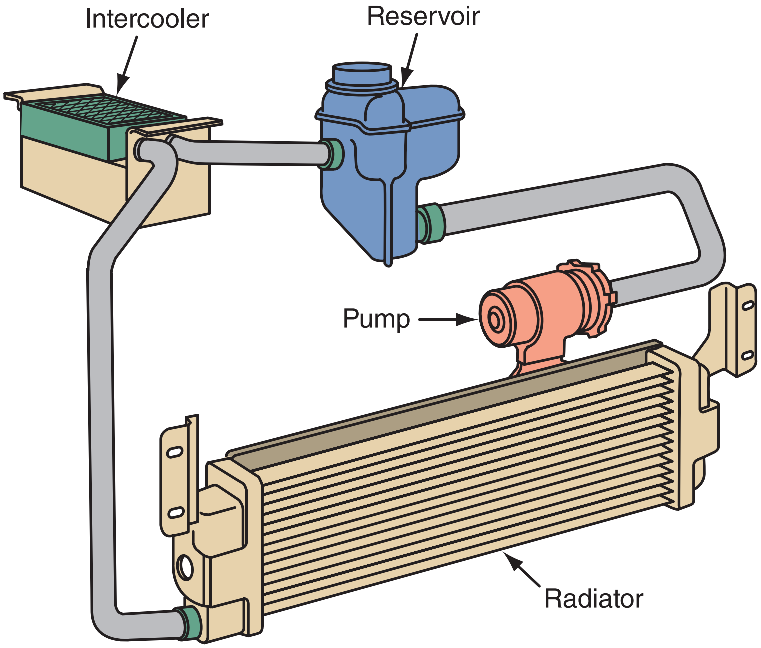


FIGURE 32–18 The main parts of a water-to-air intercooler.

Turbochargers

Turbochargers are used to increase engine power by compressing intake air before it enters the engine. Turbochargers are air pumps driven by the engine's exhaust stream. The heat and pressure of the exhaust gases spin the turbine blades (hence the name turbocharger) of the pump. The turbine wheel is connected to a compressor wheel. As the turbine spins, so does the compressor wheel. The compressor wheel spins at very high speeds and compresses the intake air. The compressed air is then sent to the cylinders. Because exhaust gas is a waste product, the energy developed by the turbine is said to be free because it theoretically does not use any of the engine's power it helps to produce.

Turbochargers are used on both diesel and gasoline engines. The main advantage of their use is that they allow for an increase of power without a substantial decrease in fuel economy. This is because they boost the engine's power output only when extra power is needed. A small engine, in most cases, can be used to provide low fuel consumption and emissions levels. When increased power is needed, the turbocharger is activated. Many manufacturers are using smaller displacement engines and installing turbochargers. The requirements to improve fuel economy and reduce exhaust emissions while maintaining customer performance expectations means many cars and light trucks are now powered by smaller, more efficient turbocharged engines.

Construction

A turbocharger is normally located close to the exhaust manifold. An exhaust pipe runs between the exhaust manifold and the turbine housing to carry the exhaust flow to the turbine wheel **(Figure 32–19)**. Another pipe connects the compressor housing intake to the throttle plate assembly or intake manifold. On some newer engine designs, the exhaust manifold is incorporated into the cylinder head **(Figure 32–20)**. This can significantly increase the efficiency of driving the turbine.

A typical turbocharger, usually called a turbo, has the following components **(Figure 32–21)**:

- Turbine wheel
- Shaft
- Compressor wheel
- Center housing and rotating assembly (CHRA)
- Wastegate valve

Inside the turbocharger, the turbine wheel (hot wheel) and the compressor wheel (cold wheel) are

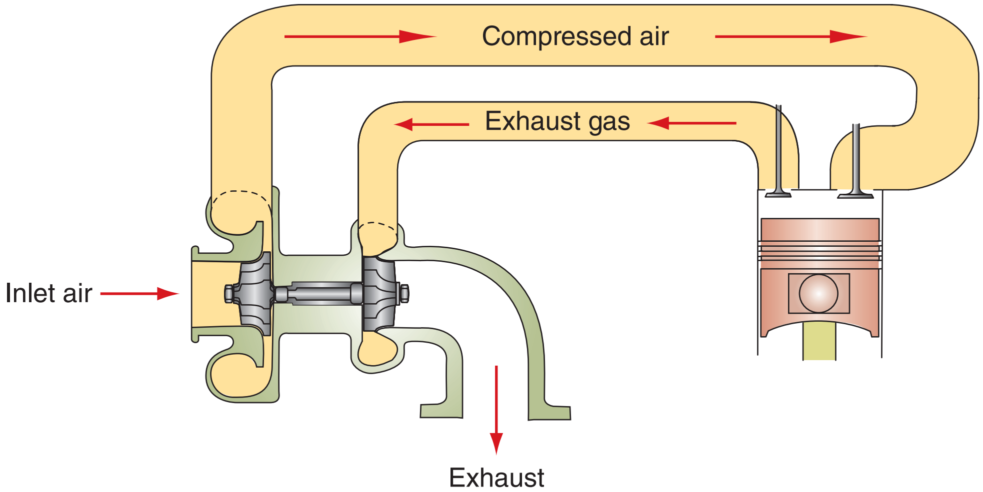


FIGURE 32–19 Exhaust gas and airflow in a typical turbocharger system.

FIGURE 32–20 An exhaust manifold integrated into the cylinder head.

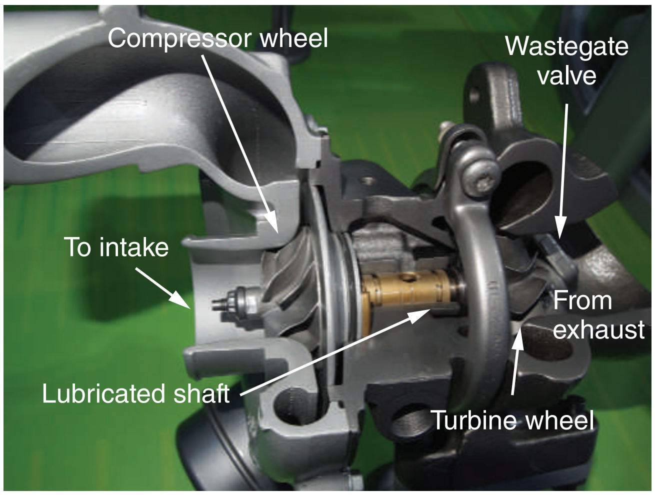


FIGURE 32–21 A cross section of a turbocharger shows the turbine wheel, the compressor wheel, and their connecting shaft.

mounted on the same shaft. The CHRA houses the shaft, shaft bearings, turbine seal assembly, and compressor seal assembly. Each wheel is encased in its own spiral-shaped enclosure in the housing that serves to control and direct the flow of exhaust and intake air. Because the turbine wheel is in the exhaust path, it gets very hot. It also spins at very high speeds; therefore, it is normally made of a heat-resistant cast iron.

A conventional turbocharger normally begins to compress intake air when the engine's speed is above 2,000 rpm. Some late-model engines have low inertia turbochargers that begin to compress intake air at lower engine speeds. The force of the exhaust flow is directed against the side of the turbine wheel. As the hot gases hit the turbine wheel, causing it to spin, the turbine fins direct the exhaust gases toward the center of the housing where they exit. This action creates a flow called a vortex. The compressor wheel (shaped like a turbine wheel in reverse) spins with the turbine. Intake air is drawn into the housing and is caught by the whirling blades of the compressor and thrown outward by centrifugal force. From there the air exits under pressure to the intake manifold and the individual cylinders.

Air is typically drawn into the cylinders by the difference in pressure between the atmosphere and engine vacuum. A turbocharger, however, is capable of pressurizing the intake charge above normal atmospheric pressure. *Turbo boost* is the term used to describe the positive pressure increase created by a turbocharger. For example, 10 psi of boost means the air is being fed into the engine at 24.7 psi (14.7 psi atmospheric plus 10 pounds of boost). A turbocharger is equipped with a wastegate valve to control the pressure of the air delivered to the cylinders.

Turbo Lag Increases in horsepower are normally evidenced by an engine's response to a quick opening of the throttle. The lack of immediate throttle response is felt with some turbocharged engines. This delay or **turbo lag** occurs because exhaust gas requires a little time to build enough energy to spin the wheels fast enough to respond to the engine's speed. This causes the power from the engine to temporarily lag behind what is needed for the conditions. Modern engine and turbo designs have nearly eliminated turbo lag that was common in older engines.

Wastegate Valve

If the pressure of the air from a turbocharger becomes too high, knocking occurs, engine output decreases, and the pressure created by the combustion of the air-fuel mixture can become so great that the engine may self-destruct. To prevent this, turbochargers have a **wastegate** valve. The wastegate valve is part of the turbine housing. It allows a certain amount of exhaust gas to bypass the turbine when the boost pressure exceeds a certain value. This action reduces the pressure.

The action of the wastegate can be controlled directly by manifold pressure **(Figure 32–22)** or by the PCM according to manifold pressure **(Figure 32–23)**. Most late-model systems have PCM-controlled wastegates. In non-PCM systems, an actuator that senses the air pressure in the induction system opens the wastegate when the pressure becomes too high. This action decreases the amount of exhaust that reaches the turbine. This, in turn, reduces turbine and compressor wheel speed and decreases the output pressure from the turbocharger. When the pressure in the intake manifold is not great enough to override the

FIGURE 32–22 The output of this turbocharger is controlled directly by manifold pressure.

FIGURE 32–23 The output of this turbocharger is controlled electronically.

spring in the actuator, the wastegate is closed and all of the exhaust flows past the turbine; therefore, the turbine spins accordingly. When the boost pressure overcomes the tension of the actuator's spring, the actuator opens the wastegate valve and some exhaust gas is diverted around the turbine wheel. As a result, turbine speed is controlled, as is boost pressure.

On late-model engines, the wastegate is controlled by the PCM that directly controls a solenoid that controls vacuum to the wastegate. When vacuum is introduced to the wastegate, it opens to allow exhaust gases to bypass the turbine. The action of the solenoid is controlled by the PCM according to various inputs. The PCM also adjusts ignition timing and air-fuel mixtures according to turbocharger output. Retarding spark timing is an often-used method of controlling detonation on turbocharged engines. Unfortunately, any time the ignition is retarded, power is lost, fuel economy suffers, and the engine tends to run hotter. Most systems use knock-sensor signals to retard timing only when detonation is detected. These sensors are also used to limit boost pressure according to the octane rating of the fuel being used. This maximizes engine performance and reduces the chances of engine knocking during all conditions regardless of the fuel's octane rating.

When the PCM detects excessive manifold pressure, it opens the wastegate and also enriches the mixture. This rich mixture reduces combustion temperature, which helps to cool the turbocharger and combustion chamber.

Turbo Lubrication and Cooling

Keeping a turbocharger cool and well lubricated is essential to the unit's durability. The turbine wheel faces very high temperatures. The temperature of

the exhaust from a gasoline engine can surpass 1,800 °F (982 °C). The exhaust from a diesel engine is cooler and ranges from 1,400° to 1,500 °F (768° to 816 °C). This heat can destroy the turbocharger if it is not controlled.

The turbine and compressor wheels rotate at very high speeds (over 200,000 rpm). Their shaft is mounted on full-floating bearings designed to keep the shaft secure while it is rotating. The bearings are lubricated by engine oil and rotate freely on the shaft and in the housing. Engine oil is delivered to the turbocharger through an oil inlet pipe and then circulated to the bearings. The bearings have outer seals to prevent oil leakage. The oil passes over the bearings and returns to the engine's oil pan through an oil outlet pipe. The circulation of the oil cools the turbocharger.

A turbocharger may be cooled by engine coolant that circulates through coolant channels built into the housing. Coolant is sent from the engine's thermostat housing through a coolant inlet pipe to the turbo housing. After the coolant has circulated through the housing, it is returned to the water pump through the coolant outlet pipe.

Various Turbocharger Designs

In an effort to increase the efficiency of turbocharged engines, manufacturers have developed various designs of turbochargers and their control systems. Common alternative designs are called variable nozzle turbine and variable geometry turbochargers. In these, the cross-sectional area through which the exhaust flows is variable. This area is adjusted via movable vanes that change their angles according to turbine speed. At lower engine speeds the vanes restrict exhaust flow, thereby increasing boost pressure. At higher engine speeds, the vanes open wider and exhaust backpressure decreases. This allows the turbocharger to provide more boost at lower engine speeds without producing too much boost at higher speeds. It is claimed that the use of a variable turbocharger can reduce a gasoline engine's fuel consumption by 20 percent.

Because variable geometry allows for more precise control of the turbo, some variable turbos do not have a wastegate. They provide a higher boost at lower engine speeds and are more responsive to changes in engine load. They also help reduce the effects of turbo lag.

Twin Turbochargers Some engines have two or more turbochargers. Their action depends on the application. Some engines have a turbo for

FIGURE 32–24 A twin turbocharger setup on an inline six-cylinder engine.

one-half of the cylinders and another for the other half **(Figure 32–24)**. Some V-type engines have a turbocharger for each bank of cylinders. The turbos use the exhaust from specific cylinders to compress the air for those same cylinders.

Some late-model engines have dual turbochargers that use a common housing and exhaust stream to send compressed air out to two separate paths **(Figure 32–25)**.

Other engines have two different-sized turbos. Each turbo is designed for specific conditions. Normally, the smaller of the two spools (spins) up to speed very quickly. This reduces turbo lag. The larger one is slower to get up to speed but adds the boost at higher engine speeds. This is a two-stage design: one for lower engine speeds and immediate increase of speed and one for sustained power.

A few engines place the twin turbochargers within the V between the cylinder banks. Called a hot V

FIGURE 32–25 A dual turbocharger assembly.

FIGURE 32–26 This V8 engine has twin turbochargers within the V between the cylinder banks.

design, this reverses the airflow through the heads and places the intake manifolds on the outside of the engine instead of between the heads. This design increases exhaust flow into the turbochargers **(Figure 32–26)**.

In a typical twin turbocharger system, the function of the two turbochargers is controlled by the operating mode of the larger turbocharger. Its operation is controlled by control valves that regulate exhaust gases to it and the amount of air from it.

During low engine speeds and loads, boost is only provided by the smaller unit. The control valves of the other turbo have it disabled. When boost pressure from the first turbo reaches a predetermined level, exhaust gas is allowed to flow to the second turbo. At this time it is spinning but not providing any boost. This is a preparation step; the second turbine is spinning before it is needed. Once the load or speed conditions demand more power, a valve opens and allows the boost pressure from the second turbo to enter the intake manifold. At this time, boost from both turbos is sent to the intake manifold. In some systems, the higher pressure from the larger turbo causes the wastegate valve, which is an integral part of the smaller turbo, to open and control the maximum boost.

When the engine moves from high to low speed, a control valve stops the flow from the second turbo to the intake. Another control valve then blocks off exhaust flow to the turbo. These actions prevent high boost during deceleration.

Twin Scroll Turbocharger

To improve turbo performance and reduce lag, some vehicles are using twin scroll turbochargers. A twin scroll turbocharger uses two turbine wheels connected to a common shaft. Each wheel is supplied exhaust from one half of the engine's cylinders by reconfiguring the exhaust manifold. Instead of all of the exhaust gas flowing into one common area to feed a standard turbo, the exhaust on a twin scroll system has two paths. The configuration is tuned so that the exhaust pulses do not interfere with each other but instead are timed to improve flow out of the engine and across the turbine.

Mazda uses a similar design and includes a throttle-type valve in the exhaust of its turbocharged 2.5 liter engine. The exhaust is a 4:3:1 design, meaning four exhaust streams (one from each cylinder) merge into three and then one. The valve is located before the turbine and restricts the flow of exhaust to the turbo at low rpm. The effect is similar to putting your thumb over the end of a garden hose—it restricts and speeds up the flow. The restriction improves low rpm response and reduces lag. The valve opens above 1,620 rpm to allow normal flow.

DualBoost Single Sequential Turbocharger

In 2011, Ford installed a DualBoost turbocharger on their 6.7 liter PowerStroke diesel engines. This turbocharger has two compressor wheels and one turbine wheel. The compressor wheels have different shapes and sizes, but they are mounted onto the same shaft. The two compressor wheel housings are also different sizes. This creates a sequential turbo by allowing fast spooling up of the small compressor followed by increased air volume from the larger wheel. The volume of the single exhaust inlet housing is controlled by the vanes of the variable geometry system **(Figure 32–27)**. A wastegate

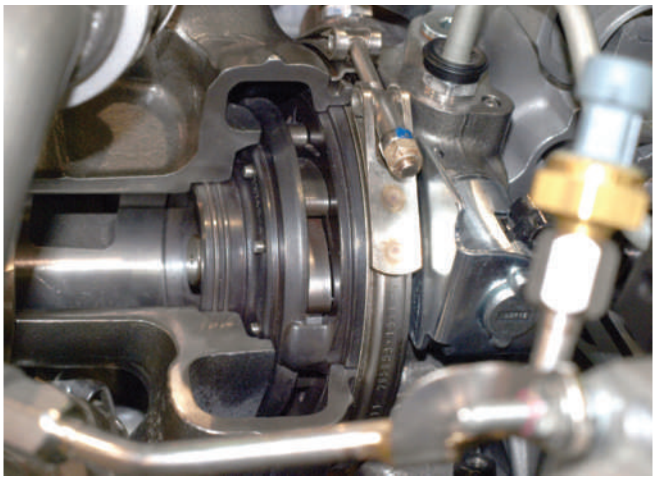


FIGURE 32–27 A cutaway of a Ford DualBoost turbocharger.

is used on the variable turbine to bypass exhaust gas as required. Because of its small size, this turbo is able to be mounted inside of the V of the engine. The airflow through the cylinder heads is reversed and exhaust gas is supplied directly from the heads into the turbo unit.

Electric Turbochargers

While still in development, several manufacturers are experimenting with electric turbos. An electrically driven turbo can supply immediate boost from idle speeds, and normal exhaust flow would take over once the engine is up to speed. There are several issues that need to be overcome before they become standard equipment, including finding an efficient way to power the turbine. However, some manufacturers are moving forward with 48-volt electrical systems, which may provide enough power for the electric turbo to be practical.

Turbocharger Inspection

To inspect a turbocharger, start the engine and listen to the sound that the turbo system makes. As you become more familiar with this characteristic sound, it will be easier to identify an air leak between the compressor outlet and engine or an exhaust leak between engine and turbo by the presence of a higher pitched sound. If the turbo sound cycles or changes in intensity, the likely causes are a plugged air cleaner or loose material in the compressor inlet ducts or dirt buildup on the compressor wheel and housing.

After listening, check the air cleaner and remove the ducting from the air cleaner to turbo and look for dirt buildup or damage from foreign objects. Check for loose clamps on the compressor outlet connections and check the engine intake system for loose bolts or leaking gaskets. Then disconnect the exhaust pipe and look for restrictions or loose material. Examine the exhaust system for cracks, loose nuts, or blown gaskets. Rotate the turbo shaft

USING SERVICE INFORMATION

General service procedures for turbocharger systems are normally in a separate section of the manufacturers' service information. Individual inputs and outputs that are part of the electronic control system are covered in the engine control or performance sections.

SHOP TALK

When oil leakage is noted at the turbine end of the turbocharger, check the turbocharger oil drain tube and the engine crankcase breathers for restrictions. When sludged engine oil is found, the engine's oil and oil filter must be changed.

assembly. Does it rotate freely? Are there signs of rubbing or wheel impact damage?

Visually inspect all hoses, gaskets, and tubing for proper fit, damage, and wear. Check the low-pressure, or air cleaner, side of the intake system for vacuum leaks.

Pressure Testing The performance of a turbocharger can be checked with a pressure gauge. The gauge is connected to the intake manifold and the amount of boost observed. This is best done on a road test. This check can also verify the action of the wastegate and its controls. Manifold pressure can be monitored with a scan tool as well.

On the pressure side of the system you can check for air leaks with soapy water. After applying the soap mixture, look for bubbles to pinpoint the source of the leak.

Exhaust leaks to the turbocharger housing will also affect turbo operation. If exhaust gases escape prior to entering the housing, the reduced temperature and pressure will cause a proportionate reduction in boost and a loss of power.

Wastegates Wastegate problems can usually be traced to carbon buildup, which keeps the unit from closing or causes it to bind. A defective diaphragm or leaking vacuum hose can result in an inoperative wastegate. Before condemning the wastegate, check the ignition timing, the spark-retard system, vacuum hoses, knock sensor, oxygen sensor, and computer. If the wastegate appears not to be operating properly (too much or too little boost), check to make sure that the connecting linkage is operating smoothly and not binding. Also make sure that the pressure sensing hose is clear and properly connected.

SHOP TALK

Because of the needed balance and sealing of the units, all repairs to turbochargers are done at specialty shops.

> **Caution!** When removing carbon deposits from turbine and wastegate parts, never use a hard metal tool or sandpaper. Remember that any gouges or scratches on these parts can cause severe vibration or damage to the turbocharger. To clean these parts, use a soft brush and a solvent.

Common Turbocharger Problems With proper care and servicing, a turbocharger will provide years of reliable service. Most turbocharger failures are caused by lack of lubrication, ingestion of foreign objects, or contamination of the lubricant **(Figure 32–28)**.

Replacing a Turbocharger

If the turbocharger is faulty, it should be replaced with a new or rebuilt unit. Always follow the procedure given in the service information. Before removing the turbocharger, plug the intake and exhaust ports and the oil inlet to prevent the entry of dirt or other foreign material. While replacing it, check for an accumulation of sludge in the oil pipes and, if necessary, clean or replace the oil pipes. Do not drop or bang the new unit against anything or grasp it by easily deformed parts.

When installing a new turbocharger, put 20 cc (0.68 oz.) of oil into the turbocharger oil inlet and turn the compressor wheel by hand several times to spread oil to the bearings.

After installing the new turbocharger, or after starting an engine that has been unused, there can be a considerable lag after engine startup before the oil pressure is sufficient to deliver oil to the turbo's bearings. To prevent this problem, follow these simple steps:

- Make certain that the oil inlet and drain lines are clean before connecting them.
- Be sure the engine oil is clean and at the proper level.
- Fill the oil filter with clean oil.

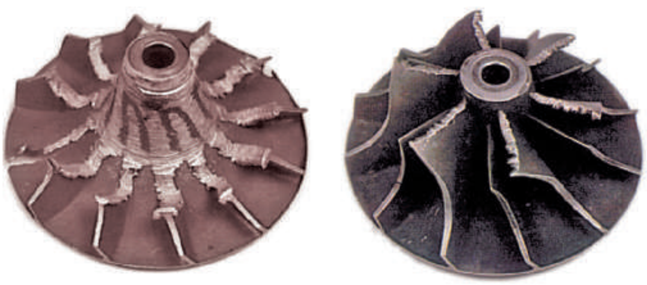


FIGURE 32–28 Damaged turbocharger wheels.

- Leave the oil drain line disconnected at the turbo and crank the engine without starting it until oil flows out of the turbo drain port.
- Disconnect the fuel pump fuse or relay and crank the engine for 30 seconds to distribute oil throughout the engine.
- Allow the engine to idle for 60 seconds.
- Connect the drain line, start the engine, and operate it at low idle for a few minutes before running it at higher speeds.

Maintenance

Turbochargers require no maintenance; however, the engine's oil and filter must be changed on a regular basis. The units operate at high speeds and high temperatures. Poor lubrication will cause the turbo to self-destruct. Also, the high heat breaks down the oil and, therefore, its service life is shorter than it would be in a conventional engine. Manufacturers typically recommend that a specific type of oil be used in these engines. After the oil and filter have been changed, the engine should run at idle for at least 30 seconds. Doing this allows oil to circulate through the turbo.

In addition to frequent oil changes, the air cleaner and filter assembly needs to be maintained. This includes making sure that there are no air leaks in the system. The slightest amount of dirt entering the turbo can damage its turbine and compressor wheels. PCV valves and filters also need to be maintained on a regular basis.

Turbo Startup and Shutdown

The number one cause of turbo failure is poor lubrication. Because its bearings are not well lubricated immediately after the engine is started, allow the engine to idle for some time before putting it under a load. If the engine has not been run for a day or more, start the engine and allow it to idle for 3 to 5 minutes to prevent oil starvation to the turbo. Engine lube systems have a tendency to bleed down. When the engine has sat for a long time, it is wise to crank the engine without starting it until a steady oil pressure reading is observed. This is called priming the lubricating system. A turbocharged engine should never be operated under load if the engine has less than 30 psi of oil pressure. The same starting procedure should be followed in cold weather. The thick engine oil will take a longer period to flow. Low oil pressure and slow oil delivery during engine starting can destroy the bearings in a turbocharger.

When the engine has been operated at high speeds or heavy loads, the turbine wheel has been

exposed to very hot exhaust gases. This heat is transferred to the turbine's shaft and the compressor wheels. If the engine is turned off immediately after high-speed driving, oil and coolant to the turbo unit will immediately stop. The shaft, however, will still spin due to its inertia. Poor lubrication at this point will destroy the bearings and shaft. Therefore, the engine should idle for 20 to 120 seconds after a hard run to allow the shaft to cool. When the engine is idling, exhaust temperatures drop to 573° to 752 °F (300° to 400 °C). The cooler exhaust gases help cool the shaft and its lubricating oil.

Superchargers

Today some engines have a supercharger as an alternative to the turbo **(Figure 32–29)**.

Superchargers are positive displacement air pumps driven directly by the engine's crankshaft via a V-ribbed belt **(Figure 32–30)**. They improve horsepower and torque by increasing air pressure and density in the intake manifold. The pressure boost is proportional to engine speed.

A typical supercharger is normally made up of a magnetic clutch, two rotors, two shafts, two rotor gears, housing, and a rear plate and cover **(Figure 32–31)**. The drive belt connects the engine to a pulley connected to one rotor shaft **(Figure 32–32)**. Gears connect the two rotor shafts and drive them in opposite directions **(Figure 32–33)**. The rotors have three helical lobes. The lobes are press-fit onto the rotor shafts and then held in position by pins and serrations. The rotors turn within a sealed housing and pressurize the air as they rotate. The rotors' shafts are supported by ball or needle bearings in the rear plate and are lubricated by oil in the supercharger unit.

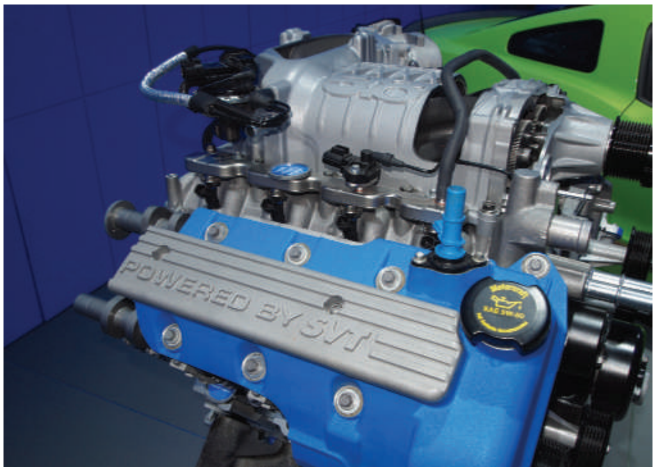


FIGURE 32–29 A supercharger on a late-model high-performance engine.

FIGURE 32–30 Superchargers are driven by a drive belt.

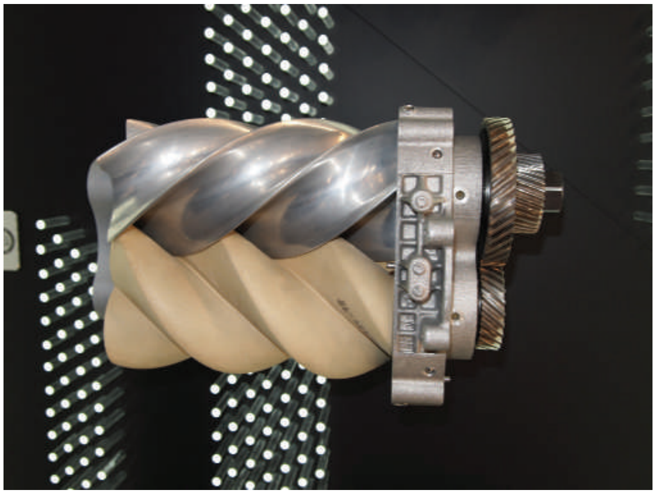


FIGURE 32–31 The rotors, front plate, and drive gears for a typical supercharger.

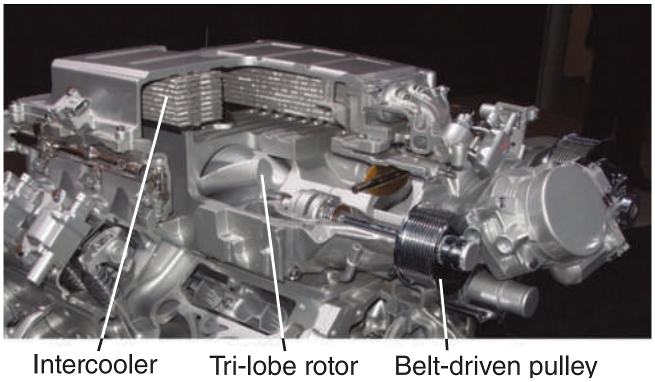


FIGURE 32–32 The drive pulley is attached to a single drive shaft.

To handle the higher operating temperatures imposed by supercharging, the engine is typically fitted with an engine oil cooler. This water-to-oil cooler is generally mounted between the engine front cover and oil filter.

FIGURE 32–33 Gears transfer the motion of the drive shaft to both rotors.

Supercharger Operation

Figure 32–34 illustrates the flow of the air through a supercharger system. The air comes in through the remote-mounted air cleaner and the mass airflow meter. It then moves through the throttle plate assembly and passes through the supercharger inlet plenum assembly, which is bolted to the back of the supercharger.

The air enters the supercharger and is pressurized by the spinning rotors. It then exits through the top of the supercharger by way of the air outlet adapter. As the air is compressed, its temperature increases. Because cooler, denser air is desired for increased power, the heated air is routed through an intercooler. An intercooler can decrease the temperature of the air by 150 °F (66 °C).

This cooled air then passes through to the intake manifold adapter assembly, which is bolted to the rear of the intake manifold. When the intake valves open, the air is forced into the combustion chambers where it is mixed with fuel delivered by the fuel injectors.

Supercharger By-Pass System

Unlike a turbocharger, the supercharger does not require a wastegate to limit boost and prevent a potentially damaging overboost condition. Because the speed of the supercharger is directly linked to the engine speed, its pumping power is limited by the rpm of the engine itself rather than revolutions produced by exhaust gases. Supercharger boost is therefore directly controlled through the opening and closing of the throttle or a by-pass system that controls the air leaving the supercharger. The by-pass system may be electrically or vacuum controlled.

The by-pass circuit allows the supercharger to idle when the extra power is not needed. The by-pass routes any excess air in the intake manifold back through the supercharger inlet plenum assembly,

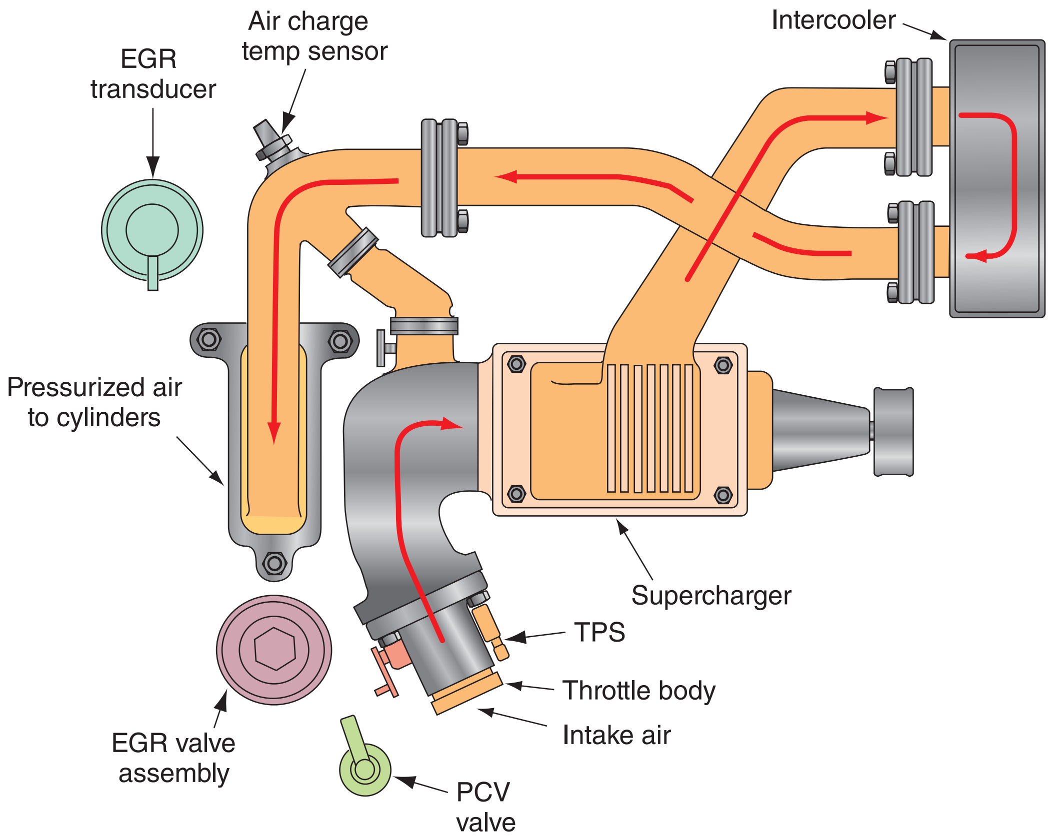


FIGURE 32–34 Airflow through a supercharger assembly into the engine.

allowing the engine to run, in effect, normally aspirated. This eliminates any boost from the supercharger. The by-pass system reduces air handling losses when boost is not needed and this results in better fuel economy.

Some systems use a PCM-controlled stepper motor to control the amount of air that bypasses the supercharger. The PCM determines the required boost pressure based on current engine conditions and controls the operation of the magnetic clutch and by-pass valve.

Other systems have a vacuum motor that regulates the amount of air to be bypassed. As the power demands from the engine increase, a vacuum motor controls a butterfly valve that routes more or less air to the intake manifold, thereby changing the boost. When this bypass is completely closed, boost can reach about 12 psi. When the actuator is open, during high-vacuum engine conditions, the air bypasses the supercharger. As the throttle is opened and engine vacuum decreases, the actuator closes and allows more air into the supercharger.

Supercharger and Turbocharger

A few European vehicles are equipped with a gasoline engine that have a supercharger and a turbocharger. These systems are called "twin-charger" systems. The supercharger is used to boost power at low speeds and the turbocharger boosts power at high speeds.

In the Volvo twin-charger system, a magnetic clutch is used to uncouple the driveshaft of the supercharger when it's no longer needed. The supercharger is used at low engine rpm, to provide boost until the turbocharger spools up. Once the engine reaches 3,500 rpm, the supercharger's clutch unlocks and the turbo takes over. Because the supercharger is only used at lower rpm, it can be overdriven and provide increased boost without having to spin at very high speeds.

Electric Superchargers

As with electric turbochargers, several companies are exploring electric superchargers. Using an electric drive eliminates the mechanical drag on the engine to turn the supercharger. Another obvious advantage is being able to relocate the unit, since it would not need to be driven by an engine belt. However, the challenge, as with electric turbochargers, is powering the device. The 12-volt system is unlikely to be able to provide enough power to offset the increased demand on the electrical system. Options are using a high-voltage system, ultracapacitors, or some type of regeneration. Each has pros and cons that need to be resolved before the technology gets widely adopted.

USING SERVICE INFORMATION

Procedures for servicing supercharger systems are normally in a separate section in the service information.

Supercharger Problems

Many of the problems and their remedies given for turbochargers hold good for superchargers. There are also problems associated specifically with the supercharger. Refer to the service information for the symptoms of supercharger failure and a summary of the causes and the recommended repairs.

Maintenance

A supercharger normally has its own oil supply and requires special oil for lubrication. Its oil level must be checked and corrected periodically. Also, the unit ought to be inspected regularly for oil leaks. Like a turbocharger, any dirt in the intake air can destroy the unit. The induction system must be checked for leaks and the filter changed on a regular basis.

Exhaust System Components

The various components of the typical exhaust system **(Figure 32–35)** include the following:

- Exhaust manifold
- Exhaust pipe and seal
- Catalytic converter
- Muffler
- Resonator
- Tailpipe
- Heat shields
- Clamps, brackets, and hangers
- Exhaust gas oxygen sensors

All the parts of the system are designed to conform to the available space of the vehicle's undercarriage and yet be a safe distance above the road.

Exhaust Manifold

The exhaust manifold **(Figure 32–36)** collects the burnt gases as they are expelled from the cylinders and directs them to the exhaust pipe. Exhaust manifolds for most vehicles are made of cast **(Figure 32–37)** or nodular iron. Many newer-vehicles

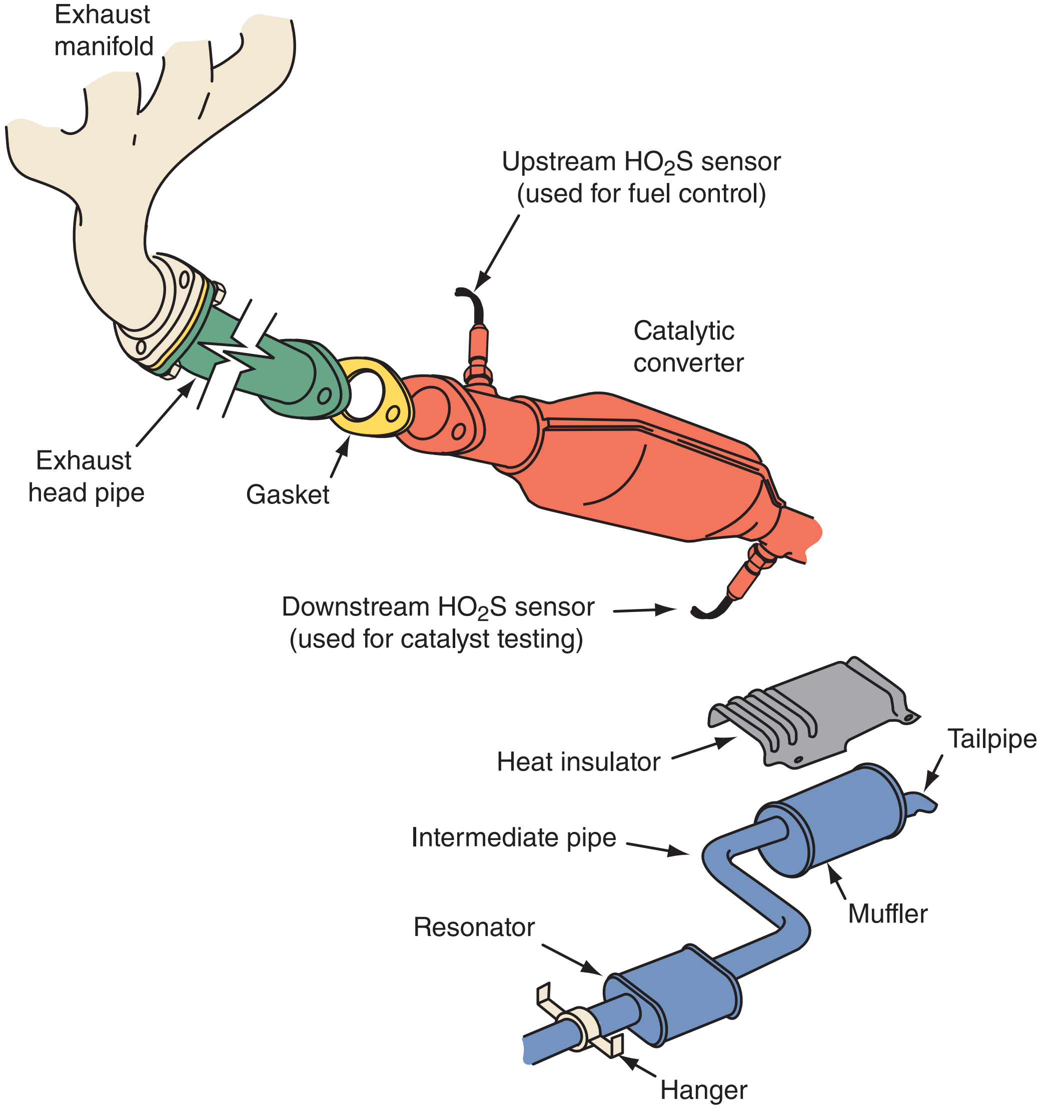


FIGURE 32–35 An exhaust system for a late-model vehicle.

have stamped, heavy-gauge sheet metal or stainless steel units. A few engines incorporate the exhaust manifold into the design of the cylinder head, such as the Pentastar V6 from Chrysler.

Most inline engines have one exhaust manifold though two manifolds are common on BMW inline 6-cylinder engines **(Figure 32–38)**. V-type engines have an exhaust manifold on each side of the engine. An exhaust manifold will have either three, four, five, or six passages, depending on the type of engine. These passages blend into a single passage at the other end, which connects to an exhaust pipe. From that point, the flow of exhaust gases continues to the catalytic converter, muffler, and tail pipe, then exits at the rear of the car.

> Caution! When inspecting or working on the exhaust system, remember that its components get very hot when the engine is running. Contact with them could cause a severe burn. Also, always wear safety glasses or goggles when working under a vehicle.

V-type engines may be equipped with a dual exhaust system that consists of two almost identical, but individual systems in the same vehicle.

Exhaust systems are designed for particular engine-chassis combinations. Exhaust system length, pipe size, and silencer size are used to tune the flow of gases within the exhaust system. Proper tuning of the exhaust manifold tubes can actually create a partial vacuum that helps draw exhaust gases out of the cylinder, improving volumetric efficiency. Separate, tuned exhaust headers **(Figure 32–39)** can also improve efficiency by

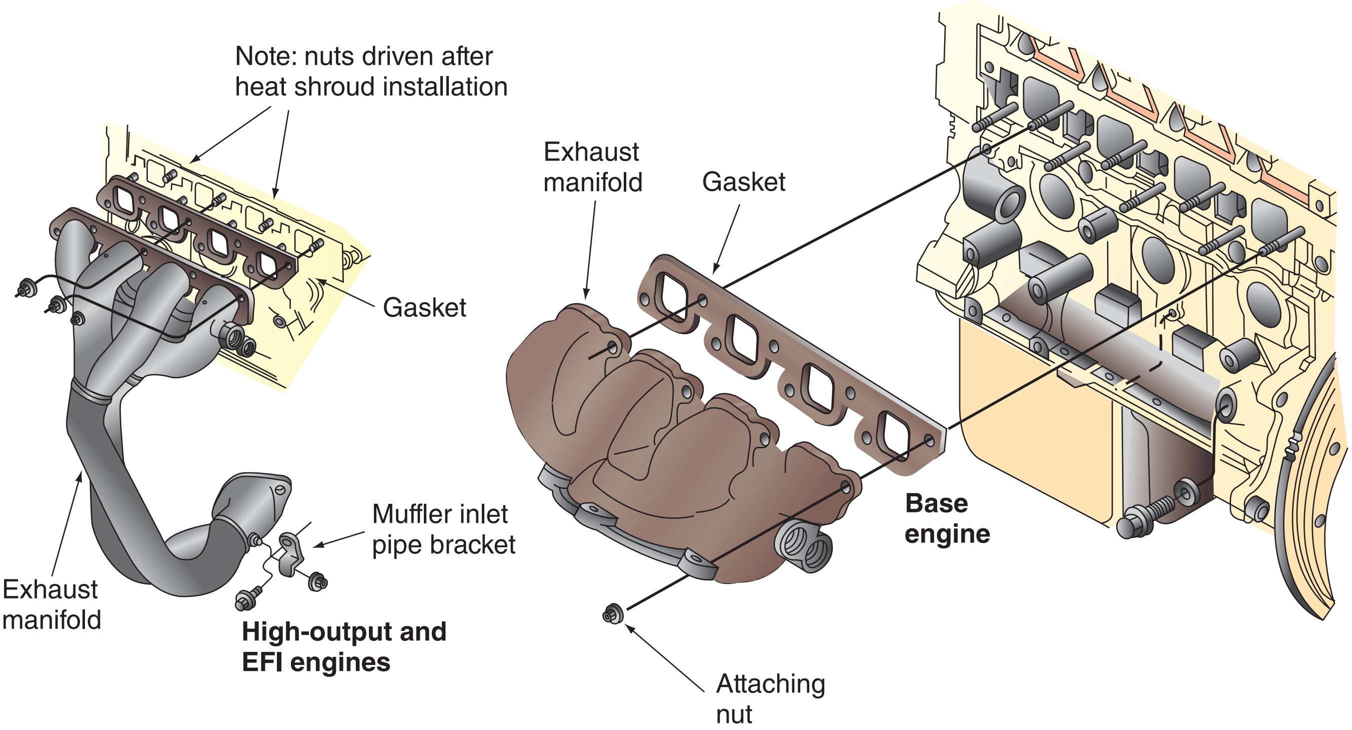


FIGURE 32–36 Two examples of exhaust manifolds.

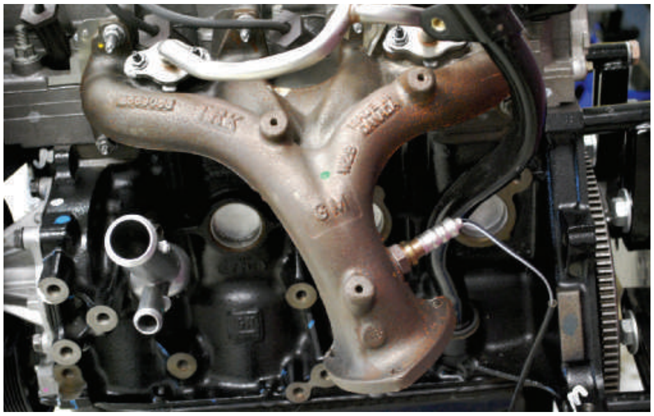


FIGURE 32–37 A cast iron exhaust manifold for a four-cylinder engine.

FIGURE 32–38 This inline six-cylinder has two separate exhaust systems.

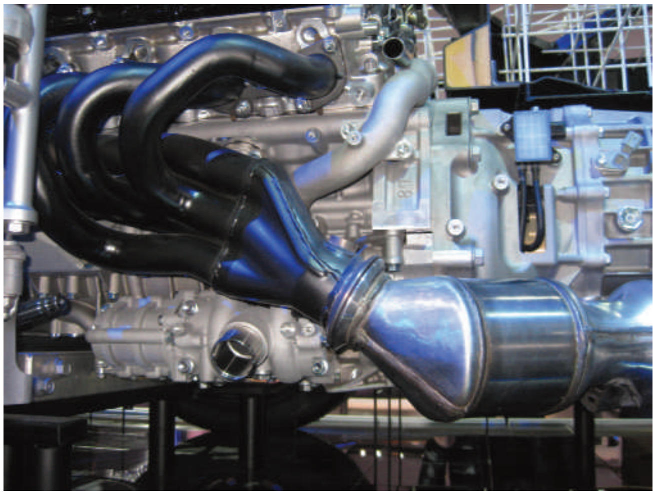


FIGURE 32–39 This V10 engine has a tuned exhaust manifold (header).

preventing the exhaust flow of one cylinder from interfering with the exhaust flow of another cylinder. Cylinders next to one another may release exhaust gas at about the same time. When this happens, the pressure of the exhaust gas from one cylinder can interfere with the flow from the other cylinder. With separate headers, the cylinders are isolated from one another, interference is eliminated, and the engine breathes better.

Perhaps the largest performance gain from using an exhaust header is that it increases the engine's volumetric efficiency. A low pressure is present in

SHOP TALK

The exhaust manifold gasket seals the joint between the head and exhaust manifold. Many new engines are assembled without exhaust manifold gaskets. This is possible because new manifolds are flat and fit tightly against the head without leaks. Exhaust manifolds go through many heating/cooling cycles. This causes stress and some corrosion in the exhaust manifold. Removing the manifold usually distorts the manifold slightly so that it is no longer flat enough to seal without a gasket. Exhaust manifold gaskets are normally used to eliminate leaks when exhaust manifolds are reinstalled.

the exhaust each time a pulse of exhaust ends. A header uses this low pressure to pull exhaust gases out of the cylinder when the exhaust valve opens. The low pressure also helps draw more air into the cylinder during valve overlap. Enhancing exhaust flow and increasing intake flow increases the efficiency of the engine.

Exhaust Pipe and Seal

The exhaust pipe is metal pipe—either aluminized steel, stainless steel, or zinc-plated heavy-gauge steel—that runs under the vehicle between the exhaust manifold and the catalytic converter **(Figure 32–40)**.

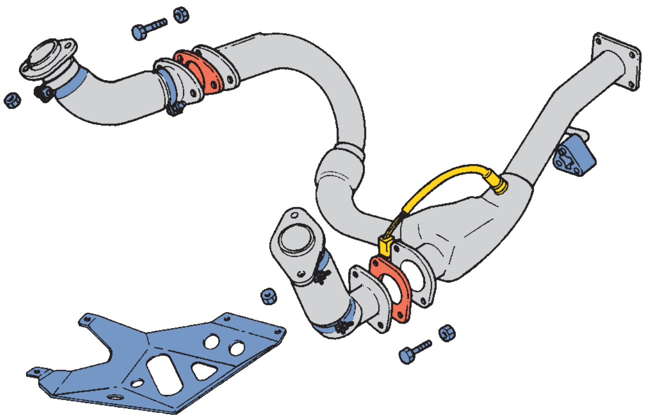
Catalytic Converters

A **catalytic converter (Figure 32–41)** is part of the exhaust system and a very important part of the emission control system. The catalytic converter is located ahead of the muffler in the exhaust system. The extreme heat in the converter oxidizes the exhaust that flows out of the engine. Because it is part of both systems, it has a role in both. As an emission control device, it is responsible for reducing the amount of harmful exhaust emissions. As part of the exhaust system, it helps reduce the noise level of the exhaust. A catalytic converter contains a ceramic element coated with a catalyst. A catalyst is a substance that causes a chemical reaction in other elements without actually becoming part of the chemical change and without being used up or consumed in the process.

GO TO Chapter 33 for a detailed discussion on catalytic converters.

Catalytic converters may be pellet type (used in older systems) or monolithic type. Exhaust gases pass over this bed of catalyst material. In a monolithic-type converter, the exhaust gases pass through a honeycomb ceramic block. The converter beads or ceramic block are coated with a thin coating of cerium, platinum, palladium, and/or rhodium and are held in a stainless steel container. These elements are used alone or in combination with each other to change the undesirable emissions into harmless compounds.

Since the late 1980s, vehicles have had a three-way converter (TWC) that treats all three controlled emission gases. It oxidizes HC and CO by adding



Courtesy of American Isuzu Motors Inc.

FIGURE 32–40 The front exhaust pipe assembly for a V6 engine.

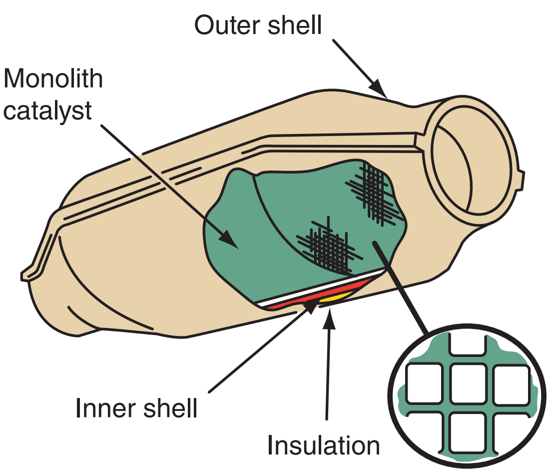


FIGURE 32–41 A catalytic converter.

FIGURE 32–42 A particulate oxidizer catalytic converter.

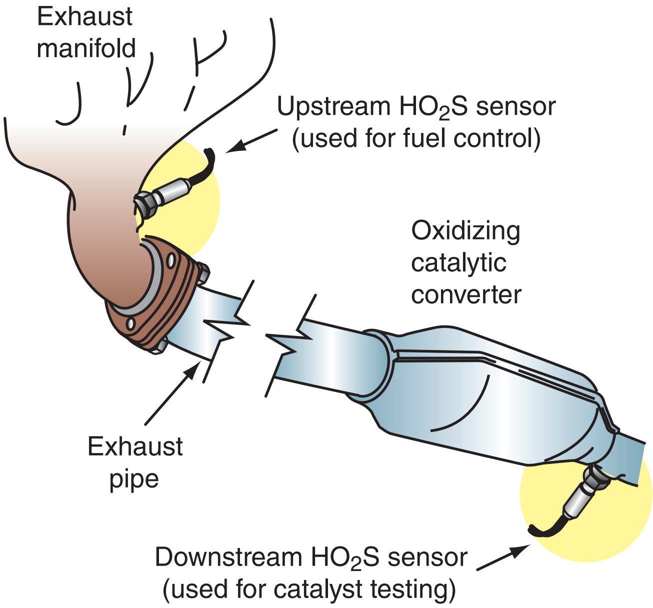


FIGURE 32–43 The basic configuration of an OBD II exhaust manifold and pipe with its oxygen sensors and catalytic converter.

oxygen and reduces NO_x by removing oxygen from the nitrogen oxides. Diesel engines have a particulate oxidizer catalytic converter **(Figure 32–42)** that collects and cleans the particulates from diesel fuel that would normally be emitted from a diesel engine as black smoke.

Most late-model engines have a mini-catalytic converter that is either built in the exhaust manifold or located just after it. These converters are used to clean the exhaust during engine warm-up and are commonly called warm-up converters.

Many older catalytic converters had an air hose connected from the AIR system to the oxidizing catalyst. This air helped the converter work by making extra oxygen available. Fresh air added to the exhaust at the wrong time could overheat the converter and produce NO_x, something the converter is trying to destroy.

OBD II regulations call for a monitoring system that looks at the effectiveness of the converter. This system uses at least two oxygen sensors, one before the catalyst and one after each catalyst **(Figure 32–43)**. If the sensors' outputs are the same, the converter is not working properly and the MIL will light and a DTC will be set.

Converter Problems

The converter is normally a trouble-free emission control device; however, it can go bad or become plugged. Often these problems are caused by overheating the converter. When raw fuel enters the exhaust because of an engine misfiring, the temperature of the converter quickly increases. The heat can melt the catalyst materials inside the converter, causing a major restriction to the flow of exhaust.

A plugged converter or any exhaust restriction can cause loss of power at high speeds, stalling after starting (if totally blocked), a drop in engine vacuum as engine rpm increases, or sometimes popping or backfiring at the carburetor.

The best way to determine if a catalytic converter is working is to check the quality of the exhaust. This is done with a five-gas exhaust analyzer. The results of this test should show low emission levels if the converter is working properly.

The efficiency of today's converters depends on the normal swings of rich and lean mixtures. Further testing of a catalytic converter is included in Chapter 34.

Mufflers

The **muffler** is a cylindrical or oval-shaped component, generally about 2 feet (0.6 meter) long, mounted in the exhaust system about midway or toward the rear of the car. Inside the muffler is a series of baffles, chambers, tubes, and holes to break up, cancel out, or silence the pressure pulsations that occur each time an exhaust valve opens.

Two types of mufflers are frequently used on passenger vehicles **(Figure 32–44)**. Reverse-flow mufflers change the direction of the exhaust gas flow through the inside of the unit. This is the most common type of automotive muffler. Straight-through mufflers permit exhaust gases to pass through a single tube. The tube has perforations that tend to break up pressure pulsations. They are not as quiet as the reverse-flow type.

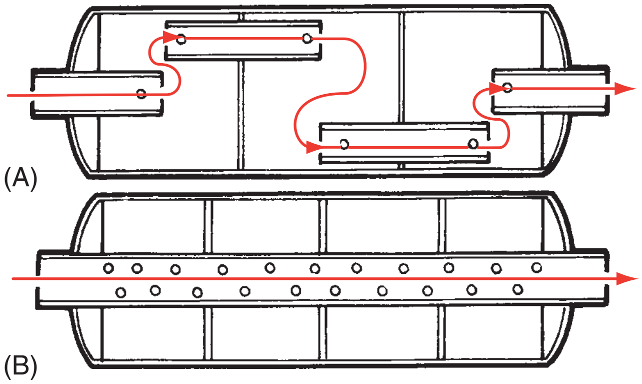


FIGURE 32-44 (A) A reverse-flow muffler; (B) a straight-through muffler.

In recent years there have been several important changes in the design of mufflers. Most of these changes have been centered at reducing weight and emissions, improving fuel economy, and simplifying assembly. These changes include the following:

New Materials More and more mufflers are being made of aluminized and stainless steel. Using these materials reduces the weight of the units and extends their lives.

Double-Wall Design This design is primarily used to retain heat which can minimize the amount of water that is in the system. Also, many cars use a double-wall exhaust pipe to better contain the sound and reduce pipe ring.

Rear-Mounted Muffler More and more often, the only space left under the car for the muffler is at the very rear. This means the muffler runs cooler than before and is more easily damaged by condensation in the exhaust system. This moisture, combined with nitrogen and sulfur oxides in the exhaust gas, forms acids that rot the muffler from the inside out. Many mufflers are being produced with drain holes drilled into them.

Backpressure Even a well-designed muffler produces some **backpressure** in the system. Backpressure reduces an engine's volumetric efficiency, or ability to "breathe." Excessive backpressure caused by defects in a muffler or other exhaust system part can slow or stop the engine. However, a small amount of backpressure can be used intentionally to allow a slower passage of exhaust gases through the catalytic converter. This slower passage results in more complete conversion to less harmful gases. Also, no backpressure may allow intake gases to enter the exhaust.

FIGURE 32-45 An exhaust bypass valve.

Some manufacturers fit bypass valves into the exhaust system **(Figure 32–45)**. When a certain driving mode is selected or the sport exhaust button is pressed, the valves divert exhaust gas flow. This increases the sound output of the exhaust and changes the tone.

Resonator

On some older vehicles, there is an additional muffler, known as a **resonator** or silencer. This unit is designed to further reduce or change the sound level of the exhaust. It is located toward the end of the system and generally looks like a smaller, rounder version of a muffler.

Tailpipe

The **tailpipe** is the last pipe in the exhaust system. It releases the exhaust fumes into the atmosphere beyond the back end of the car.

Heat Shields

Heat shields are used to protect other parts from the heat of the exhaust system and the catalytic converter. They are usually made of pressed or perforated sheet metal. Heat shields trap the heat in the exhaust system, which has a direct effect on maintaining exhaust gas velocity.

Heat shields on a catalytic converter also prevent the heat from a catalytic converter connected to a misfiring engine from setting grass or other materials on fire while it is parked. There is enough heat from an overheated converter to melt asphalt.

Flex Joints The exhaust systems on FWD vehicles have a flex joint somewhere in the front exhaust pipe. This joint allows the engine to move or roll without moving the exhaust system with it. The joint prevents the exhaust from hitting the vehicle's

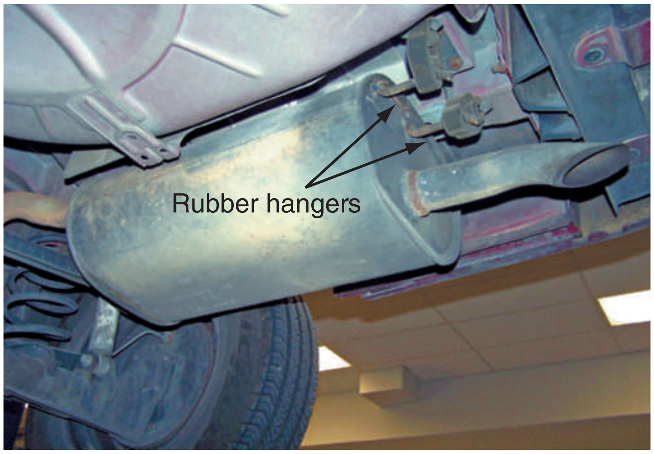


FIGURE 32–46 Rubber hangers are used to keep the exhaust system in place without allowing it to contact this pickup's frame.

underbody as well as prevents the pipe from cracking due to the stress put on it.

Clamps, Brackets, and Hangers

Clamps, brackets, and hangers are used to properly join and support the various parts of the exhaust system. These parts also help to isolate exhaust noise by preventing its transfer through the frame **(Figure 32–46)** or body to the passenger compartment. Clamps help to secure exhaust system parts to one another. The pipes are formed in such a way that one slips inside the other. This design makes a close fit. A U-type clamp usually holds this connection tight. Another important job of clamps and brackets is to hold pipes to the bottom of the vehicle. Clamps and brackets must be designed to allow the exhaust system to vibrate without transferring the vibrations through the car.

There are many different types of flexible hangers available, each designed for a particular application. Some exhaust systems are supported by doughnut-shaped rubber rings between hooks on the exhaust component and on the frame or car body. Others are supported at the exhaust pipe and tailpipe connections by a combination of metal and reinforced fabric hanger. Both the doughnuts and the reinforced fabric allow the exhaust system to vibrate without breakage that could be caused by direct physical connection to the vehicle's frame.

Some exhaust systems are a single unit in which the pieces are welded together by the factory. By welding instead of clamping the assembly together, car makers save the weight of overlapping joints as well as that of clamps.

Exhaust System Service

Exhaust system components are subject to physical and chemical damage. Any physical damage to an exhaust system part that causes a partially restricted or blocked exhaust system usually results in loss of power or backfire up through the throttle plate(s). In addition to improper engine operation, a blocked or restricted exhaust system causes increased noise and air pollution. Leaks in the exhaust system caused by either physical or chemical (rust) damage could result in illness, asphyxiation, or even death.

Exhaust System Inspection

Most parts of the exhaust system, particularly the exhaust pipe, muffler, and tailpipe, are subject to rust, corrosion, and cracking. Broken or loose clamps and hangers can allow parts to separate or hit the road as the car moves. All inspections should include listening for abnormal noises. The inspection should also include a careful look at the system while the vehicle is raised on a hoist.

Warning! During all exhaust inspection and repair work, wear safety glasses or equivalent eye protection.

Before beginning work on the system, be sure that it is cool to the touch. Also, check the system for critical clearance points so the system does not contact the chassis while the vehicle is driven.

Exhaust Restriction Test Often leaks and rattles are the only things looked for in an exhaust system. The exhaust system should also be tested for blockage and restrictions. Collapsed pipes or clogged converters and/or mufflers can cause these blockages.

There are many ways to check for a restricted exhaust. The sound of the exhaust can indicate a restriction. With a restriction, the exhaust will wheeze as it struggles to exit the exhaust system. Although this is not the most effective way to determine if there is a restriction, it is a good start.

Checking the pressure built up in the exhaust is the best way to determine if the system is blocked. This is done by installing a pressure gauge in the O_2S bore in the exhaust pipe. At idle, the gauge

should read less than 1.5 psi (10 kPa) and should be less than 2.5 psi (17 kPa) at 2,500 rpm.

Some technicians check for a restricted exhaust with a vacuum gauge. With the gauge connected to the intake manifold, the engine's speed is raised and held. The vacuum reading should rise and either hold there or increase slightly. If the vacuum decreases, there is an exhaust restriction.

Exhaust Leaks Exhaust leaks are often identified by sound, although very small leaks can be difficult to locate. One of the most effective ways to identify the source of a leak in the system is the use of a smoke machine. When smoke is introduced to the exhaust system, a trace of smoke will identify the source of the leak.

Replacing Exhaust System Components

Before beginning work on an exhaust system, make sure it is cool to the touch. Soak all rusted bolts, nuts, and other removable parts with a good penetrating oil. Finally, check the system for critical clearance points so they can be maintained when new components are installed.

Most exhaust work involves the replacement of parts. When replacing exhaust parts, make sure the new parts are exact replacements for the original parts. Doing this will ensure proper fit and alignment as well as ensure acceptable noise levels.

Exhaust system component replacement might require the use of special tools **(Figure 32–47)** and welding equipment. If it is necessary to weld exhaust components together, disconnect the battery negative cable to prevent damage to electronic components.

A new tool that often makes exhaust work easier is the induction heater. This tool uses high-frequency magnetic fields to excite and heat ferrous metal parts quickly and safely without a flame **(Figure 32–48)**.

Exhaust Manifold Servicing As mentioned, the manifold itself rarely causes any problems. On occasion, an exhaust manifold will warp because of excess heat. A straightedge and feeler gauge can be used to check the machined surface of the manifold.

Another problem—also the result of high temperatures generated by the engine—is a cracked manifold. This usually occurs after the car passes through a large puddle and cold water splashes on the manifold's hot surface. If the manifold is warped beyond manufacturer's specifications or is cracked, it must be replaced.

FIGURE 32–48 A Mini-Ductor® II can be used to heat bolts for easier removal.

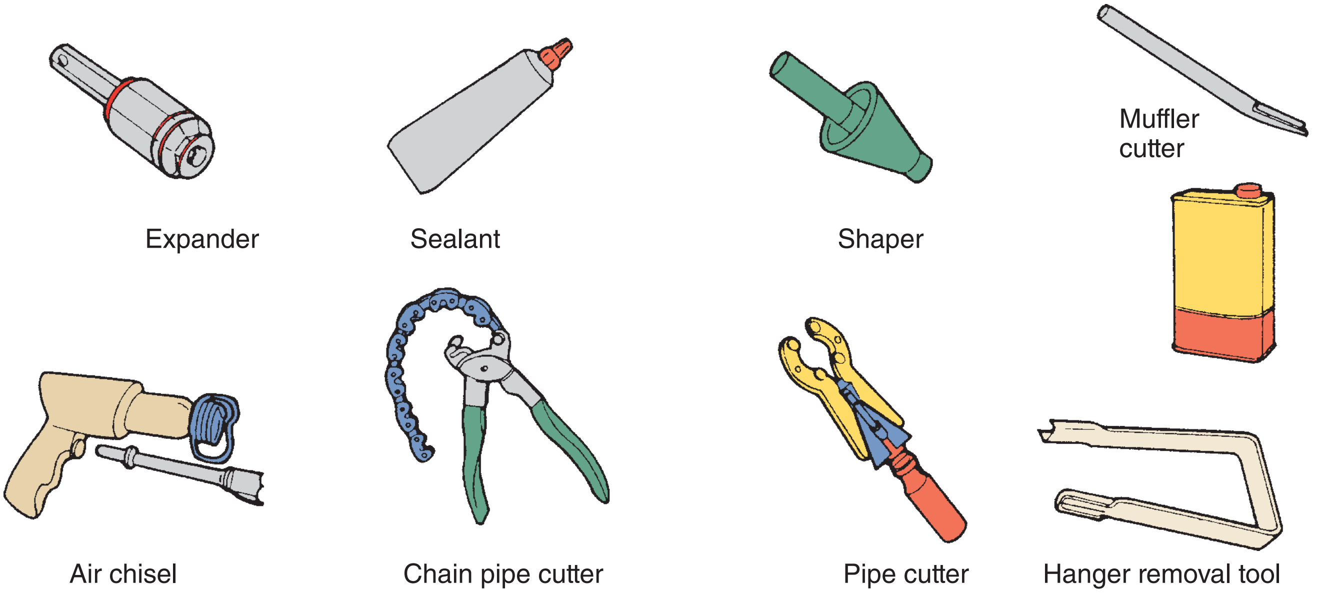


FIGURE 32–47 Special tools required for exhaust work.

FIGURE 32–49 Leaking gaskets and seals are often found between the exhaust manifold and pipe.

Replacing Leaking Gaskets and Seals The most likely spot to find leaking gaskets and seals is between the exhaust manifold and the exhaust pipe **(Figure 32–49)**.

Most often exhaust bolts are quite rusted and can be difficult to loosen. This is why it is wise to soak the bolts and nuts with penetrating fluid before attempting to disassemble the system **(Figure 32–50)**.

When installing exhaust gaskets, carefully follow the recommendations on the gasket package label and instruction forms. Read through all installation steps before beginning. Take note of any of the original equipment manufacturer's recommendations in service information that could affect engine sealing. Manifolds warp more easily if an attempt is made to remove them while they are still hot. Remember, heat expands metal, making assembly bolts more difficult to remove and easier to break.

FIGURE 32–50 Before attempting to disassemble the exhaust system, spray all nuts and bolts with penetrating oil.

To replace an exhaust manifold gasket, follow the torque sequence in reverse to loosen each bolt. Repeat the process to remove the bolts. Doing this minimizes the chance that components will warp.

Any debris left on the sealing surfaces increases the chance of leaks. A good gasket remover will quickly soften the old gasket debris and adhesive for quick removal. Carefully remove the softened pieces with a scraper and a wire brush. Be sure to use a nonmetallic scraper when attempting to remove gasket material from aluminum surfaces.

Inspect the manifold for irregularities that might cause leaks, such as gouges, scratches, or cracks. Replace it if it is cracked or badly warped. File down any imperfections to ensure proper sealing of the manifold.

Retap and redie all threaded bores. This ensures tight, balanced clamping forces on the gasket. The most common cause of manifold warpage is incorrectly torqued manifold studs and nuts. Often when an exhaust manifold is removed, the studs for the manifold unthread with the nuts. Before reinstalling the manifold, separate the nuts from the studs and thoroughly clean both. In many cases it is best to replace the studs and nuts. Make sure that the studs and nuts are exact replacements for the original parts. Lubricate all threads with a high-temperature antiseize lubricant.

Apply a small amount of contact adhesive onto the mounting surface to hold the gasket in place. Align the gasket before the adhesive dries. Allow the adhesive to completely dry before installing the manifold.

Install the bolts or nuts finger-tight. Tighten them in three steps—one-half, three-quarters, and full torque. Always follow the specifications given for that engine. Normally the nuts should be tightened in a particular sequence. This sequence typically begins at the center and continues outward in an X pattern.

Replacing Exhaust Pipes In most cases, the exhaust system is replaced as a unit. Doing this ensures a proper fit and saves much time. However, there are times when only a section or component needs to be replaced. When doing this, take care not to damage any surrounding parts. To replace an exhaust pipe, support the converter to keep it from falling and remove the O_2S. Remove any hangers or clamps holding the exhaust pipe to the frame. Unbolt the flange holding the exhaust pipe to the exhaust manifold. Disconnect the pipe from the converter and pull the front exhaust pipe loose and remove it. If the pipe is sealed with a gasket, replace it when installing the new pipe.

> **Caution!** Be sure to wear safety goggles to protect your eyes and work gloves to prevent cutting your hands on the rusted parts.

When trying to replace a part in the exhaust system, you may run into parts that are rusted together. This is especially a problem when a pipe slips into another pipe or the muffler. If you are trying to reuse one of the parts, you should carefully use a cold chisel or slitting tool on the outer pipe of the rusted union. You must be careful when doing this, because you can easily damage the inner pipe. It must be perfectly round to form a seal with a new pipe.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2011	**Make:** Ford	**Model:** F-150	**Mileage:** 78,852	**RO:** 19127
Concern:	Customer states MIL on, engine lacks power.			
The technician confirms the MIL is on and pulls a P0299–underboost condition, from the computer. Upon inspection, she finds noise from the bank 1 turbo. She checks the oil level and finds it very low and looking like it has not been changed in a long time. Suspecting the turbo has failed due to lack of oil, she requests additional time to remove and inspect the turbocharger.				
Cause:	Found bank 1 turbo bearings, turbine, and compressor damaged. Oil supply line restricted and clogged with oil sludge.			
Correction:	Replaced bank 1 turbo. Flushed and cleaned oil supply lines to both turbos. Changed engine oil.			

KEY TERMS

Backpressure
Catalytic converter
Intercooler
Muffler
Resonator
Supercharger
Tailpipe
Turbocharger
Turbo lag
Wastegate

SUMMARY

- The reason air enters the engine's cylinders is a basic law of physics—high pressure always moves toward an area of low pressure. Therefore, outside air moves into the cylinders because of the vacuum formed on the intake stroke.
- The vacuum in the intake manifold operates many systems such as emission controls, brake boosters, heater/air conditioners, cruise controls, and more. Vacuum is applied through an elaborate system of hoses, tubes, and relays. A diagram of emission system vacuum hose routing is located on the underhood decal. Loss of vacuum can create many driveability problems.
- The air induction system allows a controlled amount of clean, filtered air to enter the engine. Cool air is drawn in through a fresh air tube. It passes through an air cleaner before entering the throttle body.
- The intake manifold distributes the air or air-fuel mixture as evenly as possible to each cylinder. Intake manifolds are made of cast iron, aluminum, or plastic.
- Two approaches can be used to increase an engine's volumetric efficiency. One is to modify the internal configuration of the engine to increase the compression ratio. Another way is to increase the quantity of the intake charge; this is done by turbocharging or supercharging.
- Some turbocharged and supercharged engines are equipped with an intercooler that is designed to cool the compressed air from the turbocharger or supercharger.
- A turbocharger does not require a mechanical connection between the engine and pressurizing pump to compress the intake gases. It relies on the rapid expansion of hot exhaust gases exiting the cylinders to spin turbine blades.

- A typical turbocharger consists of a turbine, shaft, compressor, and housings. A wastegate manages turbo output by controlling the amount of exhaust gas that is allowed to enter the turbine housing.
- Turbochargers are lubricated by pressurized and filtered engine oil that is line fed to the unit's oil inlet.
- Reducing the diameter of the turbine and compressor wheels reduces turbo lag but limits the amount of boost. Using two small-diameter turbos provides good boost and very little turbo lag.
- If the turbo sound cycles or changes in intensity, the likely causes are a plugged air cleaner or loose material in the compressor inlet ducts or dirt buildup on the compressor wheel and housing. Most turbocharger failures are caused by one of the following reasons: lack of lubricant, ingestion of foreign objects, or contamination of lubricant. Turbo lag occurs when the turbocharger is unable to meet the immediate demands of the engine.
- Superchargers are air pumps connected directly to the crankshaft by a belt. The positive connection yields instant response and pumps air into the engine in direct relationship to crankshaft speed.
- A vehicle's exhaust system carries away gases from the passenger compartment, cleans the exhaust emissions, and muffles the sound of the engine. Its components include the exhaust manifold, exhaust pipe, catalytic converter, muffler, resonator, tailpipe, heat shields, clamps, brackets, and hangers.
- The exhaust manifold is a bank of pipes that collects the burned gases as they are expelled from the cylinders and directs them to the exhaust pipe. Engines with all the cylinders in a row have one or two exhaust manifolds. V-type engines have an exhaust manifold on each side of the engine. The exhaust pipe runs between the exhaust manifold and the catalytic converter.
- The catalytic converter uses the catalysts to change CO, HC, and NO_x into water vapor, CO_2, N, and O_2.
- The muffler consists of a series of baffles, chambers, tubes, and holes to break up, cancel out, and silence pressure pulsations. Two types commonly used are the reverse-flow and the straight-through mufflers.
- Some vehicles have an additional muffler called a resonator to further reduce the sound level of the exhaust. The tailpipe is the end of the pipeline carrying exhaust fumes to the atmosphere beyond the back end of the car. Heat shields protect vehicle parts from exhaust system heat. Clamps, brackets, and hangers join and support exhaust system components.
- Exhaust system components are subject to both physical and chemical damage. The exhaust can be checked by listening for leaks and by visual inspection. Most exhaust system servicing involves the replacement of parts.

REVIEW QUESTIONS

Short Answer

1. What is the difference between psia and psig readings?
2. Describe two methods to check for a restricted exhaust system.
3. What is acoustic supercharging?
4. Describe the basic operation of an intake manifold runner control (IMRC) system.
5. Why is an intercooler used on turbocharged and supercharged engines?
6. Why is a wastegate not needed on a supercharger?

True or False

1. *True or False?* All wastegates are controlled by the PCM.
2. *True or False?* Engine misfires can cause a catalytic converter to overheat.

Multiple Choice

1. A mini-converter is used ___.
   a. on small vehicles where a normal converter will not fit properly
   b. on engines that use leaded fuels
   c. in conjunction with EGR systems to supply clean exhaust for the cylinders
   d. to reduce emissions during engine warmup
2. A restricted exhaust system can cause ___.
   a. stalling
   b. loss of power
   c. backfiring
   d. all of the above

3. Which of the following is *not* characteristic of a supercharger?
   a. It is used to increase engine power by compressing the air that goes into the combustion chambers.
   b. It usually is located close to the exhaust manifold.
   c. It utilizes a belt-driven pulley.
   d. It requires a mechanical connection between the engine and the pressurizing pump to compress the intake gases.
4. Ten psi of turbo boost means that air is being fed into the engine at ___ when the engine is operating at sea level.
   a. 4.7 psia
   b. 10 psia
   c. 14.7 psia
   d. 24.7 psia
5. What manages turbo output by controlling the amount of exhaust gas entering the turbine housing?
   a. Wastegate
   b. Turbine seal assembly
   c. Turbine
   d. Compressor
6. What is the first step in turbocharger inspection?
   a. Check the air cleaner for a dirty element.
   b. Open the turbine housing at both ends.
   c. Start the engine and listen to the system.
   d. Remove the ducting from the air cleaner to the turbo and examine the area.
7. Which of the following statements concerning superchargers is incorrect?
   a. Superchargers must overcome inertia and spin up to speed as the flow of exhaust gas increases.
   b. Superchargers do not require a wastegate to limit boost.
   c. A bypass is designed into the system to allow the supercharger to idle along when extra power is not needed.
   d. Superchargers improve horsepower and torque.

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that a turbocharger has its own self-contained lubrication system. Technician B says that a turbocharger should not be operated when the engine's oil pressure is lower than 30 psi. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. Technician A makes sure that the exhaust system is cool to the touch before working on it. Technician B disconnects the battery's negative cable before welding an exhaust pipe. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. Technician A says vacuum refers to any pressure that is greater than atmospheric pressure. Technician B says vacuum changes based on altitude. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. Technician A uses sandpaper to remove carbon deposits from turbocharger wastegate parts. Technician B scrapes off heavy deposits before attempting to clean the unit. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Technician A says that a vacuum leak results in less air entering the engine, which causes a richer air-fuel mixture. Technician B says that a vacuum leak can cause the engine to run poorly. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

6. Technician A says that vacuum hose routing for the entire vehicle is illustrated on the underhood decal. Technician B says that this decal illustrates emission system vacuum hose routing. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. Before replacing any exhaust system component: Technician A soaks all old connections with penetrating oil. Technician B checks the old system's routing for critical clearance points. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. A vehicle's intake manifold is warped: Technician A says the manifold may need to be replaced. Technician B says the manifold may be able to be filed flat and reused. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. Technician A says that the catalytic converter is used only to quiet the noise of the exhaust. Technician B says that the catalytic converter is used to alter the contents of the engine's exhaust. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. Technician A says that the exhaust manifold gasket seals the joint between the exhaust manifold and the exhaust pipe. Technician B says that a resonator helps to reduce exhaust noise. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

EMISSION CONTROL SYSTEMS

CHAPTER 33

OBJECTIVES

- Explain why hydrocarbon (HC) emissions are released from an engine's exhaust.
- Describe how oxides of nitrogen (NO_x) are formed in the combustion chamber.
- Determine the causes of increased exhaust emissions. Describe oxygen (O_2) emissions in relation to air-fuel ratio.
- Describe the operation of an evaporative control system during the canister purge and nonpurge modes.
- Explain the purpose of the positive crankcase ventilation system.
- Describe the purpose and operation of an exhaust gas recirculation (EGR) valve.
- Define the purpose of a catalytic converter.
- Describe the operation of a secondary air injection system.
- Describe the emission controls commonly found on today's light-duty diesel engines.

The emission controls on today's cars and trucks are an integral part of the engine and electronic engine control system. Perhaps it is better to say that the electronic control systems are really emission control systems. The drive to have cleaner and more fuel-efficient vehicles has led to many of the control systems now in place. These systems have also contributed to significant increases in power and reliability and improved driveability.

Pollutants

Automotive emissions that are of the most concern to environmentalists, engineers, manufacturers, and technicians are hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), carbon dioxide (CO_2), and oxygen (O_2). These gases contribute to air and water pollution and climate change. The exception to this is O_2, which is not a pollutant. Oxygen emissions are, however, an indication of the completeness of the combustion process. The O_2 content in an engine's exhaust also is monitored during emissions inspections to detect holes in the exhaust pipes or broken pipes. Both of these would dilute the exhaust sample.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2016	**Make:** Toyota	**Model:** Sienna	**Mileage:** 28,242	**RO:** 19188
Concern:	Customer states MIL on.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

An exhaust gas that is not monitored in most emissions testing is sulfur dioxide (SO_2). This is a colorless gas that has a rotten egg smell. It is caused by large amounts of sulfur content in gasoline and is produced by the action of the catalytic converter. Sulfur dioxide can cause heart problems, asthma, and other respiratory problems.

HC, NO_x, and CO emissions are caused by many different things; the most important are temperatures at different spots within the combustion chamber and the air-fuel ratio. It is interesting to note that the conditions for minimizing HC emissions are the same as those that cause high NO_x emissions **(Figure 33–1)**.

The allowable amounts of automobile emissions are regulated by the government. Through the years, the maximum allowable amount emitted by an automobile has decreased **(Figure 33–2)**. Before you can understand the purpose of each emission control device and how to diagnose and service them, you must have an understanding of why these gases are emitted by an automobile.

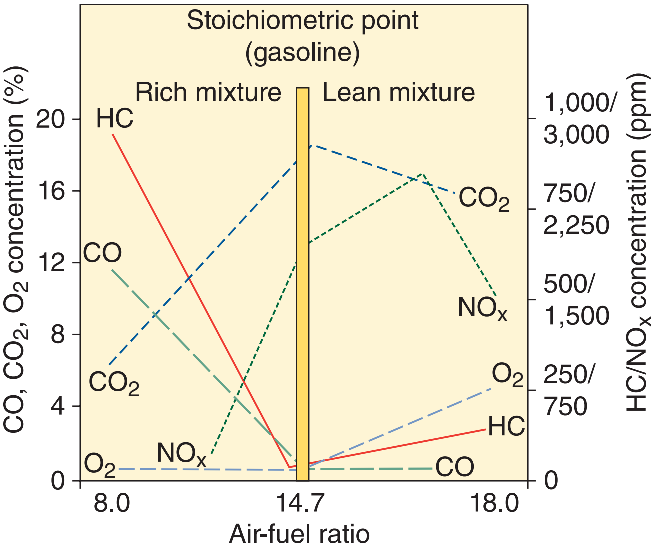


FIGURE 33–1 This chart shows how difficult it is to control exhaust emissions. Notice that NO_x and CO_2 are high when the HCs are low.

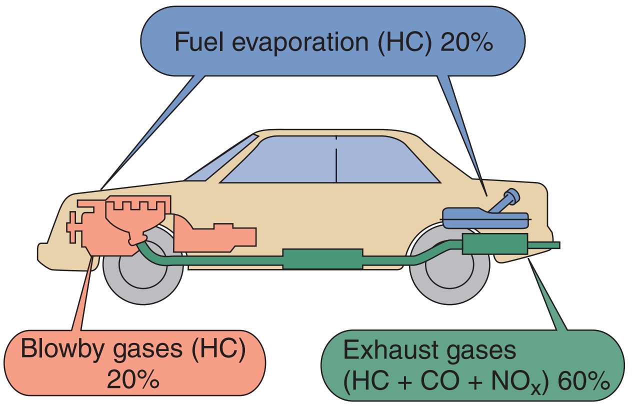


FIGURE 33–2 The main sources of automotive emissions.

All vehicles for the past 40 or more years are equipped with devices that reduce the levels of emissions released by the exhaust system. These are commonly referred to as "tailpipe" emissions. The following discussion of the various gases addresses their formation before they are reduced by the various emission control devices.

Hydrocarbons

Hydrocarbon (HC) exhaust emissions are caused by incomplete combustion, and these emissions are actually molecules of unburned or partially burned fuel. Even an engine in good condition with satisfactory ignition and fuel systems will release some HC. Evaporative emissions from the fuel storage and delivery system are also a source of HC emissions.

HC emissions from the combustion process result when the following occur:

- The air-fuel mixture is compressed into the small sheltered areas of the combustion chamber, where the flame front cannot ignite the fuel. These include the areas formed by the top piston ring and the cylinder wall, any crevices formed by the head gasket, spark plug threads, and the valve seat.
- Fuel is absorbed by the oil on the walls of the cylinder.
- Fuel is absorbed by and/or is contained within carbon deposits in the combustion chamber.
- When the flame front approaches the cooler cylinder wall, the flame front quenches, leaving some unburned HCs.
- Some of the air-fuel mixture is left unburned because the flame front stops before igniting all of the mixture (misfire).
- The fuel does not adequately mix with the air and ignite prior to the end of combustion.
- There is a misfire caused by an ignition system fault.

An excessively lean air-fuel ratio results in cylinder misfiring and high HC emissions. A very rich air-fuel ratio also causes higher-than-normal HC emissions. At the stoichiometric air-fuel ratio, HC emissions are low.

Carbon Monoxide

Carbon monoxide (CO) is a by-product of combustion. CO is a poisonous chemical compound of carbon and oxygen. CO is a colorless, odorless, and

highly poisonous gas that can cause dizziness, headaches, impaired thinking, and death by O_2 starvation. It forms in the engine when there is not enough O_2 to combine with the carbon during combustion. When there is enough O_2 in the mixture, carbon dioxide (CO_2) is formed. CO_2 is not a pollutant and is the gas used by plants to manufacture oxygen. Carbon monoxide is primarily found in the exhaust but can also be in the crankcase.

Carbon monoxide emissions are caused by a lack of air or too much fuel in the air-fuel mixture. Carbon monoxide will not occur if combustion does not take place in the cylinders; therefore, the presence of CO means combustion is taking place. As the air-fuel ratio becomes richer, the CO levels increase **(Figure 33–3)**. At the stoichiometric air-fuel ratio, the CO emissions are very low. If the air-fuel ratio is leaner than stoichiometric, the CO emissions remain very low. Therefore, CO emissions are a good indicator of a rich air-fuel ratio, but they are not an accurate indication of a lean air-fuel ratio.

Nitrogen Oxides

Nitrogen oxides (NO_x) are the various compounds of nitrogen and O_2 formed during the combustion process. Both nitrogen and O_2 are present in the air used for combustion. Exposure to NO_x can cause respiratory problems, such as lung irritation, bronchitis, or pneumonia. Photochemical smog results when HCs

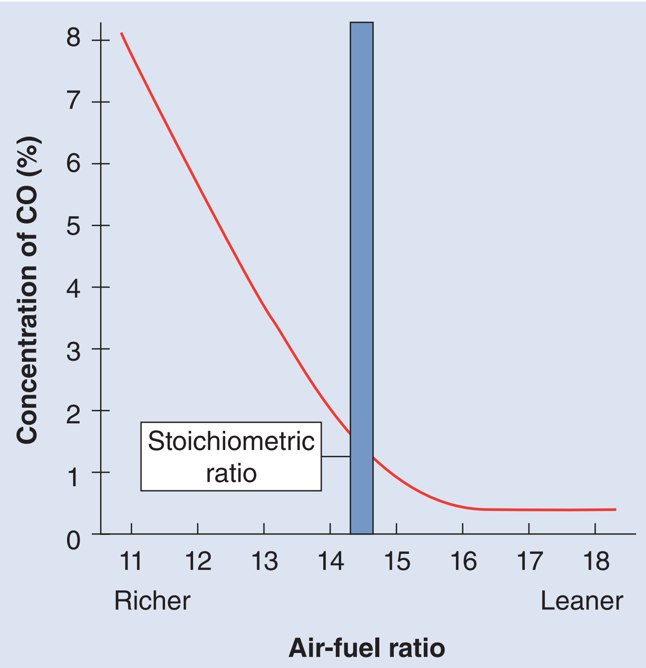


FIGURE 33–3 The amount of CO in the exhaust varies with the air-fuel mixture.

SHOP TALK

It is often said that NO_x forms at 2,500 °F (1,371 °C); studies have shown that the formation of NO_x actually begins around 2,300 °F (1,261 °C). The actual temperature is not really important; what is important is the thought that keeping combustion temperatures low keeps NO_x low.

and NO_x are combined with sunlight. Smog appears as brownish ground-level haze. Smog can cause many health problems, including chest pains, shortness of breath, coughing, wheezing, and eye irritation. When NO_x in the atmosphere mixes with rain (H_2O), nitric acid (HNO_3) or acid rain is created.

The formation of NO_x is the result of high combustion temperatures and pressures. When combustion temperatures reach more than 2,300 °F (1,261 °C), the N and the O_2 in the air begin to combine and form NO_x.

Because outside air is 78 percent N_2, the gas cannot be prevented from entering the engine. Therefore, the only way to control NO_x is to prevent N_2 from joining with oxygen during the combustion process. This is done by controlling the temperature of the combustion process. This, however, can be very tricky. When the mixture is slightly rich, the combustion temperature drops and there is less chance for the production of NO_x. However, a rich mixture will also lead to an increase in CO and HC emissions. Likewise, when the mixture is slightly lean there is less of a chance for CO and HC emissions, but there is a greater chance for the production of NO_x because combustion temperature increases.

The "x" in NO_x stands for the proportion of oxygen mixed with a nitrogen atom. The "x" is a variable, which means it could be the number 1, 2, 3, and so on, therefore, the term *NO_x* refers to many different oxides of nitrogen (NO, NO_2, NO_3, etc.). NO_x emissions from an engine are mostly nitric oxide (NO), with less than 1 percent of the total NO_x being nitrogen dioxide (NO_2). NO is unhealthy and contributes to the greenhouse effect. NO_2 is a very toxic gas and contributes to the formation of smog, ozone, and acid rain.

It is important to note that diesel engines (because combustion temperatures of the fuel are low) produce more NO_2 than gasoline engines. About one-third of the nitrogen converted in a diesel engine becomes NO_2.

Carbon Dioxide

Carbon dioxide (CO_2) is not a pollutant; however, it has been linked to another environmental concern—the "greenhouse effect." Carbon dioxide is a **greenhouse gas** and may be the major cause of global warming. The greenhouse effect simply defines the way an accumulation of gases around the earth hold the sun's rays, which causes everything inside the gases to experience a temperature increase. It is claimed that 14 percent of all CO_2 emissions in North America are from the exhaust of automobiles and 27 percent of the CO_2 is caused by all transportation.

From an efficiency standpoint, CO_2 is an ideal by-product of combustion. Therefore, large amounts of CO_2 in the exhaust are desired. As the air-fuel ratio goes from 9:1 to 14.7:1, the CO_2 levels gradually increase from approximately 6 percent to 13.5 percent. CO_2 levels are highest when the air-fuel ratio is slightly leaner than stoichiometric. The production of CO_2 is directly related to the amount of fuel consumed; therefore, more fuel-efficient engines produce less. Each gallon of gasoline can produce about 19.4 pounds (8.8 kg) of CO_2.

To put this in perspective:

- A vehicle that gets 10 mpg will emit 1.94 lb of CO_2 per mile, or 11.6 tons a year if driven 12,000 miles per year.
- A vehicle that gets 20 mpg will emit 0.97 lb of CO_2 per mile, or 6 tons a year if driven 12,000 miles per year.
- A vehicle that gets 30 mpg will emit 0.65 lb of CO_2 per mile, or 3.9 tons a year if driven 12,000 miles per year.

To reduce CO_2 levels in the exhaust, engineers are working hard to decrease fuel consumption. This, however, is difficult, because many of the methods used to increase fuel efficiency, such as lean mixtures, increase CO_2 and other emission levels. The concern for CO_2 emissions is one of the primary reasons for the continued exploration of alternative fuel and power sources for automobiles. It is also one of the main reasons the government has raised the CAFÉ mark to 35 mpg. In 2012, the government passed legislation raising the CAFÉ standard to 54.5 mpg by 2025, although that may change due to the manufacturers' cost in meeting that standard.

Other than being emitted from an engine's exhaust or the burning of fossil fuels, CO_2 is also emitted by nature. There are many natural sources of CO_2 such as the oceans and decaying plant life. Plants also use CO_2 in their photosynthesis process, which results in a release of oxygen to the atmosphere. Large amounts of CO_2 are also released by volcanic eruptions, which happen quite frequently. The current concern on global warming suggests that there is more CO_2 in the atmosphere than can be used by plant life. In fact, the more CO_2 molecules there are in the atmosphere, the warmer the earth gets.

To bring the amount of CO_2 in the atmosphere to an acceptable level, we need more plant life and we need to reduce the amount that is released to the atmosphere. A target for reducing CO_2 is the automobile. There are approximately one billion automobiles on the world's roads. They produce close to 20 percent of the world's total CO_2 emissions from burning fossil fuels **(Figure 33–4)**. The quantity of CO_2 emissions from vehicles is measured in grams per mile (g/mi.) or grams per kilometer (g/km).

Other substances are also considered greenhouse gases. These include water vapor, methane, and nitrous oxide. Greenhouse gases allow the light from the sun to freely enter the atmosphere. When the sunlight reaches the earth's surface, some of it is absorbed and warms the earth. The rest of the sunlight is reflected back to the atmosphere as heat. Greenhouse gases absorb and trap the heat. This process is considered to be the cause of global warming.

There are currently no standards for CO_2 emissions in North America; however, the European Union has standards that all new vehicles must meet. California and other states also are considering a CO_2 standard. Whether there is a CO_2 standard or not, the government is imposing new CAFÉ standards that will, in effect, reduce CO_2 emissions. Under current regulations, fleet wide CO_2 emissions

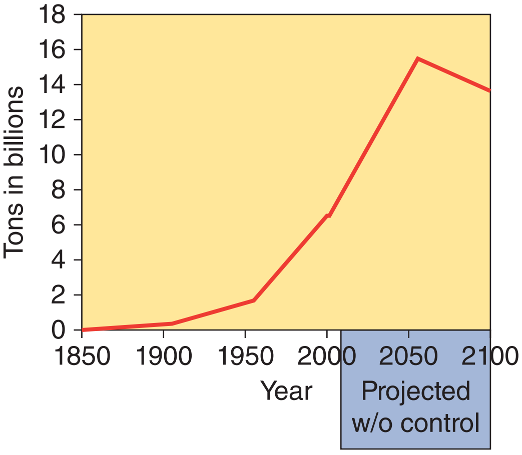


FIGURE 33–4 Total worldwide carbon emissions from burning fossil fuels.

are projected to be 163 grams/mile for the 2025 model year based on reaching the 54.5 mpg CAFÉ regulation. As of this writing, the 54.5 mpg standard is being reviewed by the current administration.

CO_2 Reduction at Factories Not only are manufacturers trying to reduce CO_2 levels emitted by the exhaust, they are also working to reduce the amount of greenhouse gases from their factories. GM, for example, announced a goal of reducing CO_2 emissions from its facilities by 40 percent by the year 2010. They are well on their way. The strategies to this include using less energy, reducing waste, increasing the use of renewable resources, and increasing the efficiency of the entire manufacturing process.

Oxygen

Oxygen (O_2) is not a pollutant; therefore, its presence in the exhaust does not pose any threat to our environment. However, too much oxygen in the exhaust does indicate that an improper air-fuel mixture or poor combustion has occurred in the engine.

If the air-fuel ratio is rich, all the oxygen in the air is mixed with fuel, and the O_2 levels in the exhaust are very low. When the air-fuel ratio is lean, there is not enough fuel to mix with all the air entering the engine, and O_2 levels in the exhaust are higher. Therefore, O_2 levels are a good indicator of a lean air-fuel ratio, and they are not affected by catalytic converter operation.

Water (H_2O)

Water (H_2O) should be emitted from a vehicle's exhaust. It is the result of oxidation, whereby HC is oxidized by the converter to form CO_2 and H_2O. The amount of water emitted depends on a number of things, including the effectiveness of the converter and the amount of HC and O_2 in the exhaust before it passes through the converter. Normally during cold engine startup, steam is emitted from the exhaust. The steam results from the heating of the water present in the converter and exhaust system. Much of this water is formed by condensation due to the cooling of the exhaust system.

Diesel Emissions

Diesel engines are the most efficient of all internal combustion engines. They have low fuel consumption rates and produce low amounts of greenhouse gases. However, there are exhaust emissions that are of concern. Some of these are currently regulated and others will be in the future. A typical diesel engine emits:

- Carbon (soot) and various carbon-based compounds
- NO_x
- Water
- Carbon monoxide
- Sulfur dioxide
- Various hydrocarbon-based compounds

Soot is the most obvious emission and is often referred to as diesel particulates. These particulates are mostly comprised of carbon-based substances that tend to absorb the other contaminants in a diesel engine's exhaust. Many factors influence the amount of soot released, including the fuel used and the engine design. Particulate emissions are the main obstacle for using diesel engines in passenger cars and light- and medium-duty trucks. California and other states have set a standard for particulate emissions. These standards will become more stringent as diesel technology advances. These emissions are measured in grams per mile or kilometer.

Emission Control Devices

According to a recent document based on a study by the Environmental Protection Agency (EPA), passenger cars are responsible for 17.8 percent of the total hydrocarbon emissions, 30.9 percent of the total carbon monoxide emissions, and 11.1 percent of the oxides of nitrogen emissions. After more than 40 years of emission regulations, these figures remain staggering. Imagine what these figures would be if automotive emissions had remained unregulated during the past 40 years!

Emission standards have been one of the driving forces behind many of the technological changes in the automotive industry. Catalytic converters and other emission systems were installed to meet emission standards. These standards have become progressively more stringent through the years, and the engine designs and devices required to meet the standards have become very complex.

Legislative History

The driving force behind the development of emission control devices has been the various federal

SHOP TALK

Through the years, vehicles have been built specifically for the State of California. The California Air Resources Board (CARB) has led the way for many emissions laws and standards. Many are specific to the state, although most of these have eventually been implemented by other states, provinces, and countries. Check the labeling on the vehicle to see if the vehicle has special equipment or calibrations designed for use in California and not found in vehicles for other states.

clean air acts put into effect over the years. The following are some key acts that have shaped the design of today's vehicles:

- The Clean Air Act of 1963 identified the automobile as a major contributor to air pollution and was responsible for as much as 40 percent of all emissions.
- The Clean Air Act Amendments of 1965 required auto manufacturers to install emissions control devices on all passenger cars and light trucks by the 1968 model year.
- The Clean Air Act Amendments of 1970 established nationwide air quality standards and linked federal building and highway funds to meeting those standards. Areas that did not meet the standards were required to institute a plan to correct the problem or lose the funds.
- The Clean Air Act Amendments of 1977 mandated that areas that did not meet air quality standards must establish and enforce basic inspection and maintenance (basic I/M) programs for all passenger cars and light trucks. The purpose of the I/M programs was to test and repair the effectiveness of all systems that affected vehicle emissions.
- The Clean Air Act Amendments of 1990 again reduced the allowable amount of exhaust emissions. However, the key part of this act was the required establishment of enhanced inspection and maintenance (enhanced I/M) programs in areas that did not meet air quality standards.
- The Energy Independence and Security Act of 2007 required a 40 percent increase in vehicle fuel economy by the year 2020. It also established mandates for increased use of renewable fuels. This act also focused on the reduction of CO_2 emissions, although no standard was set.

Inspection and Maintenance Programs

Emission standards set the maximum allowable amounts of emissions from a new automobile. These standards have become stricter through time. Amendments to the acts called for emission testing of vehicles on the road. These periodic tests are part of the inspection and maintenance (I/M) program. The purpose of these inspections is simply to identify those vehicles that have been tampered with or have not received good maintenance. Studies have shown that 20 percent of the vehicles on the road are not being properly maintained, and those vehicles account for more than 90 percent of the emissions from automobiles. I/M programs are designed to identify these vehicles and make the necessary repairs to allow those vehicles to have acceptable amounts of emissions.

The first Clean Air Act set emission standards for new cars. To make sure the new vehicles met these standards, the federal test procedure (FTP) was instituted. The test is performed on a random sample of preproduction vehicles. These vehicles are used to represent the vehicles for the next model year. Their emissions are carefully checked and compared to the standards established for that model year. If the emission levels meet or are lower than the standards, the vehicle is then certified.

The FTP uses an inertia weight dynamometer (dyno) that allows the vehicle to be driven under varying loads. The dyno is capable of simulating actual driving conditions that the test vehicle would encounter by changing the load applied to the drive wheels. Emission levels are measured with a constant volume sampling (CVS) system that measures the mass of HC, CO, CO_2, and NO_x emitted from the vehicle in grams per mile. These exhaust analyzers are much more precise, complex, and expensive than the exhaust analyzer found in most shops.

The act also prompted Californians to create CARB. CARB's purpose was to implement strict air standards, which later became federal standards. One of the approaches made by CARB to clean the air was to start periodic motor vehicle inspection (PMVI) programs. This inspection included a tailpipe

emissions test and an underhood inspection. The tailpipe test certifies that the vehicle's exhaust emissions (HC and CO) are within the limits of the law. The emissions were measured in parts per million (ppm) and were taken with the engine at idle. The allowable emissions are three to four times higher than those required for a new vehicle. This provides some tolerance for engine and system wear. The underhood and/or vehicle inspection verifies that the emission control systems have not been tampered with or disconnected. Today, California is not the only state that requires annual emissions testing. Many states have incorporated an emissions test with their annual vehicle registration procedures.

During the 1980s, this basic I/M program was changed to include tests conducted under a load with a dyno. This test was called the accelerated simulated mode (ASM). This test measured CO, HC, and NO_x emissions.

After the implementation of the Clean Air Act of 1990, more precise testing was instituted. The result is called the I/M 240 test. Many states have implemented an I/M 240 or similar program. The I/M 240 (or enhanced I/M) tests vehicle emissions while it is operating under a variety of load conditions and speeds. While on the dyno, the vehicle is operated for up to 240 seconds and under different load conditions **(Figure 33–5)**. The test drive on the dyno simulates both in-traffic and highway driving and stopping and includes the same conditions as the FTP. However, the I/M 240 test is only a small portion of a complete FTP.

The I/M 240 consists of three separate tests: (1) a transient, mass emission tailpipe test, (2) an evaporative system purge flow test, and (3) an evaporative system pressure test. The test results are given in the same increments as the FTP (grams per mile)

Image courtesy of Robert Bosch GmbH.

FIGURE 33–5 Emission levels are commonly checked with the vehicle running on a dyno.

and therefore can be directly related to the FTP standards. The test also measures HC, CO, CO_2, and NO_x emissions during the I/M 240 drive cycle.

Basically the same equipment used for the FTP is used for an I/M 240 test. A variable inertia weight dynamometer is used because it can be adjusted to match the weight of the vehicle and allows the vehicle to be driven under a variety of loads. Emission levels are determined by collecting the exhaust in a CVS and analyzing its contents through the use of very sophisticated equipment. This equipment is also similar to those used during the FTP; they include the following:

- Nondispersive infrared (NDIR) tester for measuring CO and CO_2
- Flame ionization detector (FID) for measuring HC
- Chemiluminescence detector for measuring NO_x

HC emissions from a vehicle's EVAP can be higher than the HC emissions in an engine's exhaust. Therefore, monitoring this system is an important part of the I/M 240 test. The I/M 240 test includes a visual inspection of the EVAP system and a purge volume and fuel tank pressure test. The purge test measures the flow of fuel vapors into the engine's intake during the test's drive cycle. The pressure test is used to check for leaks that would allow vapors to be released into the atmosphere.

Not all states use the I/M 240 test. Some states use the acceleration simulation mode (ASM) or ASM 2 test. In this test, a dynamometer is used to load the vehicle while an exhaust gas analyzer measures hydrocarbon, carbon monoxide, and nitrogen oxide levels. The ASM 2 test accelerates the vehicle to 15 mph using 50 percent of the vehicle's horsepower and the second test accelerates to 25 mph using 25 percent of the vehicle's horsepower.

The two speed idle (TSI) test is performed in some areas of the country. This test samples exhaust emissions at 2,500 rpm and at idle speed.

In addition to emission testing, visual inspections are also performed. The inspections typically include checking for any type of fuel leak, verifying the existence of the vehicle emission control information decal, checking all vacuum hoses are attached, and verifying that the proper emission control devices are installed.

Vehicle Emission Control Information (VECI)

All vehicles have a **vehicle emission control information (VECI)** decal that gives specific emission control information for that vehicle and engine **(Figure 33–6)**. These decals are normally located on

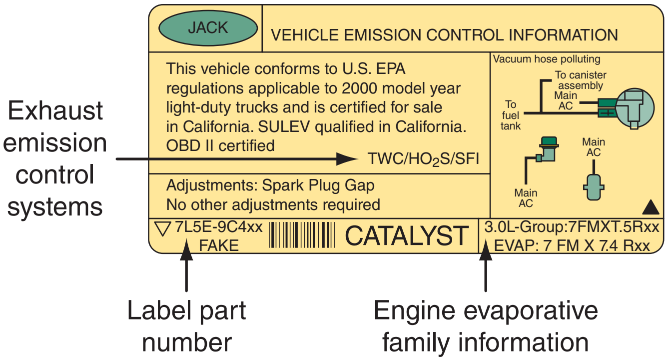


FIGURE 33-6 An example of a VECI.

the underside of the hood or on the radiator support frame. The information contained on the VECI is important when conducting an I/M test and when diagnosing or repairing an emissions-related problem. Most of the information contained on the decal is expressed by acronyms; **Figure 33–7** gives some examples of these.

Acronym	Definition
CARB	California Air Resource Board
CI	Cylinder Injection
EPA	Environmental Protection Agency
EVAP	Evaporative Emissions
GVW	Gross Vehicle Weight
GVWR	Gross Vehicle Weight Rating, curb weight plus payload
HO_2S	Heated Oxygen Sensor
ILEV	Inherently Low Emission Vehicle
LDDT	Light-Duty Diesel Truck categories
LEV	Low Emission Vehicle
LVW	Loaded Vehicle Weight, curb weight plus 300 lb (136.08 kg)
MDV	Medium-Duty Vehicle
MHDDE	Medium Heavy-Duty Diesel Engine
MPI	Multi-Port Injection
MY	Model Year
NCP	Non-Compliance Penalty
OBD	On-Board Diagnostic
ORVR	On-Board Refueling Vapor Recovery
PC	Passenger Car
PZEV	Partially Zero Emission Vehicle
SFI	Sequential Fuel Injection
SULEV	Super Ultra-Low Emission Vehicle
TWC	Three-Way Catalyst
ULEV	Ultra-Low Emission Vehicle
ZEV	Zero Emission Vehicle

FIGURE 33-7 Vehicle emission control information (VECI) acronym definitions.

Engine/Evaporative Emission System Information Since 1994, all manufacturers must use a standardized system to identify their individual engine and EVAP system families. These names must be twelve characters long and are shown in a box on the VECI. The first twelve-character ID contains the size of the engine and its family group. On the second line is another twelve-character ID. This identifies the family name of the EVAP system. Both of these names are specific to that vehicle.

Base Engine Calibration Information Important engine (powertrain) calibration information is normally given in the lower right-hand corner of the vehicle's certification label. The vehicle certification label is typically affixed on the left front door or door post. Base engine calibration information is limited to a maximum of five characters per line and no more than two lines. This coding is used during diagnostics and service. The certification label also contains a coded description of the vehicle.

Classifications of Emission Control Devices

All emission control systems fall into one of three classifications: evaporative control systems, precombustion, and postcombustion.

The evaporative control (EVAP) system is a sealed system. It traps the fuel vapors (HC) that would normally escape from the fuel delivery system into the air.

Most pollution control systems used today prevent emissions from being created in the engine, either during or before the combustion cycle. The common **precombustion control** systems are the PCV, engine modifications, spark control, and exhaust gas recirculation (EGR) systems.

Postcombustion control systems clean up the exhaust gases after the fuel has been burned. Secondary air or air injector systems put fresh air into the exhaust to reduce HC and CO to harmless water vapor and carbon dioxide by a chemical (thermal) reaction with oxygen in the air. Catalytic converters are the most effective postcombustion emission control; they reduce NO_x, HC, and CO emissions.

Evaporative Emission Control Systems

Fuel vapors from the gasoline tank and the carburetor float bowl were brought under control with the introduction of EVAP systems. These systems were first installed in 1970 model cars sold in California and in most domestic-made cars beginning with

1971 models. Through the years, EVAP emissions have been closely monitored and the control systems modified to minimize the chances of vapors entering the atmosphere. EVAP emissions are limited by law, and the current limit in the United States is two grams of HC per hour. EVAP emissions are even lower on vehicles classified as CARB LEV II vehicles.

Current systems are computer controlled and are monitored by the OBD II system. Most current EVAP systems include the following components:

- A domed fuel tank in which its upper portion is raised. Fuel vapors rise to this upper portion and collect.
- Canister vent solenoid valve
- A special filler design to limit the amount of fuel that can be put in the tank.
- Fuel tank vacuum or pressure sensor
- Fuel lines
- Vapor lines
- Fuel tank cap
- A vapor separator in the top of the fuel tank **(Figure 33–8)**
- Charcoal (EVAP) canister
- Purge lines
- Purge solenoid valve (vapor management valve)

GO TO Chapter 25 for a detailed discussion on engine control systems.

Fuel tanks are sealed units and are designed to prevent vapors that result from the evaporation of the gasoline from entering the atmosphere. Also, special devices are used to reduce the amount of gas vapors that escape from the fuel tank while the vehicle is being refueled. When the fuel cap is removed on all late-model vehicles, the filler neck is sealed with a hinged and spring-loaded flap. The size of the flap is large enough to allow an unleaded fuel nozzle to enter but too small for a leaded nozzle. Gasoline pump nozzles have also been modified to prevent fuel vapors from entering the atmosphere during refueling. Some nozzles are equipped with a rubber boot that seals the nozzle to the filler neck. Other nozzles are designed to create a vacuum that draws in vapors as the liquid fuel is being pumped into the tank. Late-model vehicles have an on-board refueling vapor recovery (ORVR) system, and the special nozzles are redundant and not really needed. ORVR systems seal the filler pipe during refueling and fuel vapors are sent to the EVAP canister.

The EVAP system moves the built-up vapors to a canister where they are stored until the system purges the canister and allows the vapors to enter the intake manifold. The EVAP system also allows some atmospheric pressure to enter the tank. This prevents the buildup of vacuum in the tank that could cause the tank to collapse.

Fuel vapors inside the fuel tank are vented at the top of the tank through the vapor separator. The separator collects droplets of liquid fuel and directs them back into the tank. The vapors leave the separator and move to the canister through the vapor line.

The **charcoal** (carbon) **canister (Figure 33–9)** is normally located in the engine compartment, but may be under the vehicle close to the fuel tank **(Figure 33–10)**. Fuel vapors from the gas tank are routed to and absorbed onto the surfaces of the canister's charcoal granules. When the vehicle is restarted, vapors are drawn by the vacuum into the intake manifold to be burned by the engine. Canister purging varies widely with vehicle make and model. On new vehicles, the PCM controls when the canister will be purged. In some instances a

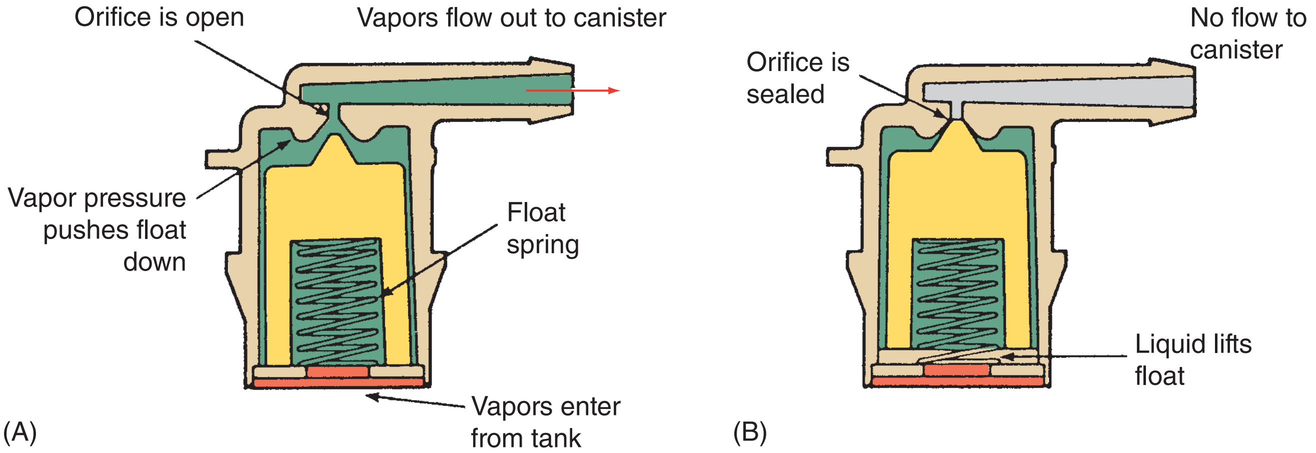


FIGURE 33–8 (A) Normal operation of a vapor separator, (B) with liquid in the separator.

FIGURE 33-9 A charcoal canister.

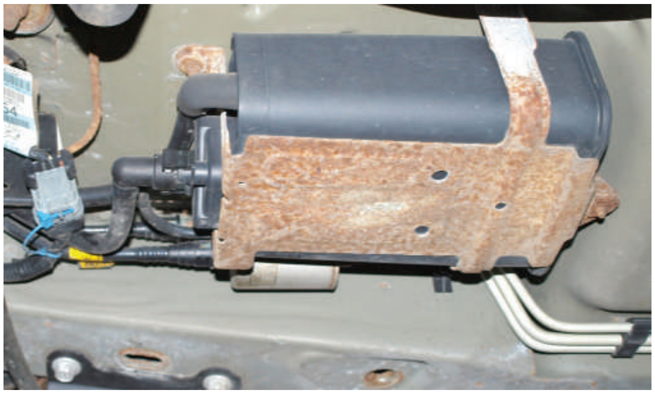


FIGURE 33-10 A charcoal canister mounted under the vehicle.

fixed restriction allows constant purging whenever there is manifold vacuum. In others, a staged valve provides purging only at speeds above idle.

The **canister purge valve** is normally closed. It opens the inlet to the purge outlet when vacuum is applied. Older systems often incorporate a thermal delay valve so the canister is not purged until the engine reaches operating temperature. Purging at idle or with a cold engine creates other problems, such as rough running and increased emissions because of the additional vapor added to the intake manifold.

The canister contains a liquid fuel trap that collects any liquid fuel entering the canister. Condensed fuel vapor forms liquid fuel. This liquid is returned from the canister to the tank when a vacuum is present in the tank. This liquid fuel trap prevents liquid fuel from contaminating the charcoal in the canister.

Warning! Gasoline vapors are extremely explosive! Do not smoke or allow sources of ignition near any component of the EVAP system. Explosion of gasoline vapors may result in property damage or personal injury.

Early EVAP systems were not controlled by the PCM but instead relied on a ported vacuum purge port, a vacuum check valve, and a thermo vacuum valve (TVV). The latter was used to prevent purging when the engine was cold. The canister was purged whenever the throttle plate was open enough to expose the vacuum port to engine vacuum. The vacuum then opened the check valve to allow vapors to move to the intake manifold. The check valve also served to keep the system sealed when the engine was not running. The amount of purged vapors was controlled by a fixed orifice. This meant that any time the controlling port had vacuum, the same amount of fuel vapors was sent to the engine, regardless of engine load or speed. This resulted in driveability problems during some conditions because the air-fuel mixture became too rich.

To gain more control of canister purging, the EVAP operation is now controlled by the PCM. These systems use a purge solenoid valve that is duty cycled by the PCM. The solenoid controls the vacuum to the canister, therefore controlling the amount of vapors purged. The purge valve is only open and controlled when the system is in closed loop, and then it only opens when the engine and conditions can respond to the extra enrichment of the vapors. Factors that can determine when purging takes place include engine coolant temperature and vehicle speed.

PCM-controlled EVAP systems allow for precise control of purge flow and vapor volume. Because the system responds to current engine and operating conditions, the purging of the vapors does not affect driveability.

Enhanced Evaporative Emission (EVAP) System

To meet OBD II regulations, late-model vehicles have an enhanced EVAP system. Enhanced EVAP

systems operate in much the same way as previous PCM-controlled EVAP systems, but they also conduct tests that can detect small, 0.020 inch (0.5 mm) system leaks and monitor canister purge flow. The tests are only run when certain conditions are present. These conditions vary with make, model, and engine type.

These systems have a fuel tank pressure (FTP) sensor and EVAP canister vent (CV) solenoid in addition to typical EVAP components **(Figure 33–11)**. Some systems are also equipped with a pump often called the leak detection pump (LDP). The CV solenoid seals the charcoal canister from the atmosphere when the system is conducting the leak check monitor. The FTP sensor measures pressure or vacuum in the fuel tank and compares it to atmospheric pressure. This input is also used to check for pinched or restricted vapor lines **(Figure 33–12)**. A vacuum is created in the system during the leak test; the FTP sensor measures the vacuum at the beginning of the test and again after a fixed period. If vacuum cannot be built into the system, or if the system will not hold a vacuum, a leak is evident. A signal fuel level input (FLI) sensor is used during the leak check to determine how much fuel is in the tank. This determines how long it should take to build a vacuum in the tank. The FLI input is also used to determine if the EVAP and other monitors can run. Too low or too high of a fuel level will not allow the monitors to run.

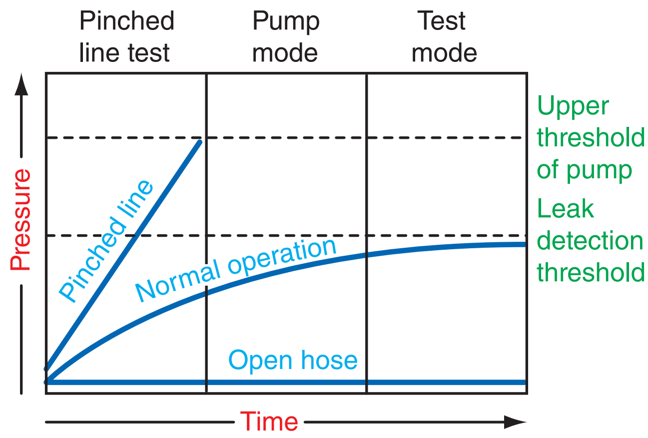


FIGURE 33–12 The rate of pressure buildup determines if the system has pinched lines or a leak, or if it is operating normally.

On systems with an LDP, the PCM turns on the pump when it is checking the system. The pump pressurizes the system. As pressure builds, the cycling rate of the pump decreases. If there is no leak in the system, the pressure will build until the

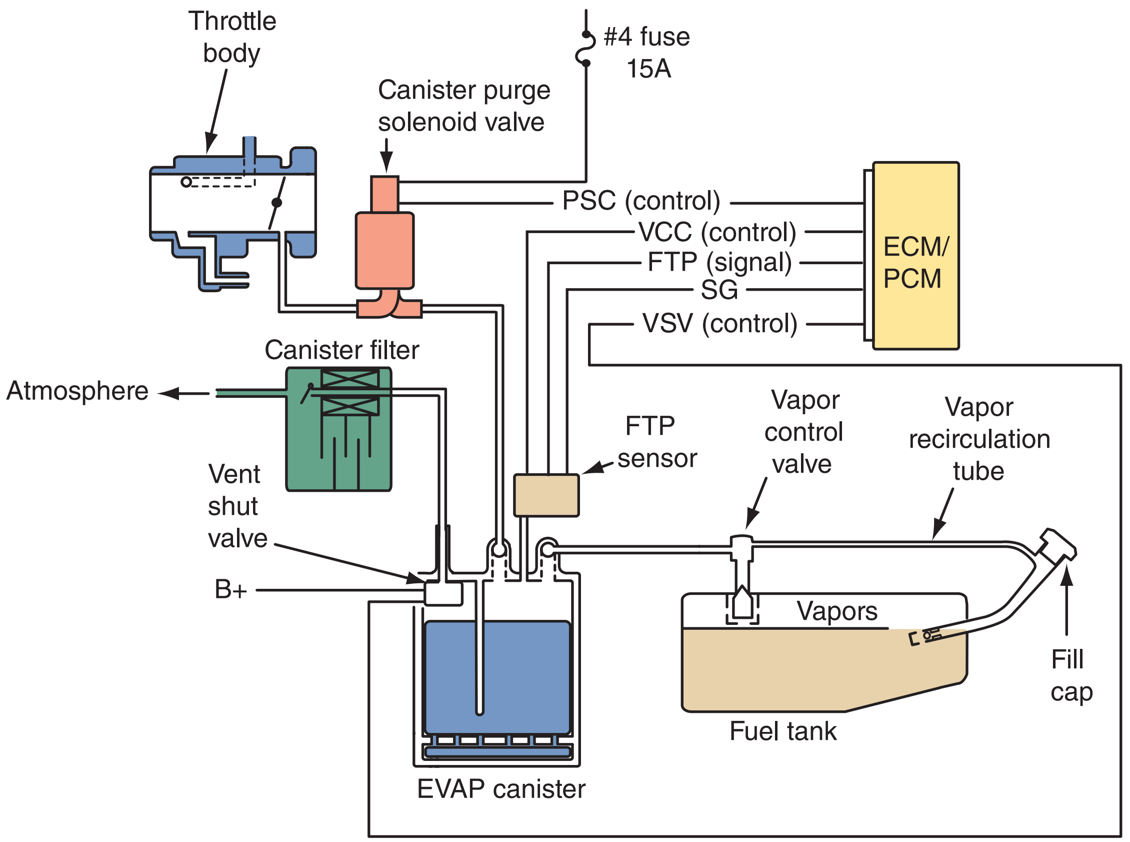


FIGURE 33–11 A diagram of an enhanced EVAP system.

pump shuts off. If there is a leak, pressure will not build up and will not shut down the pump. The pump will continue to run until the PCM determines it has run a complete test cycle.

If the PCM senses that there is no leak in the system, it will run the purge monitor. This test is completed by calculating or measuring the amount of vapors that are being purged. In many systems, the PCM calculates the purge flow based on MAF or MAP sensor data and compares it to FTP or fuel trim data. When fuel trim is used, the purge monitor determines if the purge system is functioning properly by applying a long duty cycle to the purge solenoid. The subsequent change in STFT is monitored. If the system is working correctly as the duty cycle of the solenoid is increased, the STFT should change proportionately. This is the most commonly used method for checking the operation of the purge system.

Other systems use a purge flow sensor connected to a vacuum hose between the purge solenoid and the intake manifold. The PCM monitors the signal from the sensor once per drive cycle to determine if there is vapor flow or no vapor flow through the solenoid to the intake manifold. Other EVAP systems have a vapor management valve connected in the vacuum hose between the canister and the intake manifold. The vapor management valve is a normally closed valve. The PCM operates the valve to control vapor flow from the canister to the intake manifold. The PCM also monitors the valve's operation to determine if the EVAP system is purging vapors properly. If no leaks are present and the purge cycle is correct, the system has passed the test.

If the gas cap is off or loose during the leak test, the PCM will detect this large leak and the warning lamp will illuminate. With this leak, the system will not continue its leak test.

SHOP TALK

It may be impossible to refuel a late-model vehicle when the engine is running. This is normal! If the PCM is conducting a check of the EVAP system, the vent valve will be closed and the resultant pressure in the tank will stop fuel flow from the gas pump's nozzle. This means it will be impossible to fill the tank.

Precombustion Systems

Systems designed to prevent or limit the amount of pollutants produced by an engine are called precombustion emission control devices. Although there are specific systems and engine designs that are classified this way, anything that makes an engine more efficient can be categorized as a precombustion emission control device.

Engine Design Changes

The basic engine has been modified through the years to increase its overall efficiency. Many of the changes have occurred inside the engine. Others involve the fuel and ignition systems. The result of these changes is improved performance and driveability and a decrease in exhaust emissions. Following is a summary of some of those changes.

- *Better sealing pistons:* Blowby gases are reduced through the use of better sealing piston rings and improved cylinder wall surfaces. Many engines are also fitted with low-friction piston rings. This increases fuel economy and engine power. In addition, the piston rings are located higher up on the piston, reducing the space for the mixture to get trapped between the piston and cylinder wall.
- *Combustion chamber designs:* The primary goal in designing combustion chambers is the reduction or elimination of the quench area. Another trend in combustion chamber design is locating the spark plug closer to the center of the chamber. Manufacturers have also worked with designs that cause controlled turbulence in the chamber. This turbulence improves the mixing of the fuel with the air, which improves combustion.
- *Lower compression:* For some engine designs, by keeping the compression ratio low, combustion temperatures can be kept below the point where NO_x is formed. However, new developments have allowed the use of higher compression ratios on some high-performance engines.
- *Higher compression:* Many newer engines are using high compression to extract more power out of combustion. This is possible with improved designs for pistons, exhaust systems, and by using gasoline direct injection to create a stratified air-fuel charge near the spark plug.

- *Decreased friction:* Overcoming the friction of the engine's moving parts reduces the power and energy lost during engine operation. Improved engine oils, new component materials, and weight reductions have had the biggest impact on reducing friction.
- *Intake manifold designs:* Thanks to the wide and successful use of port fuel injection, intake manifolds are designed to distribute equal amounts of air to each cylinder. The use of plastic intake manifolds has allowed for smoother runners and better heat control of the air.
- *Improved cooling systems:* High engine temperatures reduce HC and CO emissions. However, they also make the formation of NO_x harder to control. Engine cooling systems are designed to run at high temperatures but are prevented from getting too hot, thereby limiting the production of NO_x. Today's engine control systems incorporate many features that change the air-fuel mixture, ignition timing, and idle speed to control the engine's temperature.
- *Spark control systems:* Spark control systems have been in use since the earliest gasoline engines. It was discovered that the proper timing of the ignition spark helped to reduce exhaust emissions and develop more power output. Incorrect timing affects the combustion process. Incomplete combustion results in HC emissions. High CO emissions can result from incorrect ignition timing. Advanced timing can also increase the production of NO_x. When timing is too far advanced, combustion temperatures rise. For every 1° of overadvance, the temperature increases by 125 °F (51.57 °C). Spark control on today's engines is handled by the PCM. Through input signals from various sensors, the PCM adjusts ignition timing for optimal performance with minimal emissions levels.

PCV Systems

In late 1959, California established the first standards for automotive emissions. In 1967, the federal Clean Air Act was amended to provide standards that applied to automobiles. The first controlled automotive emission was crankcase vapors. During combustion some unburned fuel and other products of combustion leak past the piston rings and move into the crankcase. This leakage is called blowby. Blowby gases are largely HC gases. The PCV systems route the gases, which are mixed with outside air, into the engine's intake. From there the gases are drawn into the cylinders and burned. PCV systems were installed on all cars beginning with the 1963 models.

Blowby must be removed from the engine before it condenses in the crankcase and reacts with the oil to form sludge. Sludge, if allowed to circulate with engine oil, corrodes and accelerates the wear of pistons, piston rings, valves, bearings, and other internal parts of the engine. Blowby also carries some unburned fuel into the crankcase. If not removed, the unburned fuel dilutes the engine's oil. When oil is diluted, it does not lubricate the engine properly, which causes excessive wear.

Blowby gases must also be removed from the crankcase to prevent premature oil leaks. Because these gases enter the crankcase by the pressure created during combustion, they pressurize the crankcase. The gases exert pressure on the oil pan gasket and crankshaft seals. If the pressure is not relieved, oil is eventually forced out of these seals.

Operation The PCV system uses engine vacuum to draw fresh air through the crankcase. This fresh air enters through the air filter or through a separate PCV breather filter.

When the engine is running, intake manifold vacuum is supplied to the PCV valve. This vacuum moves air through the clean air hose into the rocker arm or camshaft cover. From there, the air flows through openings in the cylinder head into the crankcase where it mixes with blowby gases. The mixture of blowby gases and fresh air flows up through the cylinder head to the PCV valve. Vacuum draws the blowby gases through the PCV valve into the intake manifold **(Figure 33–13)**. The blowby gases mix with the intake air and enter the combustion chambers where they are burned.

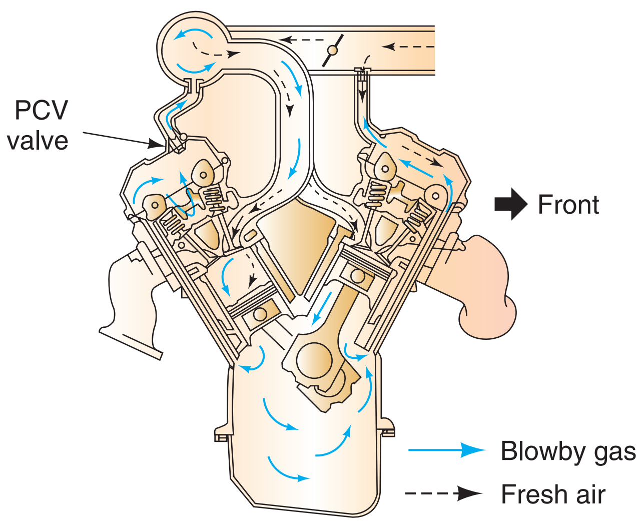


FIGURE 33–13 A typical PCV system.

FIGURE 33–14 A PCV valve.

FIGURE 33–15 Routing of the vacuum line to a PCV valve.

PCV Valve The PCV valve **(Figure 33–14)** is usually mounted in a rubber grommet. A hose connects the valve to the intake manifold **(Figure 33–15)**. A clean air hose is connected from the air filter to the opposite rocker arm cover. On some systems, the PCV valve is mounted in a vent module, and the clean air filter is located in this module.

A PCV valve contains a tapered valve. When the engine is not running, a spring keeps the valve seated against the valve housing **(Figure 33–16)**. During idle or deceleration, high intake manifold vacuum moves the valve upward against the spring tension. Under this condition, the blowby gases flow through a small opening in the valve. Because the engine is not under heavy load, the amount of blowby gas is minimal and the small valve opening is all that is needed to move the blowby gases out of the crankcase.

Manifold vacuum drops off during part-throttle operation. As the vacuum signal to the PCV valve decreases, a spring moves the tapered valve downward to increase the opening **(Figure 33–17)**.

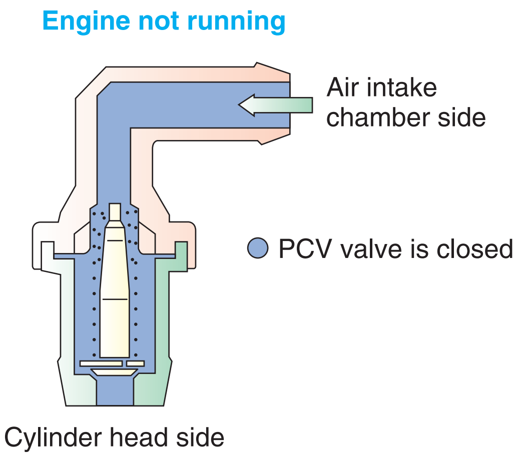


FIGURE 33–16 The PCV valve position with the engine not running.

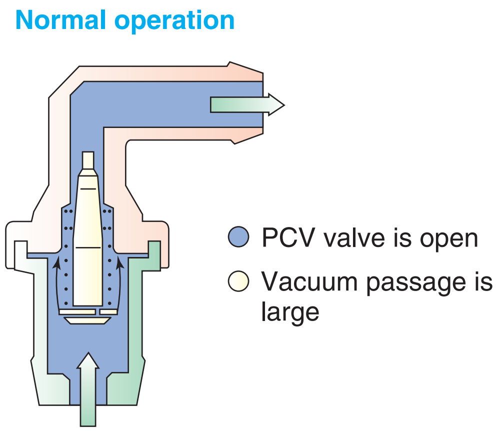


FIGURE 33–17 The PCV valve position during part-throttle operation.

Because engine load is higher at part-throttle operation than at idle, blowby gases are increased. The larger opening of the valve allows all the blowby gases to be drawn into the intake manifold.

When the engine is operating under heavy load and at wide-open throttle, the decrease in intake manifold vacuum allows the spring to move the tapered valve further down in the PCV valve. This provides a larger opening through the valve. Because higher engine load results in more blowby gases, the larger PCV valve opening is necessary to allow these gases to flow through the valve into the intake manifold.

When worn rings or scored cylinders allow excessive blowby gases into the crankcase, the PCV valve opening may not be large enough to allow these gases to flow into the intake manifold. Under this condition, the blowby gases create a pressure in the crankcase, and some of these gases are forced

through the clean air hose and filter into the air cleaner. When this action occurs, there is oil in the PCV filter and air cleaner. This same action occurs if the PCV valve is restricted or plugged.

When there is high crankcase pressure and the engine is under heavy load, the PCV gases can experience reverse flow. The high pressure and high concentration of gases accompanied with very low engine vacuum allow the gases to move out of the intake manifold. The vacuum is too weak to draw in the gases. This results in an accumulation of oil in the throttle body. Therefore, oil buildup inside the throttle body can be an indication of high crankcase pressure.

If the PCV valve sticks in the wide-open position, excessive airflow through the valve causes rough idle operation. If a backfire occurs in the intake manifold, the tapered valve is seated in the PCV valve as if the engine was not running. This action prevents the backfire from entering the engine, where it could cause an explosion.

Heated PCV Systems Crankcase vapors contain some moisture, which means the water in the vapors can freeze when the engine has sat in cold weather. This can cause the PCV system not to work until the ice melts, which may be a while. When the PCV system is not working, excess pressures can build up in the crankcase and force blowby gases out. To prevent this from occurring, some engines are equipped with heated PCV systems.

Heated systems have a heated PCV valve or heated PCV tube. The valves can be coolant heated **(Figure 33–18)** or electrically heated. Coolant heated valves have passages that allows the coolant to flow around the valve. Some electrically heated valves

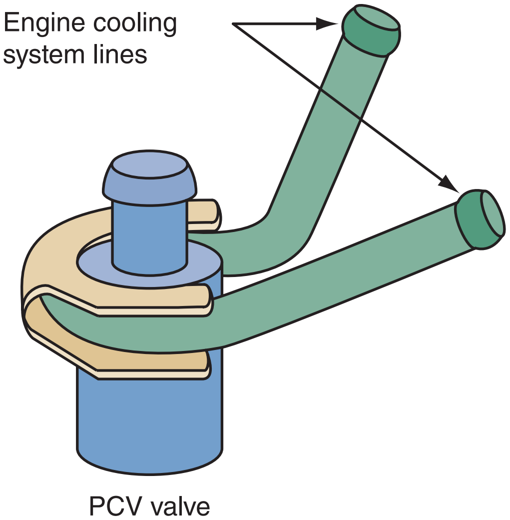


FIGURE 33–18 A coolant heated PCV valve.

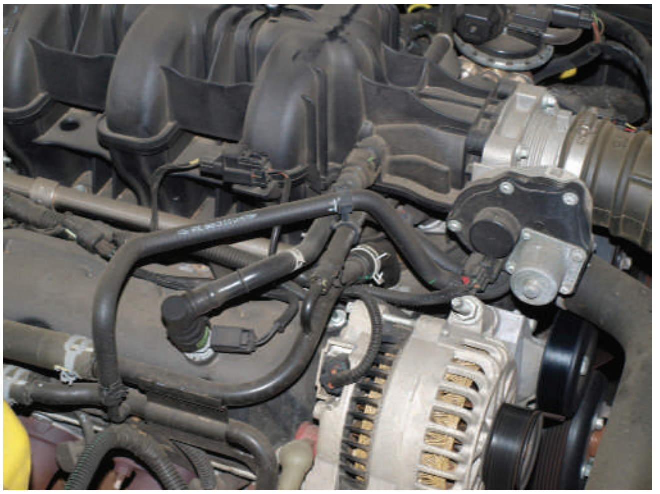


FIGURE 33–19 An electrically heated PCV valve.

are controlled by the PCM, whereas others use a thermistor in the heater's wiring harness. Heated tubes rely on electrical heaters that are either PCM controlled or use a thermistor to control the heat.

Electrically heated tubes or valves have a heating element as part of the valve, the connection between the valve and the PCV tube, or in the tube **(Figure 33–19)**. When the heating element is controlled by a thermistor, voltage is applied to the element when it is cold. Once warm, the resistance is so high that the voltage and amperage is too low to energize the element.

When the PCM controls the heating element, the heater is directly controlled by the PCM. The PCM uses IAT signals to determine when to energize the heating element.

PCV Monitor Vehicles that have OBD II PCV monitoring capabilities use special PCV valves. These valves are designed so they create a total seal when installed. Most use a cam-lock thread design that requires one-quarter to one-half turn to lock them in place **(Figure 33–20)**. The locking mechanism is

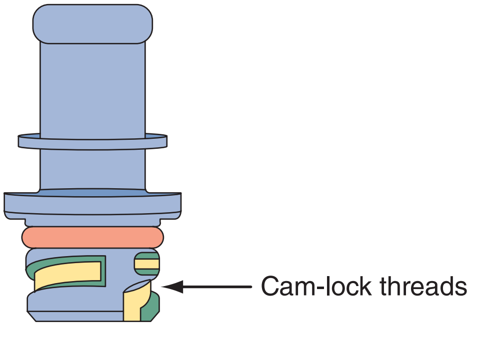


FIGURE 33–20 A PCV valve with cam-lock threads that prevent it from accidentally becoming loose.

designed to eliminate the chance of the valve accidentally becoming loose in its grommet.

EGR Systems

Most vehicle manufacturers started to provide emission control systems that reduced NO_x as early as 1970. The EGR system releases a sample of exhaust gases into the intake's air-fuel mixture. This lowers the peak temperature of combustion and therefore reduces the chances of NO_x being formed. The recirculated exhaust gas dilutes the air-fuel mixture. Because exhaust gas does not burn, this lowers the combustion temperature and reduces NO_x emissions. At lower combustion temperatures, the nitrogen in the incoming air is simply carried out with the exhaust gases.

Driveability problems can result from having too much recirculated exhaust gas in the combustion chamber. This is especially true when there is a high demand for engine power. Also, poor control of EGR flow can cause starting and idling problems. This is why EGR flow is disabled during cold starting, at idle, and at throttle openings of more than 50 percent. There is maximum EGR flow only when the vehicle is at a cruising speed with a very light load.

Many late-model engines do not have an EGR system. Rather, they rely on variable valve timing to prevent all of the exhaust gases from leaving the cylinder during the exhaust stroke during some operating conditions. The retention of the exhaust serves the same purpose as the EGR system. Other engines without an EGR system use other technologies to reduce combustion temperatures.

OBD II systems monitor the EGR system to determine if the system is operating properly. These monitors use a variety of sensors and methods. If a fault is detected in any of the EGR monitor tests, a DTC is set. If the fault occurs during two drive cycles, the MIL is illuminated. The EGR monitor operates once per OBD II trip.

EGR Valve Many older engines are equipped with a vacuum-operated EGR valve **(Figure 33–21)** to regulate the flow of exhaust gas into the intake manifold. Most late-model engines have an electrically controlled EGR valve. Typically, the EGR valve is mounted to the intake manifold.

Figure 33–22 illustrates the basic design of a vacuum-controlled EGR valve. The EGR valve is a flow control valve. A small exhaust crossover passage in the intake manifold admits exhaust gases to the inlet port of the EGR valve. Opening the EGR valve allows exhaust gases to flow through the valve **(Figure 33–23)**. Here the exhaust gas mixes with the intake air or air-fuel mixture in the intake manifold. This dilutes the mixture so combustion temperatures are minimized.

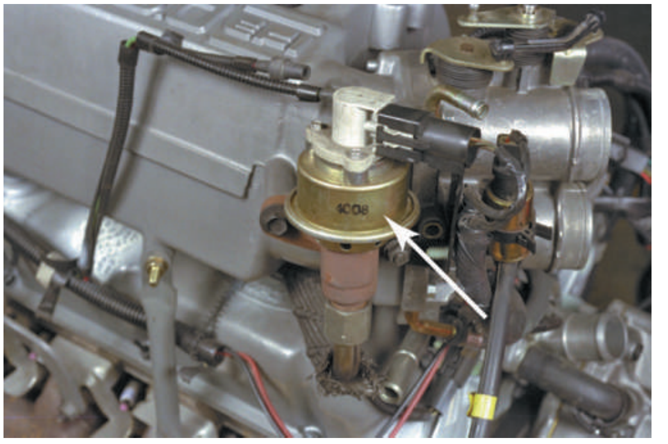


FIGURE 33–21 An EGR valve.

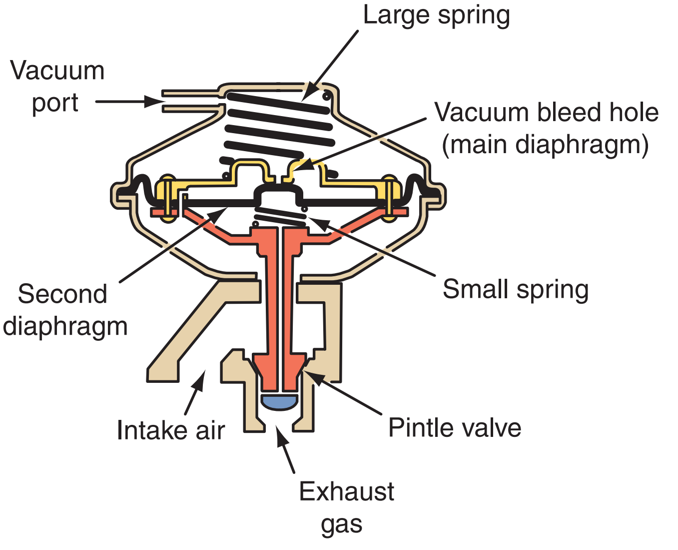


FIGURE 33–22 A typical design of a vacuum-controlled EGR valve.

On some engines, the exhaust gas from the EGR system is distributed through passages in the cylinder heads and distribution plates to each intake port. The distribution plates are positioned between the cylinder heads and the intake manifold. Because the exhaust gas from the EGR system is distributed equally to each cylinder, smoother engine operation results.

To regulate the amount of EGR flow, EGR valves have a fixed orifice or a tube with a narrow inside diameter. On some engines, the gasket for the EGR valve provides the orifice.

Vacuum EGR Valve Controls Vacuum is used to control the operation of EGR valves on older engines.

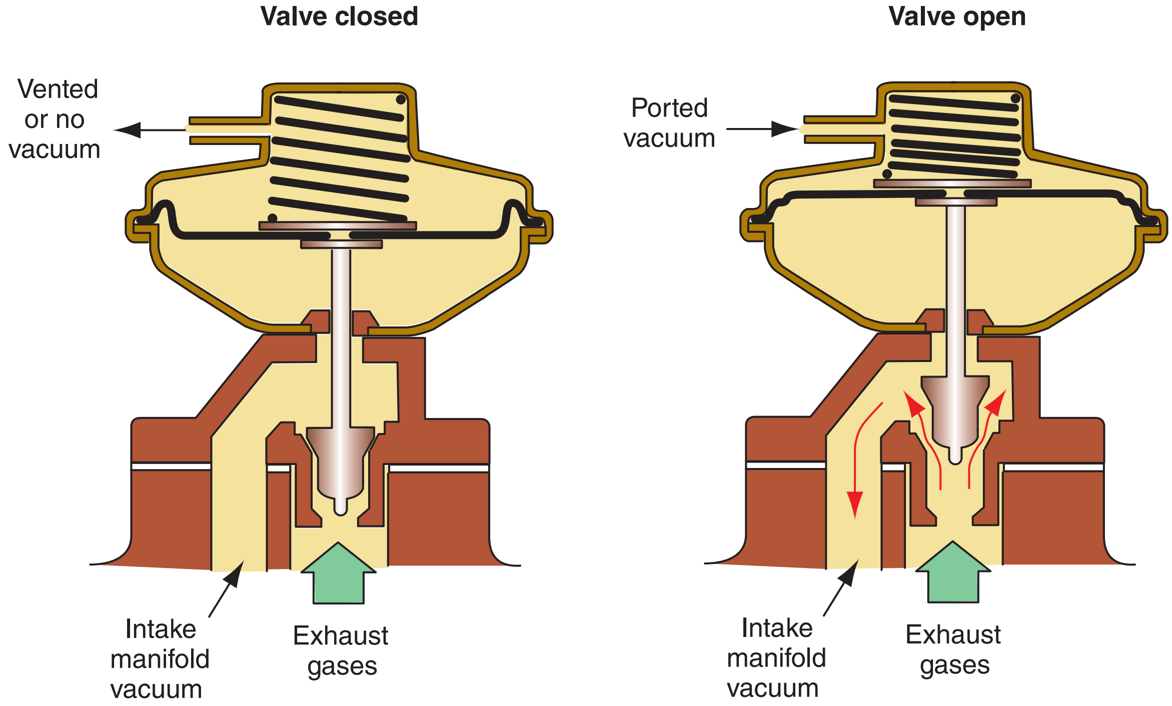


FIGURE 33–23 The operation of a normal ported EGR valve.

Many different vacuum controls have been used. Ideally the EGR system should operate when the engine reaches operating temperature and/or when the engine is operating under conditions other than idle or wide-open throttle (WOT). The following are various controls that relate directly to vacuum-controlled EGR systems.

- The thermal vacuum switch (TVS) senses the air temperature. When the engine reaches operating temperature, the TVS opens to supply vacuum to the EGR valve.
- The **ported vacuum switch (PVS)** senses coolant temperature. The PVS cuts off vacuum when the engine is cold and allows vacuum to the EGR valve when the engine is warm.
- Some engines have an EGR delay timer control system, which prevents EGR operation for a predetermined amount of time after warm engine startup.
- Some applications have a WOT valve to cut off EGR flow at WOT.

Backpressure EGR Many engines have a backpressure transducer that modulates, or changes, the amount the EGR valve opens. It controls the amount of air bleed in the EGR vacuum line according to the level of exhaust gas pressure, which is dependent on engine speed and load. The backpressure transducer may be a separate unit or incorporated into the EGR valve. There are two basic types of backpressure EGR systems.

A positive backpressure EGR valve has a bleed port and valve positioned at the center of a diaphragm. A spring holds the bleed valve open. An exhaust passage connects the lower end of the valve through the stem to the bleed valve. When the engine is running, exhaust pressure is applied to the bleed valve. At low engine speeds, exhaust pressure is not high enough to close the bleed valve. Because the vacuum supplied to the diaphragm is bled off, the valve remains closed. As engine and vehicle speed increase, the exhaust pressure also increases. Eventually exhaust pressure closes the bleed port and vacuum lifts the diaphragm and opens the valve.

In a negative backpressure EGR valve, the bleed port is normally closed. An exhaust passage connects the lower end of the tapered valve through the stem to the bleed valve. When the engine is running at lower speeds, there is a high-pressure pulse in the exhaust system. However, between these high-pressure pulses, there are low-pressure pulses. As the engine speed increases, the high-pressure pulses become closer together. The negative exhaust pressure pulses decrease and the bleed valve closes and opens the EGR valve.

PCM-Controlled EGR Valves PCM-controlled EGR valves are typically vacuum or electrically operated. When vacuum is operated, the system looks at the

pressure drop across the metering orifice in the exhaust feed tube or the valve as the valve opens and closes. At the orifice is a differential pressure feedback EGR sensor that sends a signal to the PCM **(Figure 33–24)**. This is called the differential pressure feedback EGR (DPFE) system.

In this system, the PCM calculates the desired amount of EGR flow according to the current operating conditions. The PCM looks at the inputs from many sensors before determining this value. It then calculates the necessary pressure drop across the orifice to obtain this flow. Once the value is determined, the PCM sends commands to the EGR vacuum regulator solenoid. The solenoid is duty cycled by the PCM. As the duty cycle increases, more vacuum is sent to the valve and it remains open for longer periods.

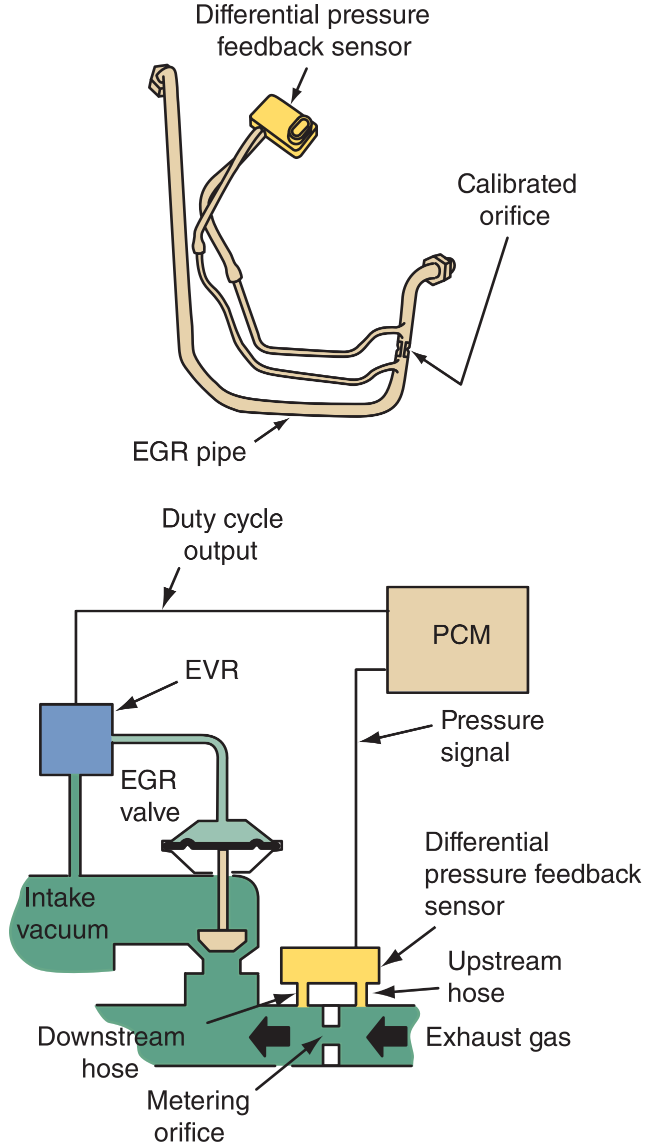


FIGURE 33–24 An EGR system with a DPFE sensor.

As exhaust gases pass through the valve, they must also pass through the orifice. The DPFE sensor measures the pressure drop across the orifice and sends a feedback signal to the PCM. Based on this signal, the PCM can make corrections to the operation of the EGR valve. Normally the voltage signal from the DPFE sensor is 0 to 5 volts and the voltage is directly proportional to the pressure drop.

Some EGR valves have an exhaust gas temperature sensor. This sensor contains an NTC thermistor; an increase in exhaust temperature decreases the sensor's resistance. Two wires are connected from the temperature sensor to the PCM. The PCM senses the voltage drop across this sensor. Cool exhaust temperature and higher sensor resistance cause a high-voltage signal to the PCM, whereas hot exhaust temperature and low sensor resistance result in a low-voltage signal.

Electric Exhaust Gas Recirculation (EEGR) System The EEGR system allows for precise control of NO_x production without relying on engine vacuum. The EEGR system uses an electric motor in the EGR valve. Normally the EEGR valve is water or air cooled. The PCM controls the stepper motor that controls the position of the EGR valve's pintle valve. The position of the valve determines the rate of EGR flow. A spring keeps the valve closed and must be overcome by the force of the motor. By using an electric motor to control the valve, the system has no need for a vacuum diaphragm, vacuum regulator solenoid, orifice or orifice tube, or DPFE sensor.

The PCM receives signals from various sensors to determine the current operating conditions. The PCM then calculates the desired amount of EGR for those conditions. Then the PCM commands the motor to move (advance or retract) a specific number of discrete steps. Normally, the stepper motor has a fixed number of possible steps, each relating to the position of the pintle valve. The position of the pintle determines the EGR flow.

Other electric EGR valves rely on solenoids that control the amount of EGR flow. A **digital EGR valve** contains up to three electric solenoids operated directly by the PCM **(Figure 33–25)**. Each solenoid contains a movable plunger with a tapered tip that seats in an orifice. When a solenoid is energized, its plunger is lifted and exhaust gas is allowed to recirculate through the orifice into the intake manifold. Each of the solenoids and orifices has a different size. The PCM can operate one, two, or three solenoids to supply the amount of exhaust recirculation required to provide optimum control of NO_x emissions.

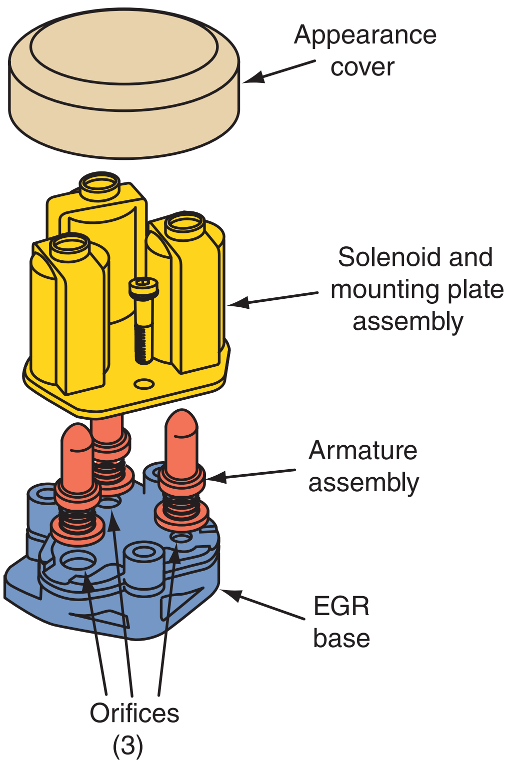


FIGURE 33–25 A digital EGR with three solenoids.

FIGURE 33–26 A linear EGR valve.

A linear EGR valve **(Figure 33–26)** has a single solenoid or stepper motor operated by the PCM. A tapered pintle is positioned on the end of the solenoid's plunger. When the solenoid is energized, the plunger and tapered valve are lifted and exhaust gas is allowed to recirculate into the intake manifold **(Figure 33–27)**. The EGR valve contains an EGR valve position sensor, which is a linear potentiometer. The signal from this sensor varies from approximately 1V with the EGR valve closed to 4.5V with the valve wide open. The PCM controls the EGR solenoid

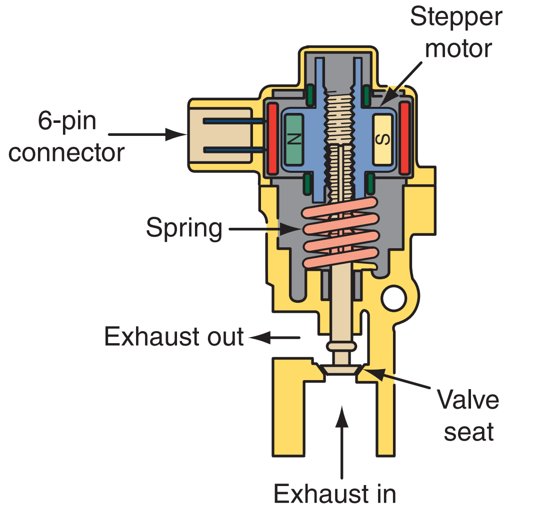


FIGURE 33–27 Basic construction of an electronically operated EGR valve with a stepper motor.

winding through pulse width modulation to provide accurate control of the plunger and EGR flow. A sensor sends feedback to the PCM to let it know that the commanded valve position was achieved.

Intake Heat Control Systems

HC and CO exhaust emissions are highest when the engine is cold. The introduction of warm combustion air improves the vaporization of the fuel in the fuel injector throttle body or intake manifold. On older engines equipped with a throttle body injection (TBI) unit, the fuel is delivered above the throttles, and the intake manifold is filled with a mixture of air and gasoline vapor. Some intake manifold heating is required to prevent fuel condensation, especially when the intake manifold is cool or cold. Therefore, these engines have intake manifold heat control devices such as heated air inlet systems, manifold heat control valves, and early fuel evaporation (EFE) heaters.

A heated air inlet control may be used on engines with TBI. This system controls the temperature of the air on its way to the throttle body. Another system used is an exhaust manifold heat control valve that routes exhaust gases to warm the intake manifold when the engine is cold. This heats the air-fuel mixture in the intake manifold. These control valves can be either vacuum or thermostatically operated.

Some intake heat systems are computer controlled. These systems use an EFE heater. The EFE heater is a resistance grid that heats the mixture as it passes from the throttle body to the manifold. The engine coolant temperature sensor sends a signal to the PCM in relation to coolant temperature. At a preset temperature, the PCM grounds the mixture

heater relay winding, which closes the relay's contacts. When the coolant temperature reaches a preset point, the PCM opens the ground circuit and the relay contacts open and shut off the current flow to the heater.

Port injection engines do not need heat risers or EFE heaters because the intake manifold delivers only air to the cylinders. Fuel is discharged into the intake ports near the intake valves or directly into the cylinders. Therefore, there is no need to warm the fuel.

Postcombustion Systems

Postcombustion emission control devices clean up the exhaust after the fuel has been burned but before the gases exit the vehicle's tailpipe. An excellent example of this is the catalytic converter. A converter is one of the most effective emission control devices on a vehicle for reducing HC, CO, and NO_x.

Another post combustion system is the secondary air or air injection system. This system forces fresh air into the exhaust stream to cause a secondary combustion and reduce HC and CO emissions.

Catalytic Converters

One of the most important developments for lowering emission levels has been the availability and use of unleaded gasoline. Since 1971, engines have been designed to operate on unleaded fuels. Removing lead from gasoline eliminates lead particles in the exhaust. It also increases spark plug life, which is important for decreasing emissions. Also, the use of unleaded fuel avoids the formation of lead deposits in the combustion chambers that tend to increase HC emissions. Unleaded fuels also led to the use of catalytic converters, which provides a way to oxidize CO and HC emissions in an engine's exhaust.

Beginning with the 1975 model year, passenger cars and light trucks have been equipped with converters. A catalytic converter is positioned within the exhaust system and converts various emissions into less harmful gases. Today's catalytic converters are extremely effective in reducing the amount of HC, CO, and NO_x emitted from a vehicle's tailpipe.

Most current vehicles have two converters in each exhaust stream. If the engine has more than one exhaust manifold, there is an exhaust stream from each and each of those streams has two converters. The first converter is located close to the exhaust manifold. Because the effectiveness of a converter depends on its temperature, placing a converter close to the manifold allows it to warm up quickly. The converters are also small, which helps them to heat up quickly. These converters are called light-up or warm-up converters, or precats **(Figure 33–28)**. Their primary purpose is to reduce emissions while the main converters are warming up.

FIGURE 33–28 A precat.

The main converter is located behind the precat. On some vehicles, it may be connected to two precats by a Y-pipe. Depending on the engine, a vehicle can have one or two main converters plus up to four precats.

The effectiveness of the converter is measured by the catalyst monitor of OBD II systems. The monitor relies on heated oxygen sensors to measure the converter's effectiveness. The location and number of HO_2S found in an exhaust stream vary with vehicle design and the emission certification level (LEV, ULEV, PZEV, etc.) of the vehicle. Most vehicles have two HO_2S in each exhaust stream. In each stream there is an HO_2S in the front exhaust pipe before the catalyst. The front sensors (HO_2S11/HO_2S21) are used for fuel control. An additional HO_2S is located after the catalyst and is used to monitor catalyst efficiency.

Many PZEVs have three HO_2S in each exhaust stream. The first HO_2S is located near the exhaust manifold and is used for fuel control. The second is in the center of the converter and monitors the amount of oxygen available in the converter. The third is after the converter and is used for long-term fuel trim control and for monitoring the effectiveness of the converter.

The converter is designed to respond to ever-changing exhaust quality. The amount and type of undesired gases change with operating conditions and driving modes **(Figure 33–29)**.

Emission	Percentage of Exhaust During			
	Idle	Acceleration	Cruise	Deceleration
CO	5.2%	5.2%	0.8%	4.2%
HC	0.08%	0.04%	0.03%	0.4%
NO_x	0.003%	0.3%	0.15%	0.006%

FIGURE 33–29 The approximate emission amounts during different driving modes.

A catalytic converter is basically a housing shaped like a muffler that contains two or more ceramic elements coated with a catalyst. The catalysts are responsible for the chemical changes that occur in the converter. A catalyst is something that causes a chemical reaction without being part of the reaction. As the exhaust gases pass over the catalyst, most of the harmful gases are changed to harmless gases. Internally, the ceramic elements are designed to expose the exhaust gases to as much surface area as possible. Ceramic materials are coated with the catalyst material to minimize the amount of catalyst material necessary. Most catalyst materials are precious metals that are quite expensive.

The catalyst coated ceramic elements have a honeycomb monolith design or are ceramic beads. Nearly all converters used on today's vehicles have the honeycomb structure **(Figure 33–30)**. Early converters were made with either design. The beads, or pellets, have a porous surface and are approximately 1/8 inch (3 mm) in diameter. The honeycomb monolith design looks like a honeycomb and each opening has 1 to 2,000 pores that are about 0.04 inch (1 mm) in size separated by thin walls. This allows an extremely large area for the gases to adhere and react to.

GO TO Chapter 3 for a detailed discussion of catalysts, reduction, and oxidation.

Prior to OBD II, catalytic converters contained two different types of catalysts: a **reduction catalyst** and an **oxidation catalyst**. The two separate catalysts created a dual-bed converter. Exhaust gases passed over the first or reduction bed where NO_x emissions were eliminated. Then the exhaust passed to the second where they were oxidized to eliminate CO and HC emissions.

During reduction, as NO_x gases pass over the catalyst, the N atoms are pulled from the NO_x molecules and combined with other N atoms to form N_2, which passes through the converter. The released O_2 atoms react with the CO in the exhaust stream and form CO_2 or pass through to the second bed. The result of NO_x reduction is pure N_2 plus O_2 or CO_2.

During the oxidation phase inside the converter, HC and CO molecules experience a second combustion. This occurs because of the presence of O_2 and the temperature of the converter. The result of this combustion or oxidation process is water vapor (H_2O) and CO_2.

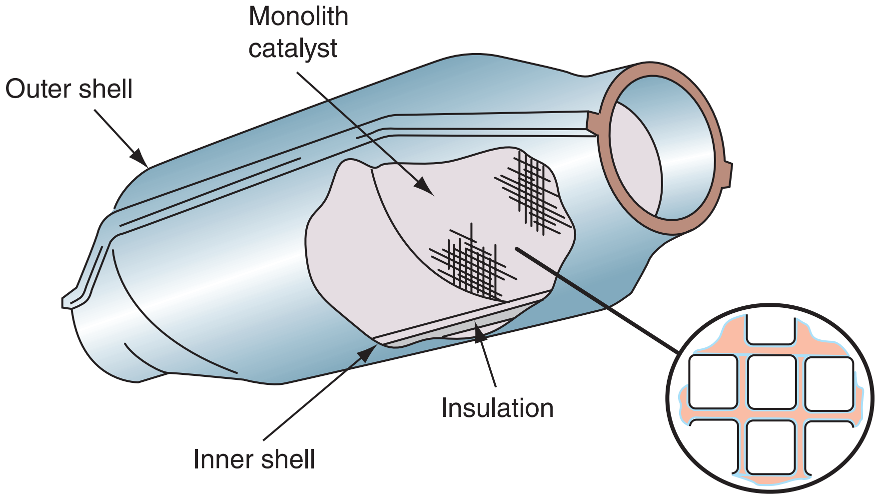


FIGURE 33–30 A honeycomb monolith-type catalytic converter.

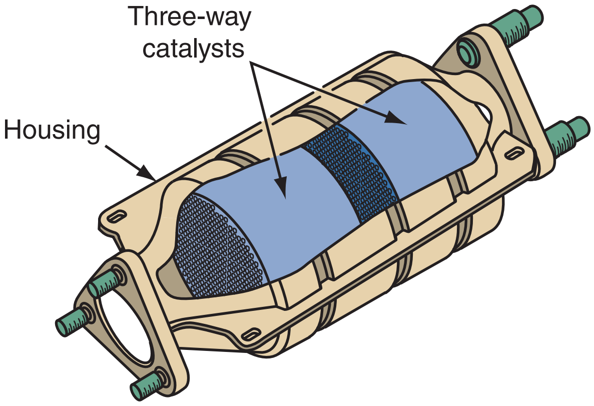


FIGURE 33–31 A typical three-way catalytic converter.

All late-model vehicles use a three-way converter (TWC) that decreases HC, CO, and NO_x emissions **(Figure 33–31)**. The catalyst used in the reduction bed is either platinum or rhodium. When NO_x is exposed to hot rhodium (Rh), it breaks down into O_2 and N_2 molecules. Some of the free O_2 molecules combine with CO molecules, and the resultant gases are O_2, CO_2, and N_2, which move to the oxidation catalyst. The oxidation catalyst, normally platinum (Pt) and palladium (Pd), combines CO and HC with the O_2 released by the reduction catalyst or in the exhaust to form CO_2 and H_2O **(Figure 33–32)**.

The presence of O_2 is important to the reduction and oxidizing processes. Early TWCs relied on fresh air injected by the secondary air system between the two catalysts. This air intake was controlled by the secondary AIR system. Other converters had a layer of cerium in the center section of the converter. The element cerium has the ability to store O_2. Late-model converters rely on the O_2 content in the exhaust. The amount of O_2 in the exhaust bounces up and down as the PCM makes slight changes to the air-fuel mixture during closed-loop operation.

As the PCM adjusts the air-fuel ratio around the desired stoichiometric ratio, it constantly toggles the mixture between slightly lean to slightly rich. This action provides the necessary O_2 and CO for the TWC. High CO content is necessary for reducing NO_x emissions, whereas high O_2 is required for the oxidation of CO and HC. When the mixture is lightly rich, more CO and less O_2 are present in the exhaust.

Emission	Process	Action	Result
NO_x	*Reduction*	$2NO + 2CO$	$N_2 + 2CO_2$
HC	*Oxidation*	$HC + O_2$	$CO_2 + H_2O$
CO	*Oxidation*	$2CO + O_2$	$2CO_2$

FIGURE 33–32 The action of a dual-bed TWC.

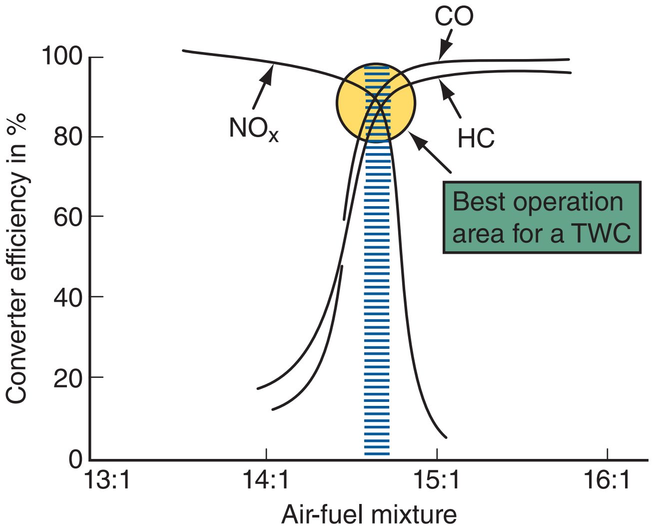


FIGURE 33–33 The efficiency of a catalytic converter is at its highest level when there is a stoichiometric mixture.

When the mixture is slightly lean, CO content decreases and O_2 content increases **(Figure 33–33)**. The converter stores some of the O_2 to allow for better oxidation during the rich cycle.

The efficiency of a catalytic converter is affected by its temperature. The temperature of the exhaust gases heat up the converter. The normal operating temperature for most converters is about 900 °F (500 °C). As the temperature of a converter increases, its efficiency increases. During converter warmup, the point at which the converter is operating at more than 50 percent efficiency is called catalyst light off. This normally occurs at 475 °F to 575 °F (246 °C to 302 °C). It takes a while for the converter to reach this temperature, especially when it is mounted away from the engine and under the vehicle. During this warm-up time, exhaust emissions levels are high. To provide cleaner exhaust after a cold start, precats are used.

Other Converter Designs Engines that run on very lean mixtures produce high amounts of NO_x. To reduce these emissions, many of these vehicles have an additional catalytic converter, called a storage or adsorber converter. After the exhaust gases leave a three-way converter, they flow through a special NO_x storage converter. This converter is coated with barium and extracts the nitrogen oxides from the exhaust and stores them until its nitrogen oxide sensor senses that the storage converter is filled. At that time, the sensor sends a signal to the PCM and the system starts to deliver a richer air-fuel mixture. As this richer exhaust flows through the storage converter, it regenerates the converter and the nitrogen oxides are converted into harmless nitrogen. When

the converter is free of nitrogen oxide, the sensor signals the system to run lean mixtures again.

Air Injection Systems

An **air injection reactor (AIR)** system was built into cars and light trucks sold in California in 1966 and used in all automobiles for several years. The AIR system reduced the amounts of HC and CO in the exhaust by injecting fresh air into the exhaust manifolds. The air caused combustion of the gases in the exhaust manifolds and pipes, thereby reducing the amount of the gases emitted from the tailpipe. O_2 in the air combines with the HC and CO to oxidize them and produce harmless water vapor and CO_2. The air was delivered by an air pump or through a pulse-air system that relied on exhaust pulses that created a vacuum and drew in outside air.

As manufacturers gained more control over emissions through engine design and advanced emission control systems, the purpose of the AIR system changed. It became known as the secondary air injection system and was modified to allow catalytic converters to operate more efficiently. The system injected air into the catalytic converter. This helped the converter oxidize and reduce the gases entering into it. AIR systems are not commonly used today. Improved combustion and better catalytic converters have eliminated their need.

Electronic Secondary Air Systems The role and use of the secondary AIR system has decreased through the years. This is because there are fewer HC and CO emissions in the exhaust of a typical engine. When engines are fitted with a secondary AIR system, they are monitored by the OBD II system and are solely used to supply O_2 to the catalytic converter. The air from the system not only helps clean up the emissions by causing combustion, it also serves to heat the converter so it can work more effectively.

The typical electronic secondary air system, like the conventional air injection system, consists of an air pump connected to a secondary air by-pass valve, which directs the air either to the atmosphere or to the catalytic converter.

The air pump is driven by an electric motor controlled by the PCM **(Figure 33–34)**. Intake air passes through a centrifugal filter fan at the front of the pump where foreign materials are separated from the air by centrifugal force. In some systems, air flows from the pump to an AIRB valve, which directs the air either to the atmosphere or to the AIRD valve. The AIRD valve directs the air to the catalytic converter or exhaust manifolds.

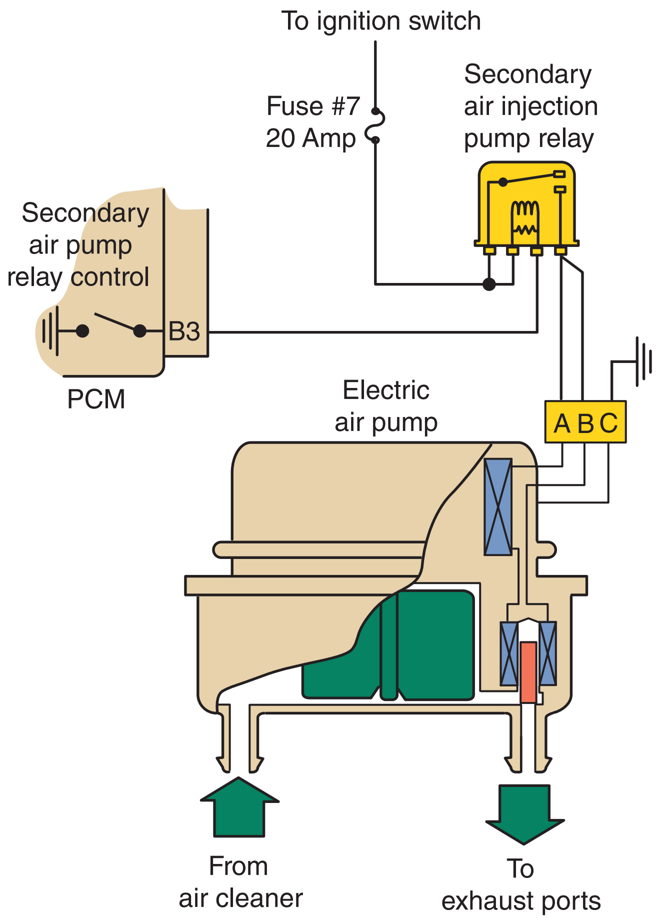


FIGURE 33–34 An electric air pump circuit.

Diesel Emission Controls

In the early 1980s, diesel-powered cars were offered by some manufacturers in North America but that trend ended quickly because they were noisy, unreliable, and dirty. However, with technological advances and the availability of low sulfur diesel fuel, diesel engines in cars and light trucks became more common. Today's diesel engines are very durable. This is because they tend to be overbuilt to withstand very high-compression pressures and the shock loading from the detonation of the air-fuel mixture. The downside is that diesel engines tend to be heavier than comparably sized gasoline engines. All reciprocating parts must be built stronger and, therefore, are heavier. Also, to produce the horsepower needed for an application, diesel engines must have a higher displacement than would be used in a gasoline engine. In spite of the increased size, diesel engines consume less fuel. To counter the increased weight and displacement, many diesels are fitted with turbochargers.

GO TO Chapter 9 for a basic description of how diesel engines operate.

Diesel engines, especially those equipped with turbochargers, produce a substantial amount of torque at low engine speeds. Diesel engines also have a much longer stroke than a gasoline engine. The longer stroke and long burning time produce high-torque outputs. The turbocharger used on a diesel engine can provide up to 30 psi of boost, which is much more than a gasoline engine can withstand. This boost significantly increases the engine's output. Diesel engines also waste less heat, which means that more of the energy of the fuel is used to power the vehicle.

The use of cleaner fuels and new technologies, such as PCM-controlled fuel injection systems, allows today's diesel engines to have emission levels that match those of gasoline engines. Clean diesel exhaust is further possible because the vehicles can be fitted with EGR and PCV valves, catalytic converters, and particulate filters. Technology has also allowed diesel engines to run quietly.

Today's diesel engines are fitted with OBD systems similar to those found on gasoline engines. These systems monitor the effectiveness of various emission-related devices, such as the fuel system, EGR system, catalyst, oxidation catalyst, particulate filter, and PCV system. They also have misfire and comprehensive component monitors. **Figure 33–35** shows how the emission standards for diesel engines have changed through the years.

Low-Sulfur Fuel

Legislation has required fuel suppliers to remove nearly all sulfur from most of the diesel fuel they produce for on-highway use. Previously up to 500 ppm were allowed. The limit for 2007 and newer diesel engines is 15 ppm. The use of this fuel not only reduces sulfur-related emissions, but it also allows diesel engines to be equipped with typically sulfur-intolerant exhaust emission controls, such as particulate filters and NO_x catalysts. This means diesel exhaust now has the capability to be as clean as that from a gasoline engine.

Year	CO_2	NO_x	HC	PM
1988	15.5	6.0	1.3	0.60
1991	15.5	5.0	1.3	0.25
1994	15.5	5.0	1.3	0.10
1998	15.5	4.0	1.3	0.10
2004	15.5	**2.4***	–	0.10
2007#	15.5	0.2	0.14	0.01

*This value is not just a NO_x standard; it is for nonmethane hydrocarbons (NMHC) + NO_x , which is why there is no standard for HC.
#The PM standard went into full effect in the 2007 model year. The NO_x and HC standards have been phased in from that time and must be met by 2010.

FIGURE 33-35 Emission standards for diesel engines (given in grams per brake horsepower per hour).

Diesel Fuel Injection

GO TO Chapter 28 for a discussion and explanation of common fuel injection systems for diesel engines.

Most current light-duty diesel engines use a common rail injection system. These systems use high pressure and this pressure is provided equally to all injectors. This allows the PCM to precisely control and monitor the amount of fuel injected into the cylinders. The introduction of highly pressurized fuel into the cylinders provides improved atomization of the fuel. This, along with precise timing, makes it possible for the engines to run cleaner and quieter. Common rail systems use solenoid-operated or piezo-inline injectors.

The use of piezoelectric injectors increases the PCM's ability to control injection timing. New common rail designs have injectors that are activated by hundreds of thin piezo crystal wafers. Piezo crystals expand quickly when a current is applied to them. The ability of these injectors to quickly respond also allows the PCM to control several injector firings in a single combustion stroke. Some systems fire the injectors five times per stroke.

Many systems fire the injector three times. To reduce combustion noise, the PCM fires the injectors to allow a small amount of fuel to enter the cylinder a few ten-thousandths of a second before firing the injector for combustion. This small spray of fuel begins the combustion process and is called the pilot injection. The pilot injection decreases the harshness of the combustion that occurs when the main injection takes place. A third injection of fuel takes place at the end of the combustion stroke to lower the temperature inside the cylinder.

PCV System

Diesel engines emit crankcase gases just like gasoline engines. However, control of these gases is much different in diesel engines because they produce very little vacuum and, therefore, conventional PCV

systems do not work. Vacuum is produced in a diesel engine in the opposite way as a gasoline engine—little to no vacuum at idle with an increase as engine speed increases. Therefore, a conventional PCV system cannot work on a diesel engine. Many diesel engines release these gases to the atmosphere through a crankcase breather or downdraft tube just like early gasoline engines. Both are a source of HC and PM emissions and are undesirable. Some systems have a PM filter that reduces those emissions but do not allow the engine to meet emission standards.

The industry has taken many different steps to control these emissions. One of these steps is the installation of a multistage filter system that is designed to collect, coalesce, and return the emitted crankcase oils to the oil sump. Another method is used on engines with a turbocharger. On these systems, intake air is drawn through an air filter and into the MAF. After the MAF, a hose connected from the valve cover draws in crankcase fumes into the intake air. Because of the low vacuum, the amount of air is very low so the system also relies on the vacuum produced by the intake for the turbocharger. The movement of air into the turbo creates a vacuum that draws the crankcase gases into the intake track.

Crankcase Depression Regulator (CDR) The crankcase depression regulator (CDR) valve is very similar to the PCV valve used in gasoline engines. It directs crankcase vapors back into the combustion chambers but is designed to work at very low levels of vacuum. It also maintains crankcase pressures to prevent oil consumption and oil leaks due to excessive buildup of pressure in the crankcase. A CDR contains a large silicone rubber/synthetic diaphragm and return spring. When vacuum is introduced to the valve, the valve opens against spring tension and allows crankcase gases to flow into the intake. CDR valves are used on both turbo and nonturbo engines but must be calibrated for the application.

EGR Systems

Normally, the efficiency of diesel engines results in high amounts of NO_x emissions. Therefore, EGR systems are integrated into the latest diesel engines. The EGR systems are the same as those used on gasoline engines, which means a sample of exhaust is introduced into the combustion chambers to reduce combustion temperatures. One of the main differences is that most manufacturers cool the incoming EGR gases before introducing them into the cylinders. This reduces the temperature of combustion and therefore reduces the amount of NO_x emitted by the exhaust **(Figure 33–36)**. Most systems with EGR coolers use engine coolant that passes through a separate circuit to cool the recirculated exhaust gases.

The PCM operates and monitors the EGR system. EGR flow is controlled by the PCM through a digital EGR valve. EGR flow will only occur when the engine is at a predetermined level and other conditions are met. The PCM's EGR monitor consists of a series of electrical and functional tests that monitor the operation of the EGR system.

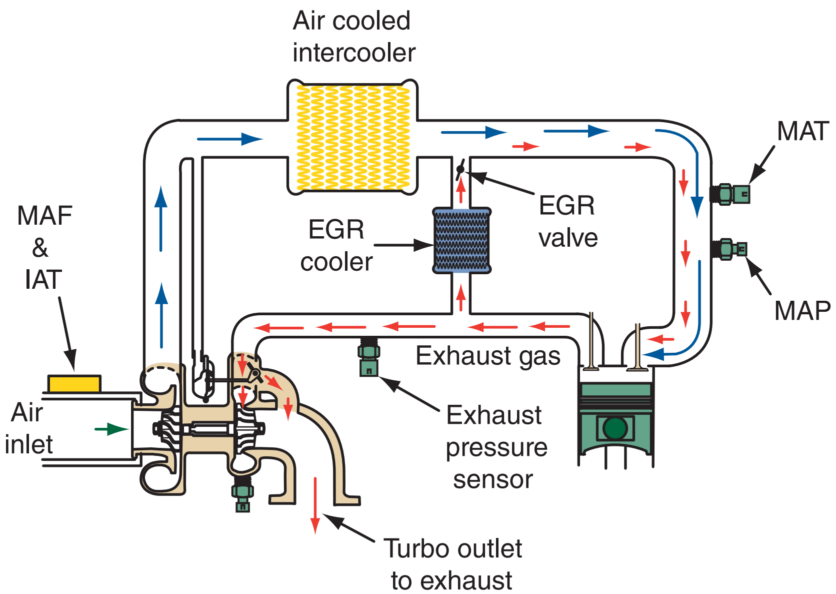


FIGURE 33-36 Intake airflow on a turbocharged diesel engine with an EGR cooler.

Catalytic Converters

The most common catalytic converter for diesel engines is an oxidation catalyst. This converter uses the O_2 in the exhaust to oxidize CO to form CO_2 and oxidize HC to form H_2O and CO_2. The converter also reduces the amount of soot. Some engines are fitted with diesel particulate filters that capture the remaining soot.

To control NO_x emissions, engines may also have a NO_x adsorber catalyst built into the oxidation converter or as a separate unit. This converter is comprised of an alkaline metal (typically barium) to store NO_x and a NO_x reduction catalyst.

Particulate Filter

Limiting the amount of PM or soot from the exhaust of a diesel engine is a top priority. Research has suggested that long-term exposure to diesel soot can cause cancer. Soot can be controlled by running the engine on a lean mixture and using a high-pressure common rail injection system. This brings soot emissions down significantly, as does the oxidizing catalytic converter. However, to meet EPA emission standards for PM emissions, late-model vehicles also have a particulate filter.

Particulate filters are placed into the exhaust system after the catalytic converter. Sometimes, the PM filter is part of the converter assembly **(Figure 33–37)**. Particulate filters are designed to trap PM. Early PM filters needed to be cleaned as part of a preventive maintenance program. Newer designs periodically burn off the collected PM and are designed to last the life of the vehicle without any special maintenance. This is done by a special cleaning mode, often called regeneration, initiated by the PCM. This combustion cleans the soot from the filter. Regeneration can be passive or active. Passive regeneration occurs during normal vehicle operation, such as during highway driving. Active regeneration occurs when driving conditions do not allow passive regeneration to occur. In these instances, extra fuel is injected so that combustion occurs within the particulate filter. The use of low-sulfur fuel has allowed for the installation of these new filters. High-sulfur fuel creates large amounts of ash buildup in the PM filter. Even with low-sulfur fuels, ash from the fuel and the burn-off of the collected soot will accumulate in the filter.

The filter is fitted with a sensor that measures exhaust backpressure. As ash builds up in the filter, exhaust backpressure increases. When the sensor informs the PCM that backpressure has reached a specified level, the PCM will order the fuel injection to spray an additional amount of fuel. The extra fuel will cause the oxidation catalytic converter to heat up and this heat will burn off the ash in the PM filter. The period of time the PCM adds fuel to clean the filter is called the regeneration cycle.

CUSTOMER CARE

Customers with late-model diesel-powered vehicles with particulate filters need to be made aware that the use of regular diesel fuel in place of low-sulfur diesel fuel will destroy the particulate filter. Regular diesel fuel has high-sulfur content and is intended to be used in farm and construction equipment only.

Selective Catalytic Reduction (SCR) Systems

To reduce NO_x emissions from a diesel vehicle, two separate technologies are used: selective catalytic reduction (SCR) and NO_x traps or adsorbers.

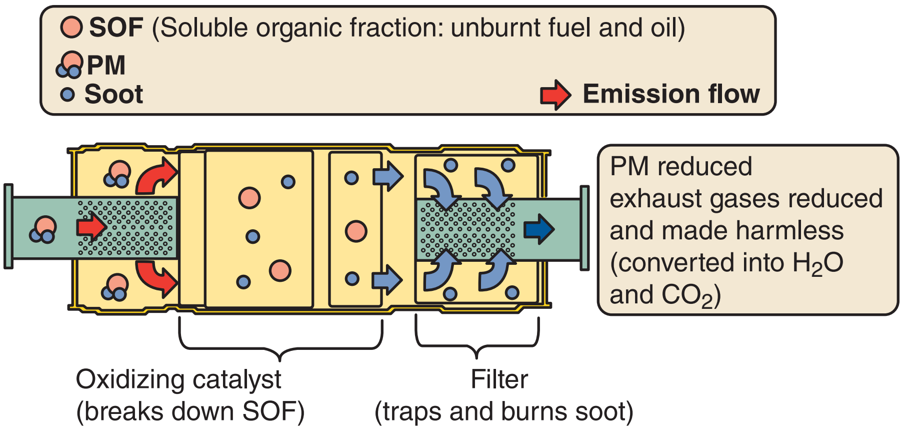


FIGURE 33–37 A continuous-regenerative diesel particulate catalyst assembly.

SHOP TALK

If the owner of a diesel-powered vehicle wants to install chrome tips on the tailpipes, there may not be the correct size available. The size and shape of the pipe is designed to draw cold air in to cool the exhaust while the particulate filter is in the self-cleaning mode. Also, make sure that the owner knows to keep the ends of the pipe clean. Any buildup of mud or other debris will block the intake of air and this can destroy the particulate filter.

Conventional reduction catalytic converters do not work well on diesel engines. This is because the O_2 content in the exhaust is high and their converters operate at a low temperature. This means a reduction converter would not be very effective.

To control NO_x emissions, many of the new diesel vehicles will have selective catalytic reduction (SCR) systems. SCR is a process where diesel exhaust fluid, called a reductant, is injected into the exhaust stream and then absorbed onto a catalyst. The reductant removes O_2 from a substance and combines another substance with the O_2 to form another compound. In this case, O_2 is separated from the NO_x and is combined with hydrogen to form water.

GO TO Chapter 28 for a more further discussion and explanation of diesel engine emission controls.

The common reductants used in SCR systems are ammonia and urea water solutions. The reductant is injected in the exhaust stream over a catalyst. These special catalytic converters work well only when they are within a specific temperature range. The engine's control unit is programmed to keep the temperature of the exhaust within that range. Also, the amount of reductant sprayed into the exhaust must be proportioned to the amount of exhaust flow. This is also something controlled by the engine's control module.

When the tanks are empty, the emission levels will not be satisfactory. The tanks that hold the reductant must be able to be refilled. This is a concern of the EPA and different ways of enforcing drivers to refill the reductant tank are being tried. Some systems have a warning lamp that informs the driver of a low tank; other vehicles have a warning lamp, and the PCM will put the vehicle into a limp-home mode when the tank is very low or empty. Some vehicles will not start if the tank is empty.

Urea The common reductant used is SCR systems is an ammonia-like substance called urea. Urea is an organic compound made of carbon, nitrogen, oxygen, and hydrogen. It is found in the urine of mammals and amphibians. Urea helps to eliminate more than 90 percent of the nitrogen oxides in the exhaust gases. Many European manufacturers call their urea injection systems the Blutec emissions treatment system.

Urea injection systems are used rather than NO_x traps because they cost much less. Also, the system does not affect engine performance and can be installed without much modification to the vehicle or engine. Urea injection systems squirt the urea solution into the exhaust pipe, before the converter, where it evaporates and mixes with the exhaust gases and causes a chemical reaction that reduces NO_x.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2016	**Make:** Toyota	**Model:** Sienna	**Mileage:** 28,242	**RO:** 19188
Concern:	Customer states MIL on.			
The technician confirms the MIL is on and pulls a P0455—EVAP gross leak. After performing a quick visual inspection, the technician checks the fuel filler cap and finds it is not threaded all the way into the filler neck.				
Cause:	Found fuel cap not tight. Tightened fuel cap, performed EVAP system test—passed. Cleared DTC.			
Correction:	Reinstalled fuel cap and showed customer how to make sure the cap is fully installed correctly.			

KEY TERMS

Air injection reactor (AIR)
Carbon dioxide (CO_2)
Charcoal canister
Digital EGR valve
Greenhouse gas
Oxidation catalyst
Postcombustion control
Precombustion control
Reduction catalyst
Vehicle emission control information (VECI)

SUMMARY

- Unburned hydrocarbons, carbon monoxide, and oxides of nitrogen are three types of emissions being controlled in gasoline engines. HC emissions are unburned gasoline released by the engine because of incomplete combustion. CO emissions are a by-product of combustion and are caused by a rich air-fuel ratio. Oxides of nitrogen (NO_x) are formed when combustion temperatures reach more than 2,300 °F (1,261 °C).
- CO_2 is a product of combustion and not a pollutant; however, it is considered a greenhouse gas.
- An evaporative (EVAP) emission system stores vapors from the fuel tank in a charcoal canister until certain engine operating conditions are present. When those conditions are present, fuel vapors are purged from the charcoal canister into the intake manifold.
- Precombustion control systems prevent emissions from being created in the engine, either during or before the combustion cycle. Postcombustion control systems clean up exhaust gases after the fuel has been burned. The evaporative control system traps fuel vapors that would normally escape from the fuel system into the air.
- The PCV system removes blowby gases from the crankcase and recirculates them to the engine intake.
- With the engine running at idle speed, the high intake manifold vacuum moves the PCV valve toward the closed position.
- During part-throttle operation, the intake manifold vacuum decreases and the PCV valve spring moves the valve toward the open position. As the throttle approaches the wide-open position, intake manifold vacuum decreases and the spring moves the PCV valve further toward the open position.
- A digital EGR valve has up to three electric solenoids operated by the PCM.
- A linear EGR valve contains an electric solenoid that is operated by the PCM with a pulse width modulation (PWM) signal.
- A pressure feedback electronic (PFE) sensor sends a voltage signal to the PCM in relation to the exhaust pressure under the EGR valve.
- Early secondary air injection systems pumped air into the exhaust ports during engine warmup and delivered air to the catalytic converters with the engine at normal operating temperatures. Newer ones move air into the catalytic converter to help in the oxidation process.
- Today's vehicles have a three-way catalytic converter that reduces NO_x and oxidizes HC and CO.
- Modern diesel engines are equipped with typical emission controls but also may have an SCR system and/or a particulate filter.

REVIEW QUESTIONS

Short Answer

1. Explain why a small PCV valve opening is adequate at idle speed.
2. At what temperature do nitrogen atoms combine with oxygen atoms to form NO_x?
3. Describe the operation of a digital EGR valve.
4. Name the three types of emissions being controlled in gasoline engines.
5. The PCV system prevents ___ ___ from escaping to the atmosphere.
6. In a negative backpressure EGR valve, if the exhaust pressure passage in the stem is plugged, the bleed valve remains ___.
7. Describe how a selective catalytic reduction system works.
8. HC emissions may come from the tailpipe or ___ sources.
9. What types of catalyst are typically used to reduce NO_x and to oxidize HC and CO?
10. Why is a PCV system critical to an engine's durability?
11. What is a catalyst?
12. Rather than relying on the AIR system for extra oxygen in a TWC, what do most late model vehicles do to support the oxidation process?

13. Why do the EGR systems on many late-model diesel vehicles include an EGR cooler?

Multiple Choice

1. Which of the following systems is designed to reduce NO_x and has little or no effect on overall engine performance?
   a. PCV
   b. EGR
   c. AIR
   d. EVAP
2. Which of the following statements about carbon dioxide is *not* true?
   a. CO_2 levels are highest when the air-fuel ratio is slightly leaner than stoichiometric.
   b. The production of CO_2 is directly related to the amount of fuel consumed; therefore, more fuel-efficient engines produce less CO_2.
   c. To reduce CO_2 levels in the exhaust, engineers are working hard to decrease fuel consumption to keep CO_2 low.
   d. The concern for CO_2 emissions is one of the primary reasons for the delayed use of alternative fuels for automobiles.

ASE-STYLE REVIEW QUESTIONS

1. While discussing PCV valve operation: Technician A says that the PCV valve opening is decreased at part-throttle operation compared to idle operation. Technician B says that the PCV valve opening is decreased at wide-open throttle compared to part throttle. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. While discussing EGR systems with a differential pressure feedback electronic (DPFE) sensor: Technician A says that the DPFE sensor sends a signal to the PCM in relation to intake manifold pressure. Technician B says that the PCM corrects the EGR flow if the actual flow does not match the requested flow. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. While discussing evaporative (EVAP) systems: Technician A says that the coolant temperature has to be above a preset value before the PCM will operate the canister purge solenoid. Technician B says that the vehicle speed has to be above a preset value before the PCM will operate the canister purge solenoid. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. Technician A says that an EGR valve that is stuck open can cause idle problems. Technician B says that a stuck closed EGR can increase HC emissions. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. While discussing SCR systems: Technician A says that they are used in place of a conventional catalytic converter to reduce NO_x, CO, and HC. Technician B says that the most common reductant used is SCR systems is an ammonia-like substance called urea. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. While discussing automotive emissions: Technician A says that oxygen emissions are monitored because they are an indication of the completeness of the combustion process. Technician B says that the conditions for minimizing HC emissions are the same as those that cause high NO_x emissions. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. Technician A says that during oxidation, as NO_x gases pass over the catalyst, the N atoms are pulled from the NO_x molecules and are absorbed by the catalyst. The released oxygen atoms then flow through the converter to the second bed. The result of NO_x oxidation is pure nitrogen plus oxygen or carbon dioxide. Technician B says that during the reduction phase inside the converter, hydrocarbon and carbon monoxide

molecules experience a second combustion. The result of this combustion or oxidation process is water vapor and carbon dioxide. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

8. While discussing PCV systems without a PCV valve: Technician A says that blowby gases are routed into the intake manifold through a fixed orifice tube. The system works the same as if it had a valve, except that the system is regulated only by the vacuum at the orifice and the size of the orifice. Technician B says that VVT systems eliminate the need for a PCV system. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

9. While diagnosing the cause of high HC and O_2 emissions: Technician A says that the HC may be elevated because of an ignition problem. Technician B says that the O_2 may be elevated because of an ignition problem. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

10. While discussing electric exhaust gas recirculation (EEGR) systems: Technician A says that some are air cooled. Technician B says that some are cooled by engine coolant. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

CHAPTER 34

EMISSION CONTROL DIAGNOSIS AND SERVICE

OBJECTIVES

- Use DTCs to initially diagnose emissions problems.
- Briefly describe the emissions-related monitoring capabilities of an OBD II system.
- Describe the reasons why certain gases are formed during combustion.
- Describe the inspection and replacement of PCV system parts.
- Diagnose engine performance problems caused by improper EGR operation.
- Diagnose and service the various types of EGR valves.
- Check the efficiency of a catalytic converter.
- Diagnose and service secondary air injection systems.
- Diagnose and service evaporative (EVAP) systems.

The quality of an engine's exhaust depends on two things: the effectiveness of the emission control devices and the efficiency of the engine. A totally efficient engine changes all of the energy in the fuel into heat energy. This heat energy is the power produced by the engine. To run, an engine must receive fuel, air, and heat.

In order for an engine to run efficiently, it must have fuel mixed with the correct amount of air. This mixture must be shocked by the correct amount of heat (spark) at the correct time. All of this must happen in a sealed container or cylinder. When these conditions are met, a great amount of heat energy is produced and the fuel and air combine to form water and carbon dioxide.

Because it is nearly impossible for an engine to receive the correct amounts of everything, a good running engine will emit some amounts of pollutants. It is the job of the

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2000	**Make:** Honda	**Model:** Civic	**Mileage:** 148,951	**RO:** 19214
Concern:	Customer states oil is leaking from a hose on the engine.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

emission control devices to clean them up. It is important to remember that the primary purpose of OBD systems is to reduce emissions; therefore, the circuits and controls in those systems must work properly in order to ensure low emissions.

The three emissions controlled in gasoline and diesel engines are unburned hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x). Federal laws require new cars and light trucks to meet specific emissions levels. State governments have also passed laws requiring that car owners maintain their vehicles so that the emissions remain below an acceptable level. Most states and provinces require an annual emissions inspection to meet that goal. The most common is the OBD II test.

OBD II Test

Because of the ability of OBD II systems to monitor and report emission related failures, many states use a check of the OBD II system as part or all of their mandatory emissions testing program. A major advantage of using the OBD II system is decreased costs since testing does not require the use of a dynamometer or gas analyzer.

Checking the OBD II system usually consists of three parts: MIL operation, checking for DTCs, and a readiness monitor check. The MIL operation test verifies that the MIL illuminates with the ignition on and that it goes out once the engine is started. If the light does not turn on or if it stays on once the engine is running, the vehicle fails this test. If the MIL stays on, DTCs are checked. If the MIL is off and no DTCs are stored, the readiness monitors are checked. Depending on the state, a vehicle may have to have all monitors ready and complete while other states may allow a monitor to be incomplete and still pass the test.

I/M 240 Test

An I/M 240 test checks the emission levels of a vehicle while it is operating under a variety of conditions and loads. This test gives a true look at the exhaust quality of a vehicle as it is working. The testing sequence normally begins with a leakage test **(Figure 34–1)** and a functional test **(Figure 34–2)** of the EVAP system and a complete visual inspection of the emission control system. Many states have plans to phase out I/M 240 testing and rely totally on OBD II tests.

During the test, the vehicle is loaded to simulate a short drive on city streets and then a longer drive on a highway. The complete test cycle includes acceleration, deceleration, and cruising. During the test, the vehicle's exhaust is collected by a CVS system that makes sure a constant volume of ambient air and exhaust pass through the exhaust analyzer. The CVS exhaust hose covers the entire exhaust pipe; therefore, it collects all of the exhaust. The hose contains a mixing tee that draws in outside air to maintain a constant volume to the gas analyzer. This is important for the calculation of mass exhaust emissions.

The test is conducted on a chassis dynamometer **(Figure 34–3)**, which loads the drive wheels to simulate real-world conditions. Testing a vehicle while it is driven through various operating conditions on a chassis dynamometer is called transient testing and testing a vehicle at a constant load on a dyno is called steady state testing.

The end result of the I/M 240 test is the measurement of the pollutants emitted by the vehicle during normal, on-the-road driving. After the test, the

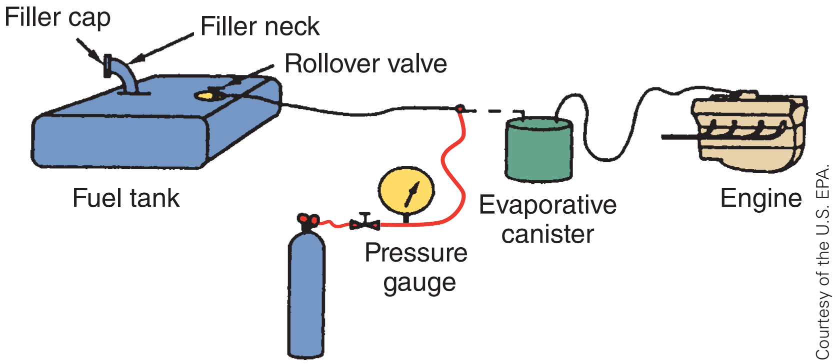


FIGURE 34-1 A typical setup for conducting a leakage test on an evaporative emission control system.

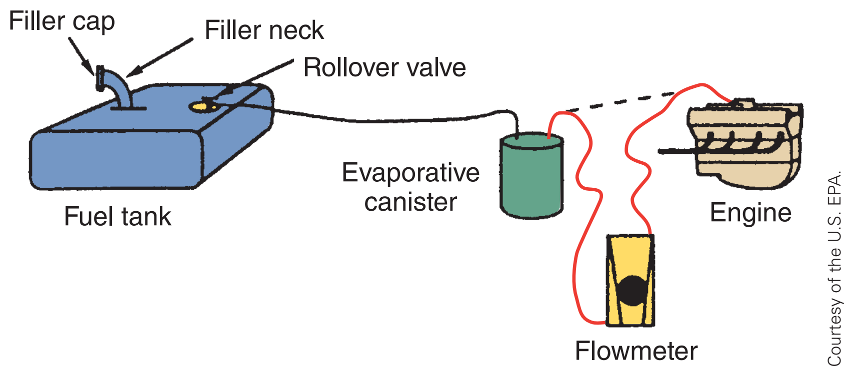


FIGURE 34-2 A typical setup for conducting a functional test of the evaporative emission control system.

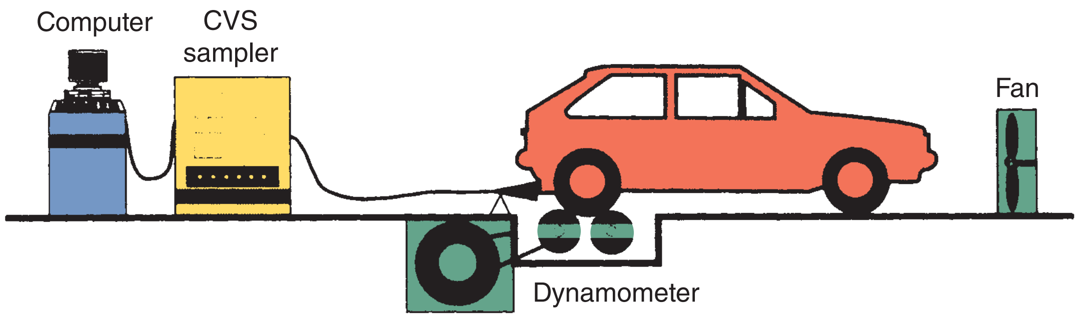


FIGURE 34-3 Components of a typical I/M 240 test station.

customer receives an inspection report. If the car failed the emissions test, it must be fixed.

The I/M 240 test measures HC, CO, NO_x, and CO_2. The job of a technician is to determine what loads and engine speeds the vehicle failed. The drive cycle is actually six operating modes. These modes need to be duplicated to identify why the vehicle failed and if the problem has been fixed:

Mode one—idle, no load at 0 miles per hour

Mode two—acceleration from 0 to 35 miles per hour

Mode three—acceleration from 35 to 55 miles per hour

Mode four—a steady cruise at 35 miles per hour

Mode five—a steady high cruise at 55 miles per hour

Mode six—decelerations from 35 miles per hour to 0 and from 55 miles per hour to 0.

Chassis Dynamometer

Chassis dynamometers are used during the I/M 240 test and can be valuable when diagnosing other driveability problems, including finding the cause of low power, overheating, and speedometer accuracy. A chassis dyno, or **dynamometer**, is designed to simulate the various road conditions in which a vehicle is driven. With a chassis dyno, a vehicle can be driven on rollers **(Figure 34–4)**. This allows the vehicle to be driven through the test conditions while it is stationary.

FIGURE 34-4 The wheels of this vehicle are ready to be dropped into the rollers of a chassis dyno.

It is important to realize that OBD II systems do not return all systems back to their normal state after repairs. The repaired vehicles should be run through a drive cycle to make sure that the repairs have been made correctly, and that all vehicle parameters are within acceptable limits.

It should be also noted that all emission testing programs will fail a vehicle if the check engine light is illuminated or if the readiness code is not at its normal or ready state.

Other I/M Testing Programs

Many state I/M programs only measure the emissions from a vehicle while it is idling. The test is conducted with a certified exhaust gas analyzer. The measurements of the exhaust sample are then compared to standards dictated by the state according to the production year of the vehicle.

Some states also include a preconditioning mode at which the engine is run at a high idle (approximately 2,500 rpm), or the vehicle is run at 30 mph on a dynamometer for 20 to 30 seconds prior to taking the idle tests. This preconditioning mode heats up the catalytic converter, allowing it to work at its best. Some programs include the measurement of the exhaust gases during a low constant load on the dyno or during a constant high idle. These measurements are taken in addition to the idle tests. A visual inspection and functional test of the emission control devices is part of some I/M programs. If the vehicle has tampered, nonfunctional, or missing emission control devices, the vehicle will fail the inspection.

CARB developed a test that incorporates steady state and transient testing. This test is called the acceleration simulation mode (ASM) test. The ASM test includes a high-load steady state phase and a 90-second transient test. This test is an economical alternative to the I/M 240 test, which requires a dyno with a computer-controlled power absorption unit. The ASM can be conducted with a chassis dyno and a five-gas analyzer.

Another alternative to the I/M 240 test is the repair grade (RG-240) test. This program uses a chassis dynamometer, constant volume sampling, and a five-gas analyzer. It is very similar to the I/M 240 test, but it is more economical. The primary difference between the I/M 240 and the RG-240 is the chassis dyno. The dyno for the RG-240 is less complicated but nearly matches the load simulation of the I/M 240 dyno.

Interpreting the Results of an I/M Test

The report from an I/M 240 test shows the amount of gases emitted during the different speeds and loads of the test. The report also gives the average output for each of the gases and shows the cutpoint for the various gases. The **cutpoint** is the maximum allowable amount of each gas. Nearly all vehicles will have some speeds and conditions where the emissions levels are above the cutpoint. A vehicle that fails the test will have many areas of high pollutant output.

To use the report as a diagnostic tool, pay attention to all of the gases and to the loads and speeds at which the vehicle went over the cutpoint **(Figure 34–5)**. Think about what system or systems are responding to the load or speed. Pay attention not only to the gases that are above the cutpoint, but also to those that are below. Also, think about the relationship of the gases at specific speeds and loads. For example, if the HC readings are above the cutpoint at a particular speed and the NO_x readings are slightly below the cutpoint at the same speed, fixing the HC problem will probably cause the NO_x to increase above the cutpoint. As combustion is improved, the chance of forming NOx also increases.

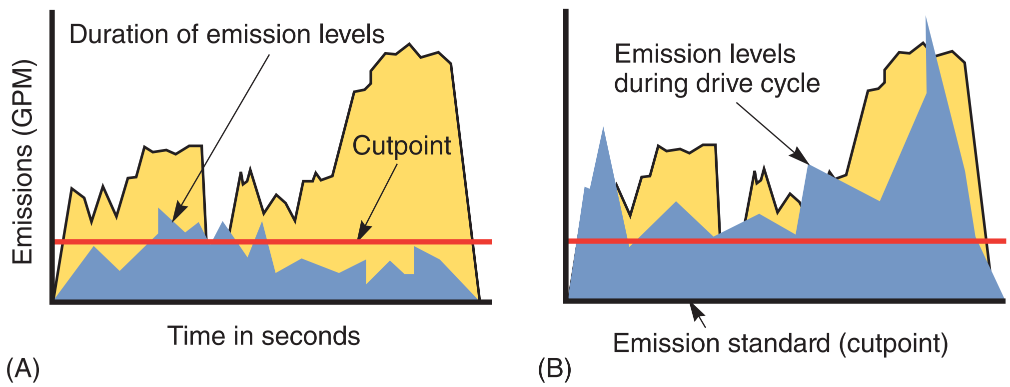


FIGURE 34–5 (A) The emissions level is acceptable. (B) The emissions level is not acceptable.

Therefore, it is wise to consider the possible causes of the almost too high NO_x, in addition to the high HC. Consider all of the correlations between the gases when diagnosing a problem.

Testing Emissions

Testing the quality of the exhaust is both a procedure for testing emission levels and a diagnostic routine. An exhaust analyzer is one of the valuable diagnostic tools for driveability problems **(Figure 34–6)**. By looking at the quality of an engine's exhaust, a technician is able to look at the effects of the combustion process. Any defect can cause a change in exhaust quality. The amount and type of change serves as the basis of diagnostic work.

Exhaust Analyzer

Early emission analyzers measured the amount of HCs and COs in the exhaust. HCs in the exhaust are raw, unburned fuel. HC emissions indicate that complete combustion is not occurring in the engine. Emissions analyzers measure HC in **parts per million (ppm)** or grams per mile (g/mi.). CO is an odorless, toxic gas that is the product of combustion and is typically caused by a lack of air or excessive fuel. CO is typically measured as a percent of the total exhaust.

SHOP TALK

The exhaust analyzers used in I/M 240 and similar tests do not measure the emissions levels in ppm or a percentage. Rather, they measure the gases in grams per mile (g/mi.). This is because an I/M test is dynamic; during the test the vehicle is operated at a variety of speeds and loads. There is no direct equivalency between the two measuring systems.

FIGURE 34–6 A hand-held exhaust gas analyzer.

FIGURE 34–7 The analyzer's probe is inserted into the vehicle's tailpipe.

An exhaust analyzer has a long sample hose with a probe in the end of the hose. Before measuring the exhaust gases, disable the air injection system, if the engine is equipped with one. Start the engine. Once the engine is warmed up, insert the probe in the tailpipe **(Figure 34–7)**. When the analyzer is turned on, an internal pump moves an exhaust sample from the tailpipe through the sample hose and the analyzer. A water trap and filter in the hose removes moisture and carbon particles.

The pump forces the exhaust sample through a sample cell in the analyzer. The exhaust sample is then vented to the atmosphere. In the sample cell, the analyzer determines the quantities of HC and CO, if the analyzer is a two-gas analyzer, or HC, CO, carbon dioxide (CO_2), and oxygen (O_2), if it is a four-gas analyzer. Most newer analyzers also measure NO_x and are called five-gas analyzers **(Figure 34–8)**.

By measuring NO_x, CO_2, and O_2, in addition to HC and CO, a technician gets a better look at the efficiency of the engine **(Figure 34–9)**. Ideally, the combustion process will combine fuel (HC) and O_2 to form water and CO_2. Although most of the air brought into the engine is nitrogen, this gas should not become part of the combustion process and should pass out of the exhaust as nitrogen.

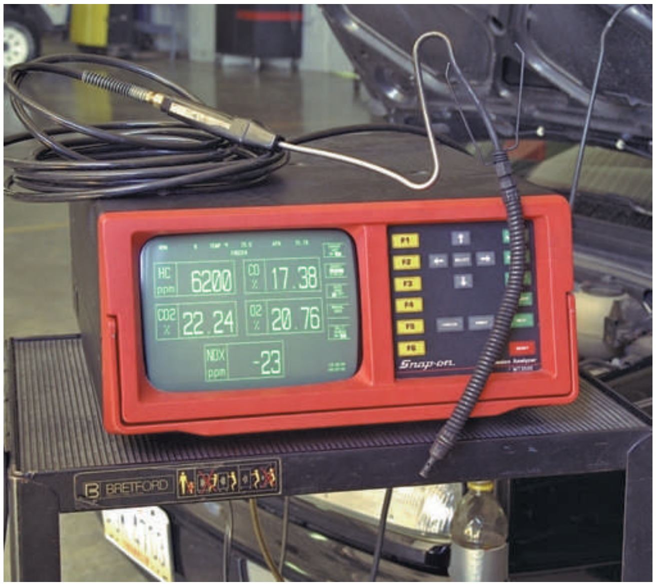


FIGURE 34-8 A five-gas exhaust analyzer.

Maximum limits for the measured gases are set by regulations according to the model year of the vehicle. These limits also vary by state or locale. It is always desirable to have low amounts of four of the five measured gases at all engine speeds. The only gas that is desired in high percentages is CO_2. Normally, the desired amount of CO_2 is 13.4 percent or more. The other gases should be kept to the lowest levels possible. Typically, CO should be 0.5 percent or less, O_2 should be about 0.1 to 1 percent, HC should be about 100 ppm or less, and NO_x should be 200 ppm or less.

Many of the emission control devices that have been added to vehicles over the past 30 years have decreased the amount of HC and CO in the exhaust. This is especially true of catalytic converters. These devices alter the contents of the exhaust. Therefore, checking the HC and CO contents in the exhaust may not be a true indication of

	IDLE	2,500 RPM	PROBABLE CAUSE
HC ppm	0–150	0–75	Normal reading
CO%	1–15	0–0.8	
CO_2%	10–12	11–13	
O_2%	0.5–2.0	0.5–1.25	
NO_x ppm	100–300	200–1,000	
HC ppm	0–150	0–75	Rich mixture
CO%	3.0+	3.0+	
CO_2%	8–10	9–11	
O_2%	0–0.5	0–0.5	
NO_x ppm	0–200	100–500	
HC ppm	0–150	0–75	Lean mixture
CO%	0–1.0	0–0,25	
CO_2%	8–10	11	
O_2%	1.5–3.0	1.0–2.0	
NO_x ppm	300–1,000	1,000+	
HC ppm	50–850	50–750	Lean misfire
CO%	0–0.3	0–0.3	
CO_2%	5–9	6–10	
O_2%	4–9	2–7	
NO_x ppm	300–1,000	1,000+	
HC ppm	50–850	50–750	Misfire
CO%	0.1–1.5	0–0.8	
CO_2%	6–8	8–10	
O_2%	4–12	4–12	
NO_x ppm	0–200	100–500	

FIGURE 34-9 The readings of the chemicals in the exhaust can lead the technician to the cause of a driveability problem.

the operation of an engine. However, a look at the other measured gases, those not altered by the system, can give a good picture of the engine and its systems.

Interpreting the Results

When using the exhaust analyzer as a diagnostic tool, it is important to realize that the severity of the problem dictates how much higher than normal the readings will be.

The levels of HC and CO in the exhaust are a direct indication of engine performance. Unburned HCs are particles, usually vapors, of gasoline that have not been burned during combustion. They are present in the exhaust and in crankcase vapors. Of course, any raw gas that evaporates out of the fuel system is classified as HC. HCs in the exhaust are a sign of incomplete combustion; the better the combustion, the less HCs in the exhaust. Today's engines are designed to be efficient and therefore release lower amounts of HCs in the exhaust. However, it is only possible to have complete combustion in a laboratory; therefore, all engines will release some HCs. This is because there is always some fuel in the combustion chamber that the flame front cannot reach.

CO forms when there is not enough O_2 to combine with the carbon during combustion. CO is a by-product of combustion. If combustion does not take place, CO will be low. When the engine receives enough O_2 in the mixture, CO_2 is formed. Lower levels of CO are to be expected when HC readings are high. When misfiring occurs, there is less total combustion in the cylinders. Therefore, CO will decrease slightly.

High NO_x readings indicate high combustion temperatures. CO_2 is a desired element in the exhaust stream and is only present when there is combustion; thus the more CO_2 in the exhaust stream, the better.

O_2 is used to oxidize CO and HC into water and CO_2. Ideally, there should be very low amounts of O_2 in the exhaust. CO and O_2 are inversely related: When one goes up, the other goes down.

SHOP TALK

Because increases in CO tend to lower NO_x emissions, it is possible that NO_x readings will increase after you have corrected the cause of the high CO readings.

General Guidelines When using gas measurements to diagnose a driveability problem, keep the following mind:

- HC is the result of incomplete combustion.
- High CO indicates an excessively rich air-fuel mixture caused by a restriction in the air intake system or too much fuel being delivered to the cylinders.
- Low CO does not indicate a lean mixture; rather, as the mixture becomes leaner, HC increases.
- When CO goes up, O_2 goes down.
- O_2 is used by the catalytic converter and may be low.
- O_2 readings are higher on vehicles with properly operating air injection systems.
- If there is a high O_2 reading without a low CO reading, an air leak in the exhaust system may be indicated.
- As the mixture goes lean, O_2 levels increase.
- As the mixture goes rich, O_2 moves and stays low.
- If there is high HC and low CO in the exhaust because of a lean misfire, the amount of O_2 will be high.
- NO_x goes high when there is a lean mixture or when the engine gets hot.
- NO_x is highest when CO and HC are lowest.
- Minimal NO_x is produced while an engine idles.
- At stoichiometric (lambda—λ), HC and CO will be at their lowest levels and CO_2 will be at its highest.
- If there is an extremely rich air-fuel mixture, there will be high HC and CO and low NO_x and O_2 readings.
- A deficiency of O_2 reduces NO_x.

For specific causes of undesirable amounts of exhaust gases, see **(Figure 34–10)**.

Problems with emission control devices will not only cause an increase in emission levels but can cause driveability problems. A no-start or hard-to-start problem can be caused by the obvious things, plus a disconnected or damaged vacuum hose, a malfunction of the EVAP canister purge, or a stuck open EGR valve. If the engine runs rough or stalls, the problem can be a problem with the EVAP canister purge system, a disconnected or damaged vacuum hose, a stuck open EGR valve, or a faulty PCV system. Excessive oil consumption can be caused by bad piston rings, poor valve oil seals, or a plugged PCV hose. Also, poor fuel economy can be caused by a number of things, including a problem with the EGR system.

Condition	Possible Condition/Problem
Excessive HC	Ignition system misfiring Incorrect ignition timing Excessively lean air-fuel ratio Dirty fuel injector Low cylinder compression Excessive EGR dilution Defective valves, guides, or lifters Vacuum leaks Defective system input sensor
Excessive CO	Rich air-fuel mixtures Plugged PCV valve or hose Dirty air filter Leaking fuel injectors Higher-than-normal fuel pressures Ruptured diaphragm in the fuel pressure regulator Defective system input sensor
Excessive HC and CO	Plugged PCV system Excessively rich air-fuel ratio AIR pump inoperative or disconnected Engine oil diluted with gasoline
Lower-than-normal O_2	Rich air-fuel mixtures Dirty air filter Faulty injectors Higher-than-normal fuel pressures Defective system input sensor Restricted PCV system Charcoal canister purging at idle and low speeds
Lower-than-normal CO_2	Leaking exhaust system Rich air-fuel mixture
Higher-than-normal O_2	An engine misfire Lean air-fuel mixtures Vacuum leaks Lower-than-specified fuel pressures Defective fuel injectors Defective system input sensor
Higher-than-normal NO_x	An overheated engine Carbon deposits on the intake valves Lean air-fuel mixtures Vacuum leaks Overadvanced ignition timing Defective EGR system Ineffective reduction catalytic converter
Higher-than-normal NO_x and HC	Poor flow through the radiator A partially closed thermostat Bad water pump An inactive EGR system

FIGURE 34-10 Possible conditions causing various emission levels. *(continued)*

Condition	Possible Condition/Problem
Higher-than-normal HC, O_2, and NO_x	A false signal from the O_2 sensor An out-of-calibration MAP sensor Plugged injector Low fuel pressure Vacuum leak Engine knock Overadvanced ignition timing
Higher-than-normal HC, CO, and NO_x	Carbon buildup on top of the piston or cylinder walls A worn or slipping timing belt

FIGURE 34–10 *(continued)*

Basic Inspection

Before diagnosing the cause of excessive emissions, make sure you inspect the entire vehicle for obvious problems. The results of the inspection may help pinpoint the cause of the problem.

- Check the battery's voltage.
- Inspect/clean the air filter for dirt or contamination.
- Disconnect the air inlet line hose from the charcoal canister. Then check that air can flow freely into the air inlet. If air cannot flow freely, repair or replace it.
- On older vehicles, check and adjust the idle speed.
- On older vehicles, make sure that base timing is set to specifications.
- Check the fuel pressure.
- Check the engine's mechanical condition.
- Check all accessible electrical connections and vacuum and air induction hoses and ducts.
- Check the condition of the PCM main grounds.
- Check all EVAP, EGR, and PCV hoses, connections, and seals for signs of leakage and damage.
- Inspect for unwanted fuel entering the intake manifold from the EVAP system, fuel pressure regulator diaphragm, or PCV system.
- Check the air tightness of the fuel tank and filler pipe.

Part of the inspection should also include a look at the MIL. Make sure the MIL illuminates during key-on bulb check. If the MIL remains on once the engine is started, a DTC is stored and this can lead to the cause of excessive emissions. Keep in mind that the primary purpose of an OBD system is to limit the amount of pollutants emitted by the engine. This is why retrieving DTCs from the control system is the best beginning for diagnosing emission problems. OBD II systems include several system monitors that relate to exhaust emission.

OBD II Monitors

The OBD II system monitors the emission control systems and components that can affect tailpipe or evaporative emissions. Through this monitoring process, problems are detected before emissions are 1.5 times greater than applicable emission standards. Each monitor requires one or more diagnostic tests. The monitors run continuously or noncontinuously and only when certain enabling criteria have been met. If a system or component fails these tests, a DTC is stored and the MIL is illuminated within two driving cycles.

GO TO Chapter 24 for a discussion of OBD II monitors.

A pending DTC is stored in the PCM when a concern is initially detected. Pending DTCs are displayed as long as the concern is present. Note that OBD regulations require a complete concern-free monitoring cycle to occur before erasing a pending DTC. This means that a pending DTC is erased on the next power-up after a concern-free monitoring cycle. However, if the concern is still present after two consecutive drive cycles, the MIL is illuminated. Once the MIL is illuminated, three consecutive drive cycles without a concern detected are required to turn off the MIL. The DTC is erased after forty engine warm-up cycles once the MIL is extinguished.

A part of many mandatory I/M inspections is taking a look at the OBD system tests. This is done by observing the system status display on a scan tool.

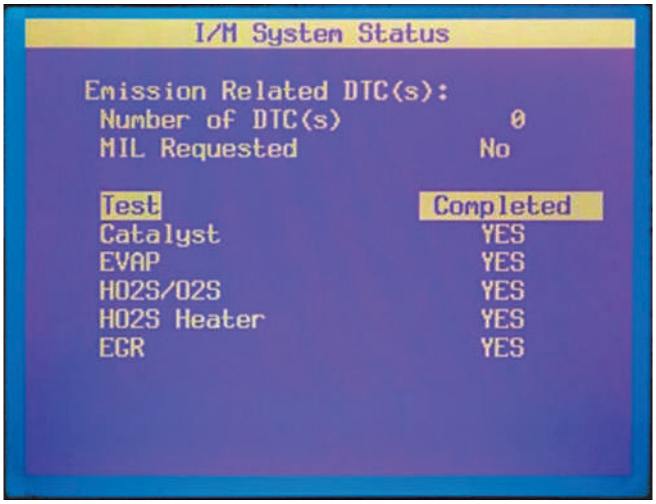


FIGURE 34–11 An I/M status screen on a scan tool showing the monitors have been completed.

If the diagnostic tests for a particular monitor have been completed, the scan tool will indicate this with a YES or COMPLETE **(Figure 34–11)**. A system monitor is complete when either all of the tests comprising the monitor have been run and had satisfactory results, or when DTCs related to the monitor has turned on the MIL. If for any reason the tests are not completed, the system status display will indicate NO or NOT COMPLETE under the completed column. If the system has set a DTC that is associated with one of the regulated systems, the required tests may not be able to run. If there are no DTCs that would prevent the vehicle from completing a particular test, the vehicle should be operated according to the recommended drive cycle so that all enable criteria are met.

Not all vehicles have the same emission control systems. For example, a vehicle may not be equipped with an AIR or EGR. Therefore, the status of these monitors will not be shown or the scan tool may display NOT SUPPORTED. Also, the status of some monitors, such as the misfire and comprehensive component monitors may not be listed. These monitors run continuously and, therefore, their status is not required by OBD II.

Once repairs are completed, the vehicle should be operated according to the drive cycle recommended by the manufacturer. This will allow the monitors to run and complete their tests. For 2012

PROCEDURE

A typical procedure for allowing the I/M system status tests to complete is as follows:

STEP 1 Observe the DTCs with a scan tool. If there is a DTC that would prevent the system status tests from completing, diagnose it before continuing.

STEP 2 Check the available service information to see if there are software updates for the vehicle.

STEP 3 Check the scan tool for the current status of the monitors. If the EVAP monitor has not been completed, diagnose and repair the system before continuing.

STEP 4 Turn off all accessories.

STEP 5 Open the hood, set the parking brake, and place the transmission in park for automatic transmissions or neutral for manual transmissions.

STEP 6 Start the engine and allow it to idle for about 2 minutes.

STEP 7 Close the hood, release the parking brake, and take the vehicle on a test drive.

STEP 8 Lightly accelerate to 45 to 50 mph (72 to 80 km/h) and maintain this speed for about 5 minutes after the engine reaches normal operating temperature.

STEP 9 Lightly accelerate to 55 mph (90 km/h) and maintain this speed for about 2 minutes.

STEP 10 Let off the throttle and allow the vehicle to decelerate for about 10 seconds.

STEP 11 Stop the vehicle and allow it to idle for about 2 minutes.

STEP 12 Turn off the ignition and allow the vehicle to sit undisturbed for about 45 minutes.

STEP 13 Check the status of the monitors with a scan tool.

STEP 14 If all tests were completed, retrieve all hard and pending DTCs.

STEP 15 If the tests were not completed, repeat the procedure.

and newer vehicles, performing a drive cycle to run a monitor is the only way to clear a permanent DTC stored in Mode 10 of the PCM. Keep in mind that a monitor may require very specific conditions to run. Refer to the service information for monitor enable criteria to ensure the vehicle and environmental conditions will allow the drive cycle to complete.

Evaporative Emission Control System Diagnosis and Service

Warning! If gasoline odor is present in or around a vehicle, check the EVAP system for cracked or disconnected hoses, and check the fuel system for leaks. Gasoline leaks or vapors can cause an explosion, resulting in personal injury and/or property damage. The cause of fuel leaks or fuel vapor leaks should be repaired immediately.

Most I/M inspections begin with a check of the EVAP system. This includes checking the results of the EVAP monitor's diagnostic tests. The EVAP system is monitored for leaks and its ability to move fuel vapor when commanded by the PCM to do so. Problems that are detected will set a DTC. Normally this is the only way a driver knows there is an EVAP problem. At times, the owner may complain of a gasoline odor in or around the vehicle. The common tools for troubleshooting an EVAP system are a diagnostic tester, smoke machine, and pressure kit. The exact procedures and tools will vary with each application.

EVAP Monitors

Many different EVAP systems and monitoring systems have been used by the manufacturers. It is important to correctly identify the system used on a particular vehicle before doing any diagnostic procedures or service on the vehicle. A system leak can generate multiple DTCs depending on the component and location of the leak. The monitor also checks the electrical integrity of the system and the vapor purge rate **(Figure 34–12)**. All EVAP monitor DTCs require two trips.

EVAP Code	Description
P0441	Incorrect or uncommanded purge flow
P0442	Small leak
P0443	Purge solenoid electrical fault
P0446	Blocked cannister vent
P0449	Cannister vent solenoid electrical fault
P0452	Tank pressure sensor voltage low
P0453	Tank pressure sensor voltage high
P0454	Tank pressure sensor voltage noisy
P0455	Large leak
P0456	Very small leak
P0457	Gross leak
P0460	Fuel level circuit
P0461	Fuel level sensor stuck/noisy
P0462	Fuel level sensor voltage low
P0463	Fuel level sensor voltage high
P0464	Fuel level sensor voltage noisy at idle
P1443 (Ford)	Gross leak, no flow
P1450 (Ford)	Excessive vacuum
P1451 (Ford)	Vent valve circuit fault
P1486 (Chrysler)	Pinched hose
P1494 (Chrysler)	LDP fault
P1495 (Chrysler)	LDP solenoid circuit

FIGURE 34–12 Common EVAP codes.

To monitor the vapor purge in most systems, the PCM changes the duty cycle of the purge solenoid while monitoring the STFT. A problem is indicated by uncorrelated changes in the STFT. Other systems use a pressure sensor to monitor the pressure in the system and the purge side of the charcoal canister. Normally, the changes in the pressures between the two are very small. A difference in pressure should be evident when the PCM commands the purge solenoid to open. If there is no difference in pressure, the PCM determines that the purge system is not working properly and will set a DTC. Enhanced EVAP systems may also calculate purge flow rate by looking at the inputs from the MAF sensor or by comparing MAP sensor readings with the input from the tank pressure sensor.

Early EVAP systems were designed to detect leaks that were 0.040 inch (1 mm) and greater. Starting with the 2000 model year, a new EVAP monitor system has been implemented. This system is designed to detect

leaks of 0.020 inch (0.5 mm). There are two different methods of leak detection used by enhanced OBD systems: system pressure and vacuum. Vacuum testing requires two solenoid valves and a fuel tank absolute-pressure sensor. The vacuum comes from the engine or an on-board vacuum pump (commonly referred to as the leak detection pump or LDP). Using the pressure method of checking the system tends to be more precise but entails the use of more components. The method used by the manufacturers varies with vehicle make and model year.

Scan Tool Being a system controlled and monitored by the OBD II, the MIL will illuminate to alert the driver that there is a problem if a failure is detected. When a defect occurs in the canister purge solenoid and related circuit, a DTC is normally set. If a DTC related to the EVAP system is set, always correct the cause of the code before doing any further diagnosis of the EVAP system.

When the scan tool is set to the appropriate mode, it will indicate whether the purge solenoid is on or off. With the engine idling, the purge solenoid should be off. Be sure all the conditions required to energize the purge solenoid are present; note this often requires the fuel level be between 15 percent and 85 percent full. If enable criteria are met, leave the scan tool connected, road test the vehicle, and observe this solenoid status on the scan tool. The tester should indicate when the purge solenoid is on. If the purge solenoid is not on under the necessary conditions, check the power supply wire to the solenoid, solenoid winding, and wire from the solenoid to the PCM.

Diagnosis

If the EVAP system is purging vapors from the charcoal canister when the engine is idling or operating at very low speed, rough engine operation will occur, especially at higher ambient temperatures. Cracked hoses or a canister saturated with gasoline may allow gasoline vapors to escape to the atmosphere, resulting in gasoline odor in and around the vehicle.

The entire EVAP system should be carefully inspected **(Figure 34–13)**. All of the hoses in the system should be checked for leaks, restrictions, and loose connections. Repair or replace them as necessary. Also check the canister for cracks or damage; if they are found, replace the charcoal canister assembly.

The operation of the charcoal canister **(Figure 34–14)** can be quickly checked on most vehicles. Close the purge port, gently blow into its vent port, and check that air flows from the port. If this does not happen, replace the charcoal canister assembly. Close the vent port and gently blow into its air inlet port. Check that air flows from the purge port. If this does not happen, replace the charcoal canister assembly. With the purge port and air inlet port closed, apply low air pressure (about 2.8 psi [19.6 kPa]) to the vent port. Make sure that the canister can hold that pressure for at least 1 minute. If this does not happen, replace the charcoal canister assembly.

Also make certain that the canister filter is not completely saturated. Remember that a saturated charcoal filter can cause symptoms that can be

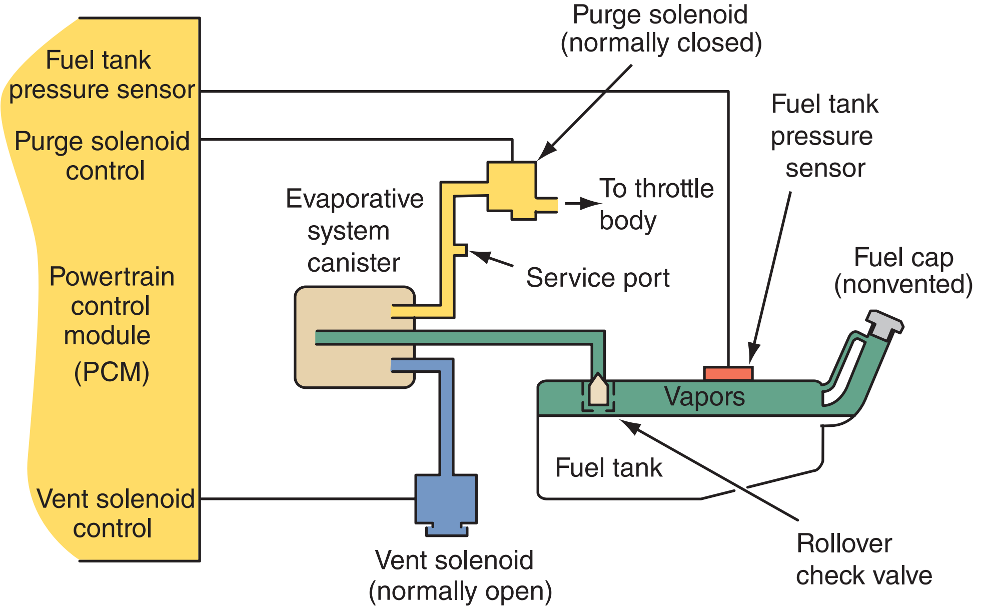


FIGURE 34–13 Check all hoses and electrical connectors and wires in the EVAP system.

FIGURE 34–14 The charcoal canister for a typical EVAP system.

mistaken for fuel system problems. Rough idle, flooding, and other conditions can indicate a canister problem. A canister filled with liquid or water causes backpressure in the fuel tank. It can also cause richness and flooding symptoms during purge or startup.

To test for saturation, unplug the canister momentarily during a diagnosis procedure and observe the engine's operation. If the canister is saturated, either it or the filter must be replaced depending on its design; that is, some models have a replaceable filter, whereas others do not.

A vacuum leak in any of the evaporative emission components or hoses can cause starting and performance problems, as can any engine vacuum leak. It can also cause complaints of fuel odor. Incorrect connection of the components can cause rich stumble or lack of purging (resulting in fuel odor).

The canister purge solenoid **(Figure 34–15)** winding may be checked with an ohmmeter. You can also test the solenoid by commanding it open and testing if there is flow through the solenoid. With the tank pressure control valve removed, try to blow air through the valve with your mouth from the tank side of the valve. Some restriction to airflow should be felt until the air pressure opens the valve. Connect a vacuum hand pump to the vacuum fitting on the valve and apply 10 in. Hg to the valve. Now try to blow air through the valve from the tank side. Under this condition, there should be no restriction to airflow. If the tank pressure control valve does not operate properly, replace the valve.

The electrical connections in the EVAP system should be checked for looseness, corroded terminals, and worn insulation. Measure the voltage drop across the solenoid and compare your readings to specifications. If the readings are outside specifications, replace the charcoal canister assembly.

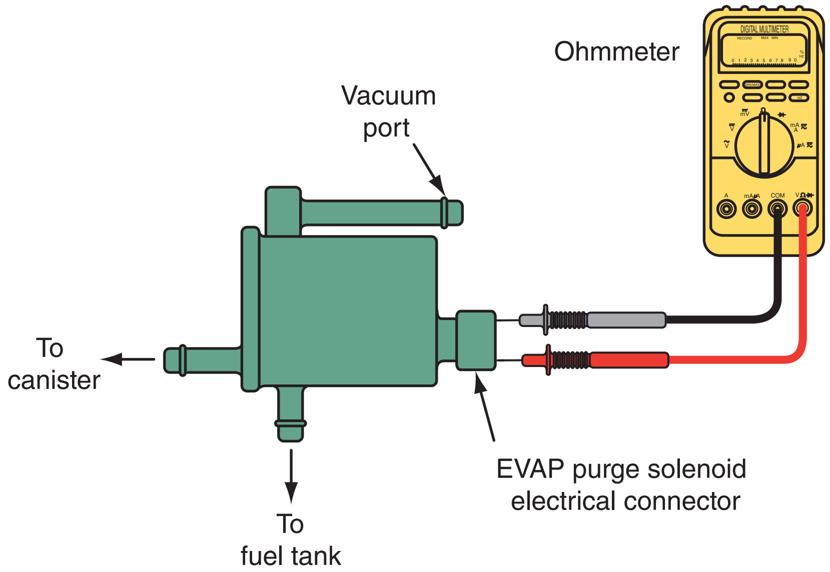


FIGURE 34–15 Checking an EVAP purge solenoid.

SHOP TALK

It is recommended to never wiggle hoses or tighten fittings and caps during a visual inspection until the system has been pressurized for further testing.

Purge Test

Certain conditions will increase the amount of fuel vapors stored in the charcoal canister and therefore should be avoided prior to I/M tests. These include prolonged periods of idling or prolonged periods of sitting in the sun on a hot day. Most vehicles should be driven at highway speeds for about 5 minutes to allow them to complete their normal purge cycle before I/M testing. Excessive fuel vapors can cause an increase in CO during testing. To determine if the canister is the cause of high CO, isolate the EVAP system and retest the emission levels. The EVAP can be isolated by disconnecting the purge hose from the throttle body or intake manifold. If the EVAP system appears to be the cause of high emissions, the system needs to be carefully checked.

Before checking the purge rate of the EVAP system, allow the engine to run until it reaches normal operating temperature. Connect the purge flow tester's flow gauge in series with the engine and evaporative canister. Zero the gauge of the tester with the engine off, and then start the engine. With the engine at idle, turn on the tester and record the purge flow rate and accumulated purge volume. Gradually increase engine speed to about 2,500 rpm and record the purge flow. A good working system will have at least 1 liter of flow within a few seconds. Most vehicles will have a flow of 25 liters during the time period required for an I/M 240 test. If the system does not establish at least 1 liter of flow during the 240 seconds, the system needs to be carefully diagnosed, repaired, and retested.

Leak Tests

The operation of a pressure test is often called a pressure decay test. It checks for leaks that allow fuel vapors to escape into the atmosphere. EVAP leak testers pressurize the system with a very low pressure (14 inches of water or about 0.5 psi). The tester typically uses pressurized nitrogen to fill the system. Nearly all OEMs recommend nitrogen (N_2) rather than compressed air. In fact many are concerned about introducing oxygen (outside air has much oxygen in it) into the system because it can cause an explosion.

Before using an EVAP leak tester, make sure that the fuel tank is at least half full. The tester kit will include a pressure guideline chart. The chart contains various size fuel tanks and different fuel levels. Interpreting the chart will let you know how much pressure should be applied to the system. The tester is normally connected to the EVAP service port **(Figure 34–16)**. If the vehicle does not have the service port, use the correct adapter for the vehicle's filler neck. Remove the fuel cap and inspect the filler neck. If the neck is rusted or damaged, this could be a source of leakage. Connect and tighten the adapter to the filler neck. Then connect the tester to the adapter. Remember to check the gas cap because it will be bypassed when leak testing is done at the filler neck.

Before an OBD II system can be tested with pressurized N_2, a scan tool must be used to set the system for an EVAP test. Doing this will close the canister's vent. Ground the EVAP leak tester **(Figure 34–17)** to the vehicle before turning it on, which is typically done by connecting a jumper wire from the ground screw on the tester to a bolt at the filler neck. Doing this eliminates the chance of **electrostatic discharge (ESD)**. ESD can ignite the fuel vapors. Then pinch off the vent hose at the carbon canister on non-OBD II systems.

Adjust the output pressure from the tester so it agrees with the chart mentioned previously. Once the tester applies pressure to the system, its gauge will show how much pressure the system is able to hold **(Figure 34–18)**. The pressure will initially fall and rise before it stabilizes. If the system remains

FIGURE 34–16 An EVAP service port.

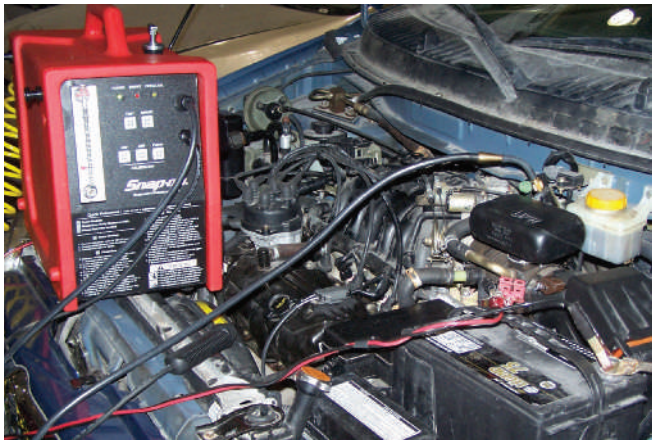


FIGURE 34-17 An EVAP leak tester.

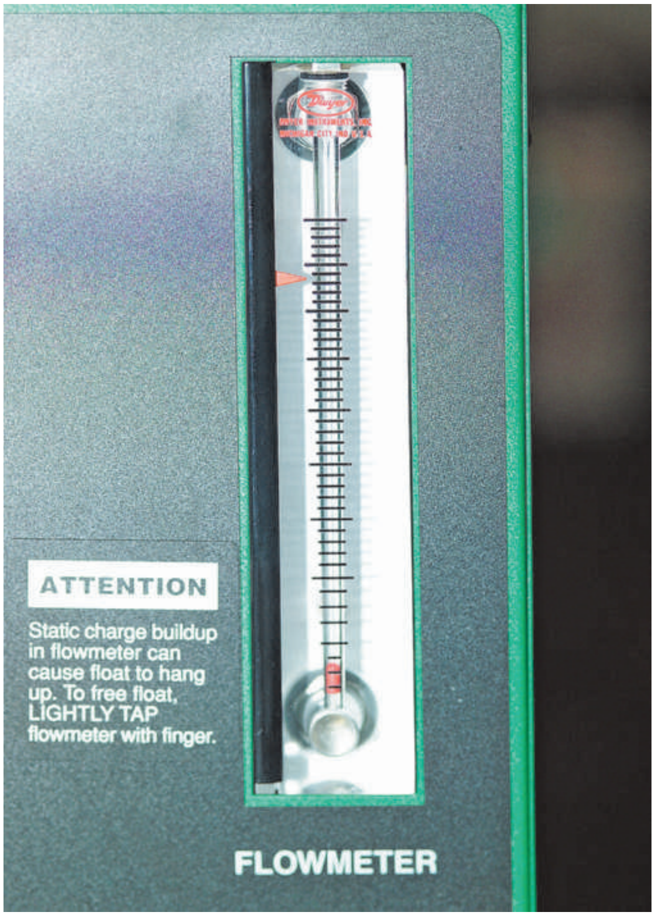


FIGURE 34-18 The flowmeter for an EVAP leak tester.

above 8 inches of water after 2 minutes, the vehicle has passed the test. Obviously if there is a leak, the system will not be able to hold pressure. If the pressure drops dramatically, listen for leaks at the fuel cap, tank, connections, valves, and hoses.

The source of the leak may be found by spraying the suspected areas with soapy water and looking for bubbles. Leaks can also be found by using an ultrasonic leak detector that will detect the sound made by the leaking vapors. An additional way to find the leak is through the use of an exhaust analyzer or combustible gas detector. This method can be a bit frustrating because it will only respond to fuel vapors. Because the nitrogen in the system will push the vapors out, the probe of the analyzer must be placed at the suspected area prior to or immediately after the system is pressurized. Obviously, the analyzer will read high HCs at the point of the leak. Once the source of the leak is found, make the necessary repairs and retest the system.

Using Dye To help identify the source of a leak, ultraviolet dye **(Figure 34–19)** can be added to the system. The dye will identify the source of a leak when the system is inspected with a UV lamp. The dye is approved by many OEMs and will not harm the system, catalytic converters, or the H_2OS.

Smoke Test A very popular way to identify leaks is with a smoke machine. Nearly all OEMs recommend this method. The smoke machine vaporizes a specially formulated, highly refined mineral oil-based fluid. The machine then introduces the resultant smoky vapor into the EVAP system.

Pressurized nitrogen pushes the smoke through the system. The source of a leak is identified by the escaping smoke **(Figure 34–20)**. As when pressure testing the system, the system must be sealed to get accurate results. This means the canister vent port must be blocked off. On some vehicles the solenoid can be closed through commands input with a scan tool.

Fuel Cap Tester Most fuel cap testers come with a variety of fuel cap adapters. Always use the one that is appropriate for the vehicle being tested. Tighten the cap to the adapter and connect the cap and adapter to the tester. Turn on the tester. The tester will create a pressure on the cap and monitor the

FIGURE 34-19 An ultraviolet leak detector kit.

FIGURE 34–20 During a smoke test, smoke will be seen at all points of leakage. Be sure to inspect the entire system.

cap's ability to hold the pressure. In most cases, the tester will illuminate lights, indicating that the cap is good or bad.

PCV System Diagnosis and Service

No adjustments can be made to the PCV system. Service of the system involves careful inspection, functional tests, and replacement of faulty parts. Some engines use a fixed orifice tube in place of a valve. These should be cleaned periodically with a pipe cleaner soaked in carburetor cleaner. Although there is no PCV valve, this type of system is diagnosed in the same way as those systems with a valve. When replacing a PCV valve, match the part number on the valve with the vehicle maker's specifications for the proper valve. If the valve cannot be identified, refer to the part number listed in the manufacturer's service information. Newer PCV valves have locking devices that prevent them from becoming loose or falling out. Make sure that the lock is fully engaged when installing the valve.

Consequences of a Faulty PCV System

If the PCV valve is stuck open, excessive airflow through the valve causes a lean air-fuel ratio and possible rough idle or engine stalling. When the PCV valve or hose is restricted, excessive crankcase pressure forces blowby gases through the clean air hose and filter into the air cleaner. Worn rings or cylinders cause excessive blowby gases and increased crankcase pressure, which forces blowby gases through the hose and filter into the air cleaner. A restricted PCV valve or hose may also cause an accumulation of moisture and sludge in the engine and engine oil.

Leaks at the engine gaskets not only will cause oil leaks, but will allow blowby gases to escape into the atmosphere. The PCV system will also draw unfiltered air through these leaks. This can result in premature wear of engine parts, especially when the vehicle is operated in dusty conditions. Check the engine for signs of oil leaks. Be sure the oil filler cap and dipstick fit and seal properly. If these do not seal, they can be the source of false air and cause a change in LTFT on MAF systems.

Visual Inspection

The PCV valve can be located in several places. The most common location is in a rubber grommet in the valve cover. It can be installed in the middle of the hose connections, as well as directly in the intake manifold.

Once the PCV valve is located, make sure that all the PCV hoses are properly connected, are not collapsed, and have no breaks or cracks **(Figure 34–21)**. Remove the air cleaner and inspect the air and crankcase filters. Crankcase blowby can clog these with oil. Clean or replace such filters. Oil in the air cleaner assembly indicates that the PCV valve or hoses are plugged. Make sure you check these and replace the valve and clean the hoses and air cleaner assembly. When the PCV valve and hose are in satisfactory condition and there was oil in the air cleaner assembly, perform a cylinder compression test to check for worn cylinders and piston rings.

FIGURE 34–21 A collapsed PCV supply hose.

Functional Checks of the PCV System

Before beginning the functional checks, double-check the PCV valve part number to make certain that the correct valve is installed. If the correct valve is being used, continue by disconnecting the PCV valve from the valve cover, intake manifold, or hose. Start the engine and let it run at idle. If the PCV valve is not clogged, a hissing is heard as air passes through the valve. Place a finger over the end of the valve to check for vacuum **(Figure 34–22)**. If there is little or no vacuum at the valve, check for a plugged or restricted hose. Replace any plugged or deteriorated hoses. Turn off the engine and remove the PCV valve. Shake the valve and listen for the rattle of the check needle inside the valve. If the valve does not rattle, replace it.

Some vehicle manufacturers recommend that the valve be checked by removing it from the valve cover and hose. Connect a hose to the inlet side of the PCV valve, and blow air through the valve with your mouth while holding your finger near the valve outlet **(Figure 34–23)**. Air should pass freely through the valve. If air does not pass freely through the valve, replace the valve. Move the hose to the outlet side of the PCV valve and try to blow back through the valve **(Figure 34–24)**. It should be difficult to blow air through the PCV valve in this direction. If air passes easily through the valve, replace the valve.

Caution! Do not attempt to suck through a PCV valve with your mouth. Sludge and other deposits inside the valve are harmful to the human body.

FIGURE 34–22 With the engine at idle, vacuum should be felt at the PCV valve.

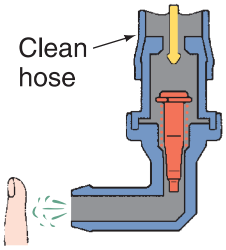


FIGURE 34–23 Blowing through the inlet of a PCV valve, air should freely flow through.

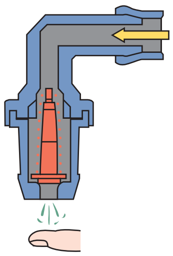


FIGURE 34–24 Blowing through the outlet of a PCV valve, air should barely flow through.

Another simple check of the PCV valve can be made by pinching the hose between the valve and the intake manifold **(Figure 34–25)** with the engine at idle. You should hear a clicking sound from the valve when the hose is pinched and released. A sound scope or stethoscope will help hear the clicking. If no clicking sound is heard, check the PCV valve grommet for cracks or damage. If the grommet is okay, replace the PCV valve.

The PCV system can be checked with an exhaust analyzer. Check and record the CO and measurements with the engine at idle. Then pull the PCV valve out of the engine and allow it to draw in air from under the hood. Check the CO and O_2 readings. The CO should decrease and the O_2 increase. If the readings did not change, clean the PCV system and replace the valve. If the CO decreased by 1 percent or more, the engine's oil may be diluted with raw fuel. Locate the cause of the fuel leakage. Then change the engine's oil and filter. Now cover the open end of the valve and observe the CO and O_2 readings after analyzer stabilizes. The CO should increase and the O_2 decrease. If readings were the same when the valve was open to underhood air or the readings changed very little, check the valve or the hose for restrictions. Clean the system and replace the valve.

Remember that proper operation of the PCV system depends on a sealed engine. The crankcase is

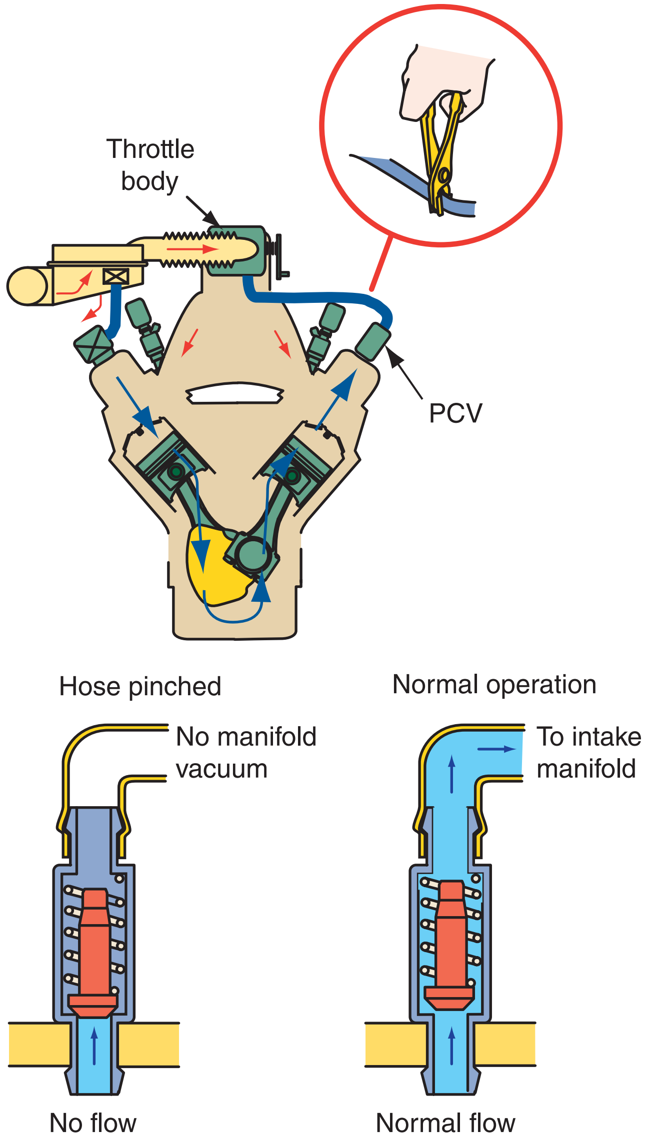


FIGURE 34-25 When the PCV hose is pinched, the valve should click.

sealed by the dipstick, valve cover, gaskets, and sealed filler cap. If oil sludging or dilution is found and the PCV system is functioning properly, check the engine for oil leaks and correct them to ensure that the PCV system can function as intended. Also, be aware of the fact that a very worn engine may have more blowby than the PCV system can handle. If there are symptoms that indicate the PCV system is plugged (oil in air cleaner, saturated crankcase filter, etc.) but no restrictions are found, check the wear of the engine.

Diesel Crankcase Ventilation Systems

Until 2007, most diesel engines removed crankcase pressures and blowby with a downdraft tube. This system is very similar to those used on gasoline engines until the late 1950s. Although the systems had a filter to collect some particulate matter, most was vented to the atmosphere.

Since then diesel engines are required to control crankcase emissions. The most common systems have a filter that collects the blowby gases and a system to return them to the engine's intake or crankcase. These systems are designed to self-clean but problems in this system can occur. Therefore, it is important to inspect and clean the system as necessary as well as check the engine for excess crankcase pressures. When pressure builds up because the valve is stuck closed, crankcase pressure can force oil past some gaskets and seals. If the valve is stuck open, oil from the crankcase will be drawn into the engine and burned as fuel; however, it is heavier and thicker than diesel fuel and will cause excessive heat in the cylinders. If there is oil or oil mist present in the intake, check the valve.

Measuring Crankcase Pressure

To measure crankcase pressure, bring the engine up to normal operating temperature. Then connect a water manometer to the dipstick tube after the dipstick has been removed. With the engine at idle, observe the reading on the meter. If the reading is greater than 1 inch H_2O, check the crankcase valve. If the valve is clean and working properly, check the compression and leakage of the cylinders. If the crankcase pressure is less than 1 inch H_2O, raise

SHOP TALK

If a water manometer is not available, you can make one with clear plastic tubing that will fit over the dipstick tube. Form a 3-inch "U" bend in the hose with at least 12 inches on each side of the "U." Attach the hose to a board with large staples spaced at 1-inch intervals. These intervals will be used for measurement. Fill the tube with water so that approximately one-third of the tube has water in it. On the wood, mark the level of the water. Connect one end of the tube to the dipstick tube and start the engine. Measure the amount the water moved; this is the pressure inside the crankcase as measured in inches of H_2O.

the engine to above 2,000 rpm. If the pressure drops to a negative value of 4 to 5 inches H_2O, the system is okay. If the drops are more than that, replace the valve. Keep in mind that a restriction in the air intake system will increase inlet vacuum in turbocharged engines and the intake vacuum on nonturbocharged engines.

EGR System Diagnosis and Service

Manufacturers calibrate the amount of exhaust gas recirculation or EGR flow for each engine. Too much or too little can cause performance problems by changing the engine's breathing characteristics. Also, with too little EGR flow, the engine can overheat, detonate, and emit excessive amounts of NO_x. When any of these problems exist and it seems likely that the EGR system is at fault, check the system. Typical problems that show up in ported EGR systems follow:

- *Rough idle* can be caused by a stuck open EGR valve, a clogged EGR vent, dirt on the valve seat, or loose mounting bolts (this also causes a vacuum leak and a hissing noise).
- *No-start, surging, or stalling* can be caused by an open EGR valve.
- *Detonation (spark knock)* can be caused by any condition that prevents proper EGR gas flow, such as a valve stuck closed, leaking valve diaphragm, restrictions in flow passages, disconnected EGR, or a problem in the vacuum source.
- *Excessive NO_x emissions* can be caused by any condition that prevents the EGR from allowing the correct amount of exhaust gases into the cylinder or anything that allows combustion temperatures.
- *Poor fuel economy* is typically caused by the EGR system if it relates to detonation or other symptoms of restricted or zero EGR flow.

Scan Tool

On OBD II systems, the EGR system monitor is designed to test the integrity and flow characteristics of the EGR system. The monitor is activated during EGR operation and after certain engine conditions are met. Input from the ECT, IAT, TP, and CKP sensors are required to activate the monitor. Once activated, a typical EGR monitor carries out these tests:

- The differential pressure feedback EGR sensor and circuit are continuously tested for opens and shorts.
- The EGR vacuum regulator solenoid is continuously tested for opens and shorts. The monitor compares circuit voltage to what should exist when the EGR valve is in its commanded state.
- Non-DPFE systems monitor STFT while opening the EGR value; the STFT should decrease. Some non-DPFE systems use the MAP sensor to determine if the EGR is functioning by monitoring pressure in the intake with the valve open.
- The EGR flow rate test is checked by comparing the actual differential pressure feedback EGR circuit voltage to the desired EGR flow voltage for the current operating conditions to determine if the EGR flow rate is acceptable.
- The hoses connected to the differential pressure feedback EGR sensor hoses are tested once per drive cycle. They are checked for restrictions and opens when the EGR valve is closed and during acceleration. The monitor checks the voltage from the differential pressure feedback EGR sensor. A reading not within the normal range for a closed valve indicates a problem with the hose.
- Checking for a stuck open EGR valve or some EGR flow at idle is continuously done at idle. The monitor compares the differential pressure feedback EGR circuit voltage to the differential pressure feedback EGR circuit voltage stored during key on engine off operation to determine if there is EGR flow.
- The MIL is illuminated after one of these tests fails on two consecutive drive cycles.

Different methods of EGR flow monitoring are used; these include temperature sensors, manifold pressure changes, fuel trim changes, and differential pressure measurement. Using temperature sensors, an EGR temperature sensor is installed in the EGR passageway. During normal EGR flow, the temperature of the EGR temperature sensor will rise at least 95 °F (35 °C) above ambient air temperature. When the EGR valve is open, the ECM compares EGR temperature to intake air temperature. If the temperature does not rise a specified amount over ambient temperature, the ECM assumes there is a problem in the system, and this information is stored in the ECM.

MAP systems base their calculations on the assumption that low intake manifold vacuum means the engine is under a heavier load and greater airflow. Too much EGR flow will increase manifold pressure and the PCM will interpret this as an increase in airflow and will increase the amount of fuel delivered

to the cylinders. The system compares MAP readings with the reading from the H_2OS. The PCM will also try to compensate for this by correcting the fuel trim. Excessive EGR flow will cause negative fuel trims, and low EGR flow will cause higher-than-normal fuel trim readings. If fuel trim readings seem to be out of line, EGR flow may be the cause.

When the PCM detects a problem in the system, it will set a DTC. It is important to note that the conditions required to set a DTC vary with manufacturer and model. It is also important to realize that inputs from the engine control system EGR operation. Therefore, all engine-related DTCs should be dealt with before moving into detailed diagnostics of the EGR system. Some DTCs pertain solely to the EGR valve and its solenoids **(Figure 34–26)**.

EGR System Troubleshooting

Before attempting to troubleshoot or repair a suspected EGR system on a vehicle, make sure that the engine is mechanically sound, that the injection system is operating properly, and that the spark control system is working properly.

DTC	Description
P0106	MAP sensor rationality error
P0107	MAP sensor voltage low
P0108	MAP sensor voltage high
P0109	MAP sensor intermittent (non-MIL) problem
P0400	EGR system leak detected
P0401	Insufficient EGR flow
P0402	DPFE EGR stuck open
P0403	EVR circuit open or shorted
P0404	EGR control circuit range/performance problem
P0405	EGR valve position sensor circuit low
P0406	EGR valve position sensor circuit high
P1400 (Ford)	DPFE circuit low
P1401 (Ford)	DPFE circuit high
P1405 (Ford)	Upstream hose off or plugged
P1406 (Ford)	Downstream hose off or plugged
P1409 (Ford)	EVR circuit open or shorted
P2413 (Honda)	EGR system malfunction
P2457 (Ford)	Insufficient EGR cooler performance

FIGURE 34–26 Samples of EGR-related DTCs.

Most often an electronically controlled EGR valve functions **(Figure 34–27)** in the same way as a vacuum-operated valve. Apart from the electronic control, the system can have all of the problems of any EGR system. Those that are totally electronic and do not use a vacuum signal can have the same problems as others, with the exception of vacuum leaks and other vacuum-related problems. Sticking valves, obstructions, and loss of vacuum produce the same symptoms as on non–electronic-controlled systems. If an electronic control component is not functioning, the condition is usually recognized by the PCM. The solenoids, or the EVR, should normally cycle on and off frequently when EGR flow is being controlled (warm engine and cruise rpm). If they do not, a problem in the electronic control system or the solenoids is indicated. Generally, an electronic control failure results in low or zero EGR flow and might cause symptoms like overheating, detonation, and power loss.

EGR solenoids are used with all types of EGR valves, especially backpressure-type valves. The PCM uses a solenoid to regulate ported or manifold vacuum to the EGR valve.

The solenoid is actually a vacuum switch. The PCM controls the switch through pulse width modulation. No vacuum is sent to the valve unless the PCM allows it. The EGR solenoid has two or more vacuum lines and an electrical connector. The solenoid also has an air bleed and sometimes an air filter. Vacuum is bled off through the filter vent. If the filter becomes clogged, the EGR valve will open too much and cause a driveability problem.

Before attempting any testing of the EGR system, visually inspect the condition of all vacuum hoses for kinks, bends, cracks, and flexibility. Replace defective hoses as required. Check vacuum hose routing against the underhood decal or the service information; correct any misrouted hoses. If the system is fitted with an EVP sensor, the wires routed to it should also be checked.

If the EGR valve remains open at idle and low engine speed, the idle operation is rough and surging occurs at low speed. When this problem is present, the engine may hesitate on low-speed acceleration or stall after deceleration or after a cold start. If the EGR valve does not open, engine detonation occurs. When a defect occurs in the EGR system, a DTC is usually set in the PCM memory.

EGR Valves and Systems Testing

On many older engines, a single diaphragm EGR valve can be checked with a hand-operated vacuum pump **(Figure 34–28)**. Before conducting this

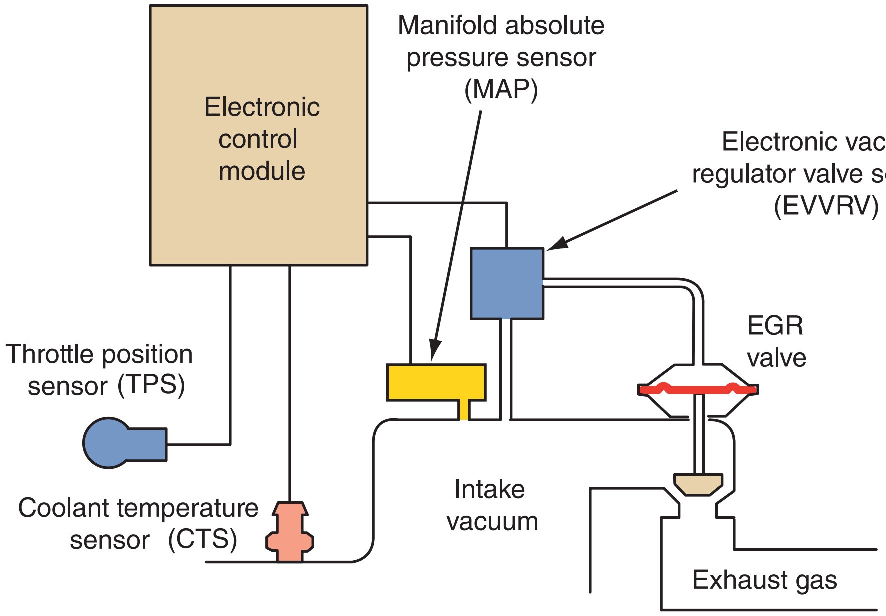


FIGURE 34–27 The circuit of a typical computer-controlled EGR system.

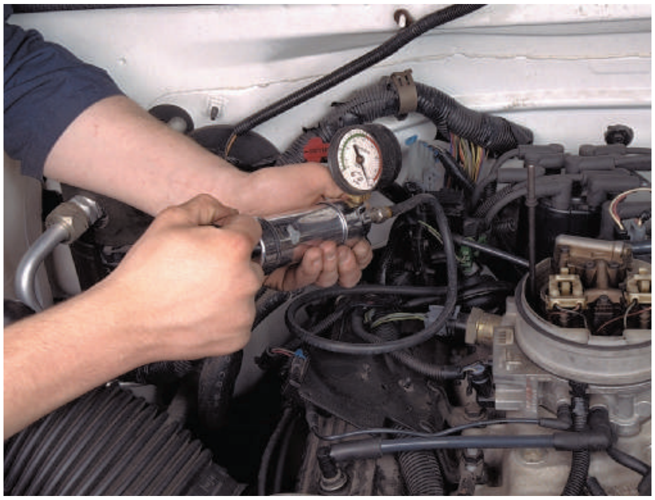


FIGURE 34–28 Watch the action of the valve when vacuum to it is applied and released.

test, make sure that the engine produces enough vacuum to properly operate the valve. This is done by connecting a vacuum gauge to the engine's intake manifold. Then start the engine and gradually increase speed to 2,000 rpm with the transmission in neutral. The reading should be above 16 inches of mercury. If not, there could be a vacuum leak or exhaust restriction. Before continuing to test the EGR, check the MAP and/or correct the problem of low vacuum.

To check the valve with a vacuum pump, remove the vacuum supply hose from the EGR valve port. Connect the vacuum pump to the port and supply 18 inches of vacuum. Observe the EGR diaphragm movement. When the vacuum is applied, the diaphragm should move. If the valve diaphragm did not move or did not hold the vacuum, replace the valve.

With the engine at normal operating temperature, observe the engine's idle speed. If necessary, adjust the idle speed to the emission decal specification. Slowly apply 5 to 10 inches of vacuum to the EGR valve. The idle speed should drop more than 100 rpm (the engine may stall) and then return to normal again when the vacuum is removed. If the idle speed does not respond in this manner, remove the valve and check for carbon in the passages under the valve. Clean the passages as required or replace the EGR valve. Carbon may be cleaned from the lower end of the EGR valve with a wire brush, but do not immerse the valve in solvent and do not sandblast the valve. Also, make sure that the vacuum hoses are in good condition and properly routed.

Diagnosis of a Negative Backpressure EGR Valve

A negative backpressure EGR valve is identified by the letter "N" stamped on it. The valve is opened by a combination of engine vacuum and the negative exhaust system pulses that occur as each exhaust valve closes. As soon as the valve opens, backpressure is reduced slightly, which opens a vacuum bleed and the valve quickly closes. This causes the opening of the valve to modulate according to negative exhaust system pulses.

With the engine at normal operating temperature and the ignition switch off, disconnect the vacuum hose from the EGR valve and connect a hand vacuum pump to the vacuum fitting on the valve. Supply 18 inches of vacuum to the EGR valve. The EGR valve should open and hold the vacuum for 20 seconds. If the valve does not open or cannot hold the vacuum, it must be replaced.

If the valve was okay in the first test, continue by applying 18 inches of vacuum to the valve and start the engine. The vacuum should drop to zero, and the valve should close. If the valve does not react this way, replace it.

Diagnosis of a Positive Backpressure EGR Valve

A positive backpressure EGR valve can be identified by the letter "P" stamped next to the part number and date code. It has a thicker-than-normal pintle shaft because it is hollow. The hollow design allows exhaust gases to flow into the shaft and push up on it. With positive backpressure from the exhaust system, the shaft rises and seals the control valve. Once the control valve is closed, it allows applied vacuum to pull up on the diaphragm. With low backpressure, the valve will not hold vacuum and the vacuum is bled to the atmosphere. As engine load increases, so does engine backpressure, which causes the control valve inside the EGR to trap vacuum and open up. To test this valve, bring the engine up to 2,000 rpm to create backpressure, then apply vacuum. EGR should open and cause a 100 rpm drop or more. Positive backpressure EGR valves are used in simple vacuum-controlled systems as well as more complex pulse width modulated applications.

Diagnosis of a Digital EGR Valve

Digital EGR valves are only found on GM products. They are totally electronically controlled units. They have two or three solenoids, and part of the valve is always open. Use a scan tool to check a digital EGR valve. Start the engine and allow it to run at idle speed. Select the EGR control on the scan tool, and then energize the solenoids one at a time. Engine speed should drop slightly as each EGR solenoid is energized.

If the EGR valve does not respond correctly, make sure 12 volts are applied to the EGR valve. Then check the resistance of the valve. Connect an ohmmeter across the electrical terminals on the valve **(Figure 34–29)**; the windings can be checked for opens, shorts, and excessive resistance. If any resistance reading is not within specs, the valve should be replaced. Visually check all of the wires between the EGR valve and the PCM. Also make sure that the EGR passages are not restricted or plugged. To do this, you will need to remove the valve.

Linear EGR Valve Diagnosis

The correct procedure for diagnosing a linear EGR valve **(Figure 34–30)** will vary, depending on the vehicle make and model year. Always follow the recommended procedure in the vehicle manufacturer's

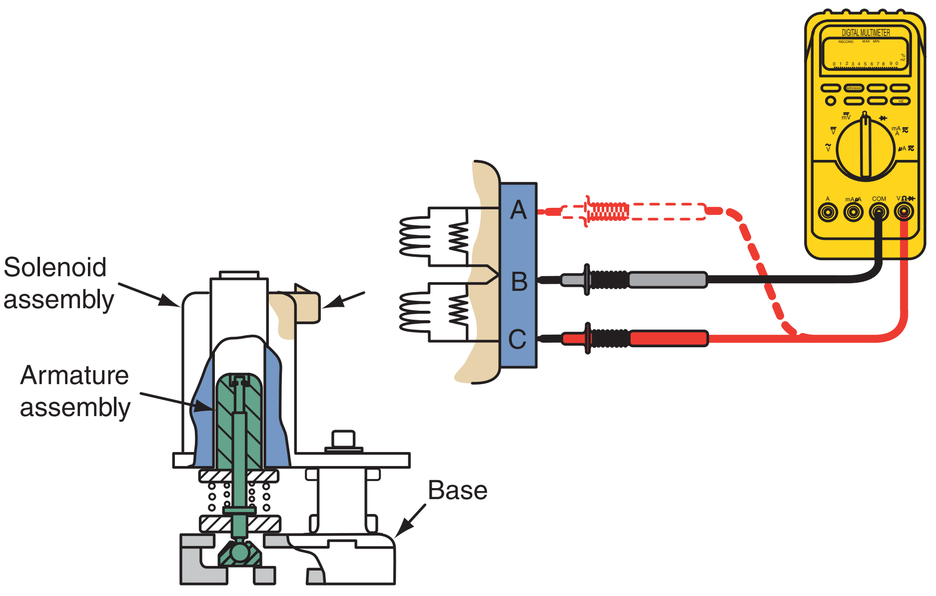


FIGURE 34–29 Ohmmeter connections for checking a digital EGR valve.

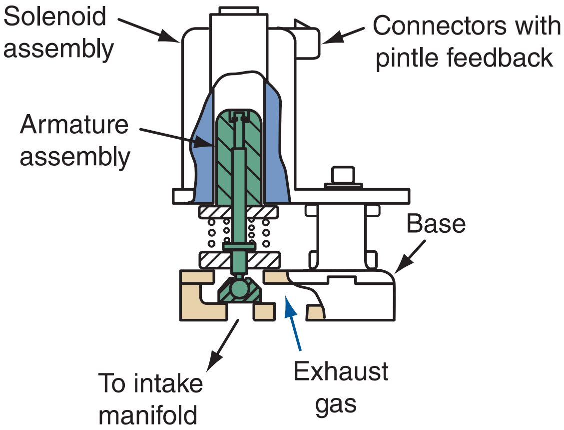


FIGURE 34–30 A linear EGR valve relies on a solenoid to move the pintle.

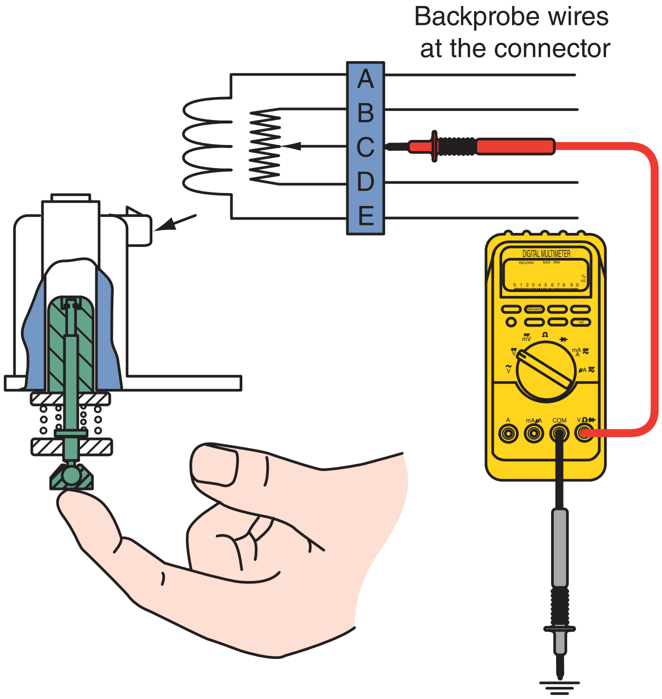


FIGURE 34–31 To check a linear EGR valve, check the voltage at the various pins of its connector.

service information. A scan tool may be used to diagnose a linear EGR valve. The engine should be at normal operating temperature. Because the linear EGR valve has an EVP sensor, the actual pintle position may be checked on the scan tool. The pintle position should not exceed 3 percent at idle speed. The scan tool may be operated to command a specific pintle position, such as 75 percent, and this commanded position should be achieved within 2 seconds. With the engine idling, select various pintle positions and check the actual pintle position. The pintle position should always be within 10 percent of the commanded position.

If a linear EGR valve does not operate properly, check the fuse in the supply wire to the EGR valve. Also check for open circuits, grounds, and shorts in the wires connected from the EGR valve to the PCM **(Figure 34–31)**. Verify that the EVP sensor is receiving a 5-volt reference signal and verify that the ground circuit is good. If these are okay, remove the valve with the wiring harness still connected to it. Then connect a DMM across the pintle position wire at the EGR valve to ground and manually push the pintle upward. The voltmeter reading should change from approximately 1 to 4.5 volts. If the EGR valve did not operate properly, it should be replaced.

Checking EGR Efficiency

Although most testing of EGR valves involves the valve's ability to open and close at the correct time, we are not really testing what the valve was designed to do—control NO_x emissions. EGR systems should be tested to see if they are doing what they were designed to do.

Many technicians wrongly conclude by thinking that an EGR valve is working properly if the engine stalls or idles very rough when the EGR valve is opened. Actually this test just shows that the valve was closed and that it will open. A good EGR valve opens and closes, but it also allows the correct amount of exhaust gas to enter all of the cylinders. EGR valves are normally closed at idle and open at approximately 2,000 rpm. This is where the EGR system should be checked.

To check an EGR system, use a five-gas exhaust analyzer. Allow the engine to warm up, and then raise the engine speed to around 2,000 rpm. Watch the NO_x readings on the analyzer. In most cases, NO_x should be below 1,000 ppm. It is normal to have some temporary increases over 1,000 ppm; however, the reading should be generally less than 1,000. If the NO_x is above 1,000, the EGR system is not doing its job. The exhaust passage in the valve is probably clogged with carbon.

If only a small amount of exhaust gas is entering the cylinder, NO_x will still be formed. A restricted exhaust passage of only $^1/_8$ inch will still cause the engine to run rough or stall at idle, but it is not enough to control combustion chamber temperatures at higher engine speeds. Never assume that the EGR passages are okay just because the engine stalls at idle when the EGR is fully opened. Plugged EGR passages will cause a disproportionate amount of EGR gas into the cylinders without plugged passages. This can cause the engine to run rough but not adequately control NO_x during normal engine operation.

Electronic EGR Controls

When the EGR valve checks out and everything looks fine visually but a problem with the EGR system is evident, the EGR controls should be tested. Often a malfunctioning electronic control will trigger a DTC. Typically, the service information gives the specific directions for testing these controls; always follow them.

Some EGR valves are electronic/mechanical EGR valves. These valves have different names depending on the application. These types of valves operate in the same way as a single diaphragm EGR valve. However, they have a position sensor above the EGR diaphragm. This tells the PCM how far the valve is open. The valve position sensor is a potentiometer and can wear. The sensor can be checked with a DMM or lab scope. The pattern should show a clean sweep as the valve is opened and closed. The EGR monitor system watches the output from the sensor and if the sensor's voltage reading is too high or low, a DTC will be set.

EGR Vacuum Regulator (EVR) Tests

Connect a pair of ohmmeter leads to the EVR terminals to check the winding for open circuits and shorts. An infinite ohmmeter reading indicates an open circuit, whereas a lower-than-specified reading means the winding is shorted. Then connect the ohmmeter leads from one of the EVR solenoid terminals to the solenoid case. You should get an infinite reading; a low ohmmeter reading means the winding is shorted to the case. A scan tool can also be used to diagnose the operation of an EVR solenoid.

Exhaust Gas Temperature Sensor Diagnosis

To test an exhaust gas temperature sensor, remove it and place it in a container of oil. Place a thermometer in the oil and heat the container. Connect the ohmmeter leads to the exhaust gas temperature sensor terminals. The exhaust gas temperature sensor should have the specified resistance at various temperatures.

Diesel Engines

Diesel engines are also equipped with EGR valves. These systems release a sample of exhaust gases into the intake of the turbocharger or the intake manifold. When the exhaust gases pass through the intercooler, the temperature is decreased, which lowers the chances of NO_x formation. Most diesel EGR valves are coupled with an EGR cooler. Engine coolant passes through the EGR cooler to remove heat from the exhaust gas before it recirculates back in to the engine.

SHOP TALK

The same driver in a powertrain control module (PCM) may operate several outputs. On General Motors' computers, drivers sense high current flow. If a solenoid winding is shorted and the driver senses high current flow, the driver shuts down all the outputs it controls. This prevents damage caused by the high current flow. When the PCM does not operate an output or outputs, always check the resistance of the output's solenoid windings before replacing the PCM. A lower-than-specified resistance in a solenoid winding indicates a shorted condition, and this problem may explain why the PCM driver is not operating the outputs. Also, in some EGR systems, the PCM energizes the EVR solenoid at idle and low speeds. Under this condition, the solenoid shuts off vacuum to the EGR valve. When the proper input signals are available, the PCM de-energizes the EVR solenoid and allows vacuum to the EGR valve.

There are basically two types of EGR systems used on diesel engines:

- High-pressure EGR captures the exhaust gas prior to the turbocharger and redirects it back into the intake air. Sometimes, the system will have a catalyst in the high-pressure EGR loops to reduce PM levels that are recirculated back through the combustion process.
- A low-pressure EGR collects the exhaust after the turbocharger and a diesel particulate filter and returns it to the intercooler. Diesel PM filters are always used with a low-pressure EGR system to make sure large amounts of particulate matter are not recirculated to the engine, which would result in accelerated wear in the engine and turbocharger.

Catalytic Converter Diagnosis

The catalytic converter monitor looks at a converter's ability to store O_2. Oxygen storage is only one function of a converter but is a good indication of how efficient the converter is. As the catalyst efficiency declines due to thermal and chemical deterioration, its ability to store O_2 also declines. Therefore, OBD II systems compare the O_2 content in the exhaust before and after the converter. This is done by monitoring the signals from O_2 sensors placed before and after the converter.

The catalyst monitor will run after the HO_2S monitor has been completed, when there are no DTCs stored by the secondary AIR and EVAP systems. Inputs from the ECT, IAT, MAF, CKP, TP, and vehicle speed sensors are required to enable the catalyst efficiency monitor. After the engine has warmed up and the necessary inputs are available, the PCM will calculate whether the converter has warmed up or not. If it is warm, the monitor will run. Converter efficiency is determined by comparing the precatalyst HO_2S or A/F sensor signal with the signal from the postcatalyst HO_2S. The PCM looks at the signal differences between the two sensors to measure converter efficiency **(Figure 34–32)**. As the ratio of rear to front switching increases, meaning the rear HO_2S signal switching resembles that of the front HO_2S, the PCM will set a catalyst efficiency DTC, either a P0420 or P0430. If other DTCs are stored in addition the catalyst efficiency codes, diagnose and repair those first. Once any other concerns are corrected, complete a drive cycle and recheck for the P0420 or P0430.

During normal operation, the front HO_2S switches more often and with a greater amplitude than the rear HO_2S. The rear HO_2S also has a shorter signal. The monitor compares the cross counts of each sensor as well as the signal length. When the converter has lost some of its ability to store O_2, the postcatalyst or downstream HO_2S signal begins to switch more rapidly with increasing amplitude and signal length. It starts to look like the signal from the precatalyst or upstream HO_2S.

When the signals become alike and stay that way through a number of drive cycles, the PCM will set a DTC and illuminate the MIL. The activity of the HO_2S can be monitored on a scan tool or lab scope. Doing this will help determine if either of the sensors is bad or the converter is bad. A converter-related DTC does not always indicate that the converter is bad. These DTCs can be set for a number of other reasons, such as:

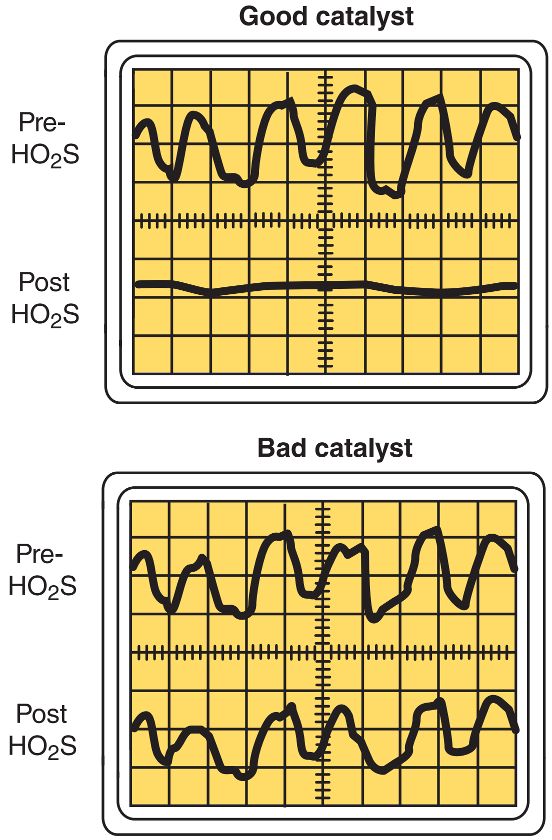


FIGURE 34–32 A comparison of the HO_2S signals for a good and a bad catalytic converter.

- A small leak in the secondary AIR system
- A slight misfire that is causing extra O_2 to enter the exhaust stream
- An exhaust leak downstream of the front HO_2S

Converter Diagnosis

Typically, catalytic converters fail because of deterioration of the catalyst material or because of physical damage. A converter should be checked for cracks and dents. It is also possible that the internal components of the converter are damaged or broken. A quick test of internal damage is done with a rubber mallet. The converter is smacked with the mallet. If the converter rattles, it needs to be replaced and there is no need to do other testing. A rattle indicates loose catalyst substrate, which will soon rattle into small pieces. This test is not used to determine if the catalyst is good.

Converters often fail because the catalyst material becomes coated with foreign materials. This normally is the result of contaminated fuel, sealants, incorrect motor oil use, or coolant entering the exhaust stream. A buildup of this material reduces the catalysts' ability to reduce NO_x and oxidize HC and CO.

An overheated converter can become plugged and restrict exhaust flow. The typical cause of an overheated converter is engine misfiring. A plugged converter or any exhaust restriction can cause loss of power at high speeds, stalling after starting (if totally blocked), or sometimes popping or backfiring at the intake manifold.

A vacuum gauge can be used to watch engine vacuum while the engine is accelerated. Another way to check for a restricted exhaust or catalyst is to insert a pressure gauge in the exhaust manifold's bore for the O_2 sensor **(Figure 34–33)**. With the gauge in place, hold the engine's speed at 2,000 rpm and watch the gauge. The desired pressure reading will be less than 1.25 psi. A very bad restriction will give a reading of over 2.75 psi.

You can use Mode $06 data to monitor how the PCM is measuring catalyst efficiency. As the catalyst ages and efficiency decreases, the Mode $06 data will show an increase in the catalyst monitor index ratio.

Oxygen Storage Test The O_2 storage test is based on the fact that a good converter stores O_2. Begin by warming up a four- or five-gas analyzer. Disable the air injection system **(Figure 34–34)**. Once the converter is warmed up, insert the analyzer's probe into the tailpipe, and hold the engine at 2,000 rpm. Watch the O_2 readings. Once the numbers stop dropping, check the O_2 level on the gas analyzer. The O_2 readings should be about 0.0 percent. This shows that the converter is using the available O_2. Immediately after the O_2 drops, quickly snap the throttle and watch the O_2 reading just as the CO begins to increase. If the O_2 now exceeds 1.2 percent, the converter is failing this test. If the O_2 readings never reached zero, the test may need to be repeated after adding some propane through the air intake until all of the O_2 stored in the converter is depleted.

Checking Converter Efficiency This converter test uses a principle that checks the converter's efficiency. Before beginning this test, make sure that the converter is warmed up and there are no ignition problems, vacuum leaks, or fuel restrictions. Disable the air injection system and then disconnect the HO_2S. Calibrate a four- or five-gas analyzer and insert its probe into the tailpipe. With a propane

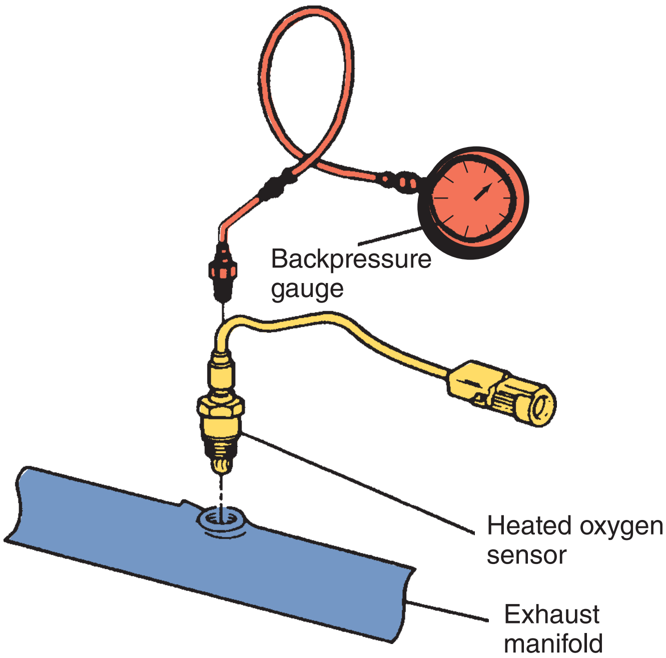


FIGURE 34-33 To measure exhaust system backpressure, insert a pressure gauge into the oxygen sensor's bore in the exhaust.

FIGURE 34-34 Before conducting an oxygen storage test, disable the air injection system.

FIGURE 34-35 While checking converter efficiency, you may need to add some propane into the intake to enrich the mixture.

enrichment tool **(Figure 34–35)**, richen the air-fuel mixture until the CO reading is about 2 percent. Then reconnect the air injection system. Observe the HC, CO, and O_2 readings. If the converter is working correctly, the O_2 should increase and HC and CO should decrease when the air injection system is reconnected. If the O_2 increased but the CO and HC did not change much, or if the O_2 is higher than the CO and the CO is greater than 0.5 percent, the converter is faulty. If the O_2 is lower than the CO, the converter is not oxidizing HC and CO.

AIR System Diagnosis and Service

Not all engines are equipped with an air injection system; only those that need them to meet emissions standards have them. Therefore, air injection systems are vital to proper emissions on engines equipped with them. Each system has its own test procedure; always follow the manufacturer's recommendations for testing.

Most AIR systems are computer controlled and rely on solenoids to control the direction of airflow to the exhaust manifold or to the converter. When the system is in closed loop, the air from the air injection system must be directed away from the O_2 sensor. Some systems have switching valves that allow a small amount of air to flow past the O_2 sensor. The computer knows how much and adjusts the O_2 input accordingly. Sometimes the amount of air that can move through a closed switching valve is marked on its housing. The pump has at least two hoses. The inlet hose is the larger of the two and connects to the air filter assembly or a small dedicated air filter. The output hose carries output air through the valve and into the exhaust.

Secondary AIR Monitor

The operation of the secondary air injection (AIR) system is checked by an OBD II monitor. The monitor looks at the complete electrical circuit for the AIR system, especially the electric pump (if so equipped) and pump relay. It checks it for shorts, opens, and high resistance. It checks the ability of the system to inject air into the exhaust. It does this through input from the HO_2S. It compares the HO_2S signals when the system is off and when it is energized. The condition of the pump and hoses is also checked at this time.

The monitor runs when the AIR system is operating but when the enable criteria are met. Most AIR systems will set DTCs in the PCM if there is a fault in the solenoids and related wiring. In some AIR systems, DTCs are set in the PCM memory if the airflow from the pump is continually upstream or downstream. Always use a scan tool to check for any DTCs related to the AIR system, and correct the causes of these codes before proceeding with further system diagnosis. When a fault is detected, a DTC is set and the MIL will be lit if the fault is detected during two consecutive drive cycles.

Late-model AIR systems use an electric air pump controlled by the PCM **(Figure 34–36)**. These systems have an AIR solenoid and solenoid relay. When the PCM provides a ground for the relay, battery voltage is applied to the solenoid and the pump. Typically, DTCs will be set if one of the components fails or if the hoses or check valves leak. A quick check of the system can be made with a scan tool.

Set the scan tool to watch the voltage at the O_2 sensor(s). Start the engine and allow it to idle. Once

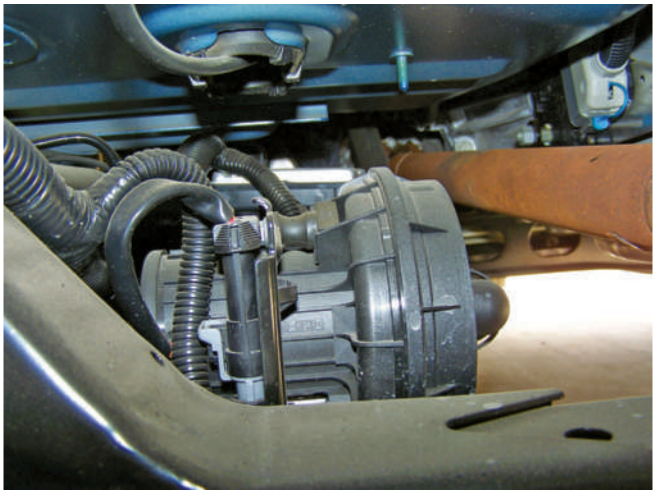


FIGURE 34-36 An electric air pump.

the engine has reached normal operating temperature, enable the AIR system and check the HO_2S voltages. If the voltages are low, the AIR pump, solenoid, and shutoff valve are working properly. If the voltages are not low, each component of the system needs to be checked and tested. For testing purposes, most bidirectional scan tools can turn the AIR pump on for testing purposes.

Secondary AIR System Service and Diagnosis

The first step in diagnosing a secondary air injection system is to check all vacuum hoses and electrical connections in the system. Most belt-driven AIR pumps have a centrifugal filter behind the pulley to keep dirt out of the pump. Air flows through this filter into the pump. The pulley and filter are bolted to the pump shaft and are serviced separately **(Figure 34–37)**. If the pulley or filter is bent, worn, or damaged, it should be replaced. Also check the AIR pump's belt for condition and tension and correct it as necessary. The pump assembly is usually not serviced.

In some AIR systems, pressure relief valves are mounted in the AIRB and AIRD valves. Other AIR systems have a pressure relief valve in the pump. If the pressure relief valve is stuck open, airflow from the pump is continually exhausted through this valve, which causes high tailpipe emissions.

If the hoses in the AIR system show evidence of burning, the one-way check valves are leaking, which allows exhaust to enter the system. Leaking air manifolds and pipes result in exhaust leaks and excessive noise.

If the AIR system does not pump air into the exhaust ports during engine warmup, HC emissions are high during this mode, and the HO_2S, or sensors, takes longer to reach normal operating temperature. Under this condition, the PCM remains in open loop longer. Because the air-fuel ratio is richer in open loop, fuel economy is reduced.

When the AIR system pumps air into the exhaust ports with the engine at normal operating temperature, the additional air in the exhaust stream causes lean signals from the HO_2S or sensors. The PCM responds to these lean signals by providing a richer air-fuel ratio. This increases fuel consumption. A vehicle can definitely fail an emissions test because of air flowing past the HO_2S when it should not be. If the HO_2S is always sending a lean signal back to the computer, check the air injection system.

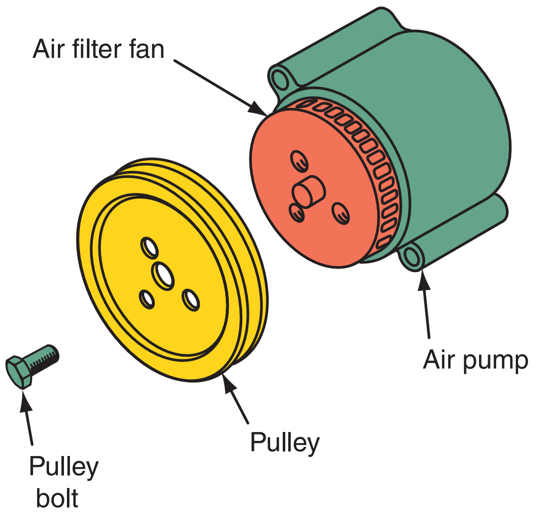


FIGURE 34-37 An AIR pump pulley and filter assembly.

Noise Diagnosis

Leaks in the AIR system can cause a noise. It may sound like an exhaust leak or a hissing, depending on where the leak is. To verify that the system is leaking, disconnect the pressure hose from the switching or combination valve. Plug the end of the hose and run the pump. Normally the sound will be amplified and can be found. The pump itself can be the source of a leak. This typically results in a whistling noise when the pump is running. At times, the source of the leak can be found by feeling around the pump as it runs. A common source of leakage is a bad or loose seal at the pump shaft.

A pump problem can also be the cause of a noise. One common pump noise is a rattling that is heard only when the pump is running. The common cause of this noise is worn or damaged pump isolator mounts.

System Efficiency Test

When the AIR system is working properly, HC, CO and CO_2 are decreased and O_2 is increased. Run the engine at about 1,500 rpm with the secondary AIR system on (enabled). Using an exhaust gas analyzer, measure and record the emission levels. Next, disable the secondary AIR system and continue to allow the engine to idle. Again, measure and record the emission levels in the exhaust gases. The O_2 readings should be at least 4 percent less than they were when the AIR system was enabled. Less than that indicates an AIR problem.

AIR Component Diagnosis

Not all AIR systems have the same components. The following are some of the more common parts used in today's AIR systems.

AIRB Solenoid and Valve When the engine is started, listen for air being exhausted from the AIRB valve for a short period. If this air is not exhausted, remove the vacuum hose from the AIRB and start the engine. If air is now exhausted from the AIRB valve, check the AIRB solenoid and connecting wires. When air is still not exhausted from the AIRB valve, check the air supply from the pump to the valve. If the air supply is available, replace the AIRB valve.

During engine warmup, remove the hose from the AIRD valve to the exhaust ports and check for airflow from this hose. If airflow is present, the system is operating normally in this mode. When air is not flowing from this hose, remove the vacuum hose from the AIRD valve and connect a vacuum gauge to this hose. If vacuum is above 12 in. Hg, replace the AIRD valve. When the vacuum is zero, check the vacuum hoses, the AIRD solenoid, and connecting wires.

With the engine at normal operating temperature, disconnect the air hose between the AIRD valve and the catalytic converters and check for airflow from this hose. When airflow is present, system operation in the downstream mode is normal. If there is no airflow from this hose, disconnect the vacuum hose from the AIRD valve and connect a vacuum gauge to the hose. When the vacuum gauge indicates zero vacuum, replace the AIRD valve. If some vacuum is indicated on the gauge, check the hose, the AIRD solenoid, and connecting wires.

SHOP TALK

With the engine at normal operating temperature, the AIR system sometimes moves back into the upstream mode with the engine idling. It may be necessary to increase the engine speed to maintain the downstream mode.

Combination Valve This valve is typically part of the AIR monitoring system. It can be quickly checked with a hand-held vacuum pump. Apply vacuum to the valve. It should open. If it does not, replace it. If it does open, check the valve's vacuum source for adequate vacuum and the solenoids that control vacuum to it.

Check Valve All of the types of air injection systems have at least one thing in common—a one-way check valve. The valve opens to let air in but closes to keep exhaust from leaking out. The check valve can be checked with an exhaust gas analyzer. Start the engine and hold the probe of the exhaust gas analyzer near the check valve port. If any amount of CO or CO_2 is read, the valve leaks. If this valve is leaking, hot exhaust is also leaking, which could ruin the other components in the air injection system.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2000	**Make:** Honda	**Model:** Civic	**Mileage:** 148,951	**RO:** 19214
Concern:	Customer states oil is leaking from a hose on the engine.			
The technician inspects the engine compartment and finds oil coming from the air induction hose and air cleaner housing. Once removed, he finds oil puddled in the intake hose and under the air filter. Knowing the oil is likely due to a failure in the PCV system, he inspects the PCV valve and hoses.				
Cause:	Found collapsed PCV hose.			
Correction:	Replaced PCV hose and valve. Cleaned induction hoses and air cleaner housing. No other oil leaks found at this time.			

KEY TERMS

Cutpoint
Dynamometer
Electrostatic discharge (ESD)
Parts per million (ppm)

SUMMARY

- The quality of an engine's exhaust depends on the effectiveness of the emission control devices and the efficiency of the engine.
- The three emissions controlled in gasoline and diesel engines are unburned hydrocarbons

(HC), carbon monoxide (CO), and oxides of nitrogen (NO_x).

- Most states and provinces require an annual emission inspection, the most common of which is the OBD II system test.
- Chassis dynamometers are used during the I/M 240 test and can be valuable when diagnosing other driveability problems, including finding the cause of low power, overheating, and speedometer accuracy.
- The report from an I/M 240 test shows the amount of gases emitted during the different speeds and loads of the test. These can be valuable when diagnosing an emission or engine problem.
- An exhaust analyzer is used to look at the quality of an engine's exhaust, which can indicate the quality of the combustion process taking place in the engine.
- Unburned hydrocarbons are particles of gasoline that have not been burned during combustion. They are present in the exhaust and in crankcase vapors.
- Carbon monoxide forms when there is not enough oxygen to combine with the carbon during combustion.
- High NO_x readings indicate high combustion temperatures.
- CO_2 is a desired element in the exhaust stream and is only present when there is combustion.
- O_2 is used to oxidize CO and HC into water and CO_2 and, therefore, very low amounts of O_2 in the exhaust are desirable.
- The OBD II system monitors the emission control systems and components that can affect tailpipe or evaporative emissions.
- EVAP systems can be tested with a scan tool, DMM, hand-held vacuum pump, pressure gauge, and leak tester.
- PCV systems are most commonly checked visually or checked with an exhaust gas analyzer.
- EGR systems can be checked visually or with a scan tool, exhaust analyzer, hand-held vacuum pump, and DMM.
- The most common ways to check the efficiency and operation of a catalytic converter are to monitor the pre- and postconverter HO_2S and retrieve DTCs, or conduct the delta temperature, oxygen storage, and efficiency tests.
- Secondary AIR systems are typically checked with a scan tool or exhaust analyzer.

REVIEW QUESTIONS

Short Answer

1. A rich air-fuel ratio causes HC emissions to ___.
2. What will result from too little EGR flow? And what can cause a reduction in the flow?
3. What can result from a charcoal canister that is filled with liquid or water?
4. What happens if a PCV valve is stuck in the open position?
5. Explain why the I/M 240 and similar tests are being replaced by the OBD II system test.
6. How do you test the operation of a secondary AIR system?
7. List five common causes for high HC emissions.
8. Describe carbon monoxide (CO) emissions in relation to air-fuel ratio.

Multiple Choice

1. An EGR valve that does not fully close can cause all of the following *except* ___.
   a. a no-start
   b. stalling
   c. surging
   d. detonation
2. A restricted catalytic converter can cause all of the following *except* ___.
   a. stalling after the engine starts
   b. popping or backfiring through the intake manifold
   c. a drop in engine vacuum
   d. increased power at high speeds
3. Which of the following statements about EVAP systems is *not* true?
   a. If the system is purging vapors from the charcoal canister when the engine is running at high speeds, rough engine operation will occur.
   b. Cracked hoses or a canister saturated with gasoline may allow gasoline vapors to escape to the atmosphere, resulting in gasoline odor in and around the vehicle.
   c. Rough idle, flooding, and other similar conditions can indicate a saturated canister.
   d. A vacuum leak in the system can cause starting and performance problems.

4. As a catalytic converter begins to deteriorate, the signal from the postcatalyst HO2S becomes ___ the signal of the precatalyst HO2S.
   a. shorter than
   b. more like
   c. larger than
   d. flatter than
5. How much pressure does a typical EVAP pressure tester apply to the system during testing?
   a. 14 in. Hg
   b. 14 psi
   c. 1 in. H_2O
   d. 0.5 psi
6. Which of the following exhaust gases is typically not measured during an I/M 240 test?
   a. HC
   b. O_2
   c. NO_x
   d. CO
7. A vehicle is setting a lean exhaust code and the HO_2S data shows the exhaust to be very lean. Technician A says a malfunctioning AIR system may be the cause. Technician B says a clogged EGR may be the cause. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

ASE-STYLE REVIEW QUESTIONS

1. While discussing the proper way to test a catalytic converter: Technician A says that a pressure gauge can be inserted into the oxygen sensor bore and the backpressure caused by the converter measured. Technician B says that restrictions in the converter can be checked with a vacuum gauge while the engine is being quickly accelerated. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. While discussing tailpipe emissions and cylinder misfiring: Technician A says that cylinder misfiring causes a significant increase in HC emissions. Technician B says that cylinder misfiring results in a large increase in CO emissions. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. While discussing catalytic converter diagnosis: Technician A says that Mode $06 data should be checked. Technician B says that a good converter is evident by low amounts of CO_2 in the exhaust. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. While discussing EGR valve diagnosis: Technician A says that if the EGR valve does not open, the engine may hesitate on acceleration. Technician B says that if the EGR valve does not open, the engine may detonate on acceleration. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. While discussing EGR valve diagnosis: Technician A says that a defective throttle position sensor may affect the EGR valve operation. Technician B says that a defective engine coolant temperature (ECT) sensor may affect the EGR valve operation. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. When discussing the diagnosis of a positive back pressure EGR valve: Technician A says that with the engine running at idle speed, if a hand pump is used to supply vacuum to the EGR valve, the valve should open at 12 in. Hg of vacuum. Technician B says that with the engine not running, any vacuum supplied to the EGR valve should be bled off and the valve's diaphragm should not move. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

7. While diagnosing a PCV problem: Technician A says that a stuck open PCV valve will cause a richer than normal air-fuel mixture. Technician B says that oil in the air cleaner assembly can be caused by a restricted PCV hose. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. Technician A says that the AIR system should pump air into the exhaust manifold(s) during engine warmup. Technician B says that the secondary air system check valve can be checked with an exhaust gas analyzer. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. While discussing PCV system diagnosis: Technician A says that a defective PCV valve may cause rough idle operation. Technician B says that satisfactory PCV system operation depends on a properly sealed engine. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While discussing EVAP testing: Technician A says that most OEMs recommend that clean, high-pressure shop air be used to pressurize the system to test for leaks. Technician B says that nitrogen is typically used to drive the smoke through the system when checking the system with a smoke machine. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER

35

HYBRID VEHICLES

OBJECTIVES

- Explain the differences between the different platforms for hybrid vehicles.
- Explain how manufacturers provide four-wheel drive in hybrid SUVs.
- Describe the purpose of an inverter.
- Explain how the stop-start feature operates.
- Explain how regenerative brakes work.
- Describe the primary advantage of plug-in hybrid vehicles.
- Explain how a belt alternator starter system works.
- Describe the basic operation of the hybrid system used in Honda's IMA system.
- List and describe the common sense precautions that should be adhered to while working around or on a hybrid vehicle.
- List the tools and equipment that are needed to safely diagnose, service, and repair hybrid vehicles.
- Describe what preventative maintenance procedures are unique to a hybrid vehicle.
- Explain the proper steps to take when diagnosing a problem in a typical hybrid vehicle.

Hybrid electric vehicles (HEVs) are or will soon be available from all of the major automobile manufacturers. Any vehicle that combines two or more sources of power is called a hybrid. Current HEVs have an internal combustion engine and one or more electric motors. Toyota introduced the first mass-produced hybrid vehicle in 1997. That hybrid, the Prius, was only available in Japan until 2000, when it was brought to North America. Since then many different hybrid models have been available **(Figure 35–1)**.

Hybrid Vehicles

The logic for using two power sources is simple. A vehicle with an internal combustion engine has more power available than it needs for most driving situations. Most engines can produce more than 150 horsepower, however only 20 to 40 horsepower is normally needed to maintain a cruising speed. The rest of the power is used only for acceleration and overcoming loads, such as climbing a

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2017	**Make:** Chevy	**Model:** Volt	**Mileage:** 11,054	**RO:** 16412
Concern:	Service charging system warning lamp is displayed and the charging connector shows orange instead of green when connected to vehicle.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

FIGURE 35–1 The Acura NSX is a hybrid supercar.

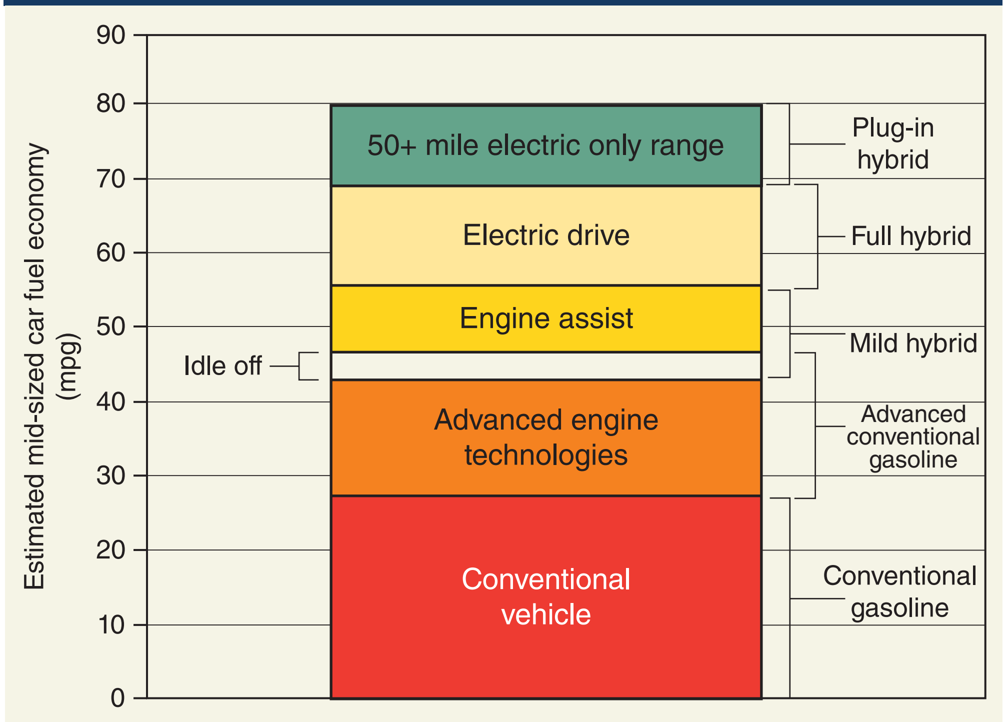
hill. Hybrid vehicles use a smaller engine and the output from an electric motor to provide power for acceleration and overcoming loads. Since the electric motor does not use gasoline, there is a savings in fuel costs.

The power from the electric motor supplements the engine's power. As a result, HEVs use much less fuel in city driving than comparable gasoline vehicles because the engine does not need to supply all of the power required for stop and go traffic. HEVs also use less gasoline when traveling on the highway because highway speeds can be maintained with smaller and highly efficient engines. Also, hybrids can have more than 90 percent fewer emissions than the cleanest conventional vehicles.

The overall efficiency of a hybrid can be, and in most cases is, enhanced by a number of other features. One of these is the stop-start system. When a hybrid vehicle is stopped in traffic, the engine is temporarily shut off. It restarts automatically when the driver presses the accelerator pedal, releases the brake pedal, or shifts the vehicle into a gear. In addition, to reduce the required energy to drive the generator, hybrids have regenerative braking. Rotated by the vehicle's wheels, the motor acts as a generator to charge the batteries when the vehicle is slowing down or braking. This feature recaptures part of the vehicle's kinetic energy that would otherwise be lost as heat in a conventional vehicle. **Table 35–1** compares the various hybrid configurations and the resultant fuel economy.

Most hybrids use transmissions specifically designed to keep the engine operating at its most efficient speed. Efficiency can also be increased by the use of low-rolling resistance (LLR) tires, which are stiff and narrow to minimize the amount of energy required to turn them. Hybrids may also be designed to minimize aerodynamic drag and made lighter.

TABLE 35–1 ESTIMATED FUEL ECONOMY POTENTIAL FOR VARIOUS HYBRID CLASSIFICATIONS



Types

Often hybrids are categorized as series or parallel designs. Many hybrid vehicles are parallel types and rely on power from an electric motor and the engine. When necessary, the motor and engine work together (in parallel) to drive the vehicle **(Figure 35–2)**.

In a series hybrid **(Figure 35–3)**, the engine never directly powers the vehicle. An electric motor powers the vehicle. The gasoline or diesel engine drives a generator, and the generator either charges the batteries or directly powers the electric motor that drives the wheels. A computer controls the operation of the engine depending on the power needs of the battery and/or motor. When the computer senses that system voltage is low, the engine quickly starts and drives the generator. Currently, there are few series hybrids available to the public. These vehicles are widely marketed as extended range electric vehicles.

Most current hybrids are classified as series-parallel designs. With this design, the vehicle can be powered by the electric motor, the engine, or both. The engine also drives the motor/generator to charge the high-voltage battery pack. During deceleration, the motor works as a generator to charge the batteries and to help slow down the vehicle.

Some hybrids are capable of shutting down the engine when the vehicle is traveling at highway speeds with light loads. The decision to power the vehicle by electricity, gasoline, or both is made by an electronic control system.

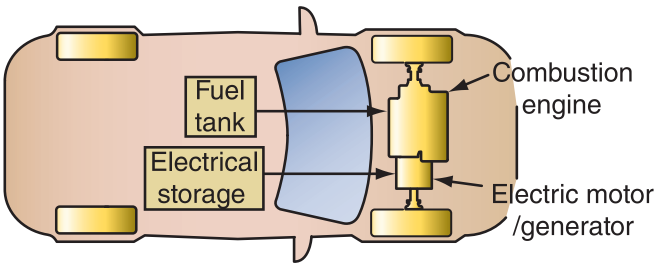


FIGURE 35–2 The basic layout for a parallel hybrid.

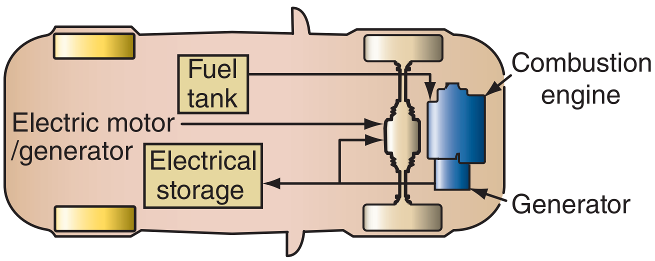


FIGURE 35–3 The basic layout for a series hybrid.

> **SHOP TALK**
>
> Do not get confused between the motor and the engine in a hybrid vehicle. A vehicle's engine has been, and still is, often called a motor. It is not a motor in spite of the fact that we put motor oil in it. The real name for motor oil should be engine oil. By definition, a motor is a machine that converts electrical energy into mechanical energy. An engine converts chemical energy into mechanical energy.

Other Hybrid Classifications

Hybrid configurations are further defined by the role of the electric motor. Keep in mind that whenever the gasoline engine does not run, a savings in fuel and lower emissions will result. Although there are many variations in designs, hybrids can be classified as mild or full. Also, keep in mind, non-hybrid vehicles may be equipped with some of the features of a hybrid vehicle, such as stop-start and regenerative braking. These are designed to minimize fuel consumption.

A mild (micro) hybrid has stop-start, regenerative braking, and electric motor assist available when the engine needs added power to overcome the load. An electric motor helps or assists the engine to overcome increased load, but the vehicle is never powered by only the electric motor. Mild hybrids include those vehicles that have a stop/start system, in which the engine turns off when it would otherwise be idle and then restarts instantly on demand.

A **full hybrid** can run on just the engine, just the batteries, or a combination of the two. A full hybrid has stop-start, regenerative braking, electric motor assist, and can be driven by only electricity.

There are two additional classifications: the performance hybrid (some call this a "muscle hybrid") which is a full hybrid designed for improved acceleration without using more fuel, and a plug-in hybrid—a full hybrid which uses an external electrical source to charge the batteries thereby extending the electric-only driving range by fully charging the battery pack when the vehicle is not in use.

Plug-In Hybrids

Plug-in hybrid electric vehicles (PHEVs) are full hybrids with larger batteries. A battery charger can be plugged into a normal 110-volt outlet to recharge the battery. Charged overnight, PHEVs can drive up to 60 miles without the engine ever turning on. When the batteries run low, the engine starts and powers the vehicle and the generator operates to charge the batteries.

The biggest advantage of plug-in hybrids is they can be driven in an electric-only mode for a distance. During that time, the vehicle consumes no fuel. Under normal conditions, a plug-in hybrid can be twice as fuel-efficient as a regular hybrid. A fully charged PHEV will produce half the exhaust emissions of a normal HEV. This is simply due to the fact there are no exhaust emissions when the engine is not running.

The manufacturing costs of a PHEV are about 20 percent higher than a regular HEV. The increase in cost is mainly due to the price of the larger batteries. Of course, as battery technology advances and more "high-tech" batteries are produced, the cost will decrease.

FIGURE 35–4 The battery pack in a Toyota Camry hybrid.

Hybrid Technology

Hybrids are rolling examples of modern technology. The control systems attempt to precisely control the engine and electric motor. To do this, they need very complex electronics that are capable of controlling and synchronizing the operation of the engine and the motors.

Batteries

The available voltage of a hybrid's battery pack **(Figure 35–4)** depends on the system and the manufacturer. The voltage range is from 115 volts to 360 volts. Most battery packs are basically several small batteries connected together to provide the required voltage. Most hybrids also have an additional 12-volt battery to power conventional electrical items, such as lighting, wipers, sound systems, etc.

Nickel-Metal Hydride (NiMH) Nickel-metal hydride batteries are more environmentally friendly than other designs and are more capable of receiving a full recharge. The cells have electrodes made of a metal hydride and nickel hydroxide. The electrolyte is potassium hydroxide.

Lithium-Ion (Li-Ion) The electrodes in lithium-ion cells are made of a carbon compound (graphite) and a metal oxide. The electrodes are submersed in lithium salt. Overheating these cells may produce pure lithium in the cells. This metal is very reactive and can explode when hot. To prevent overheating, Li-Ion cells have built-in protective electronics and/or fuses to prevent reverse polarity and overcharging. Li-Ion batteries have very good power-to-weight ratios and are making their way into hybrid vehicles.

Motor/Generators

The main difference between a generator and a motor is that a motor has two magnetic fields that oppose each other, whereas a generator has one magnetic field and wires are moved through the field. Using electronics to control the current to and from the battery, a motor that also works as a generator is used in hybrids; these are commonly referred to as motor/generators. A motor/generator may be based on two sets of windings and brushes, a brushless design with a permanent magnet, or switched

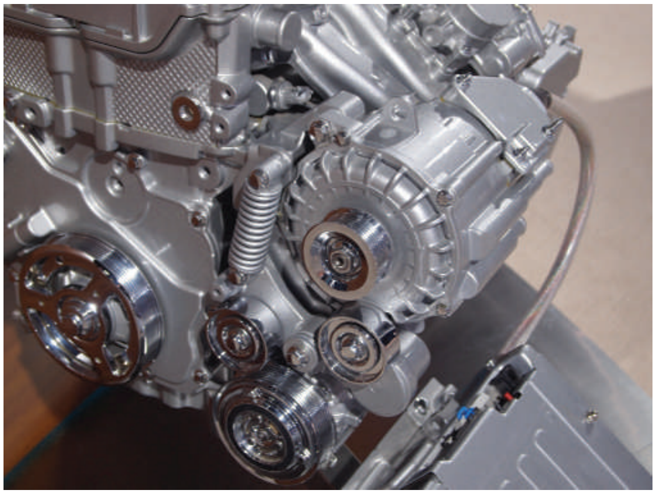


FIGURE 35–5 The unit at the top is called a Belt Alternator Starter (BAS) unit.

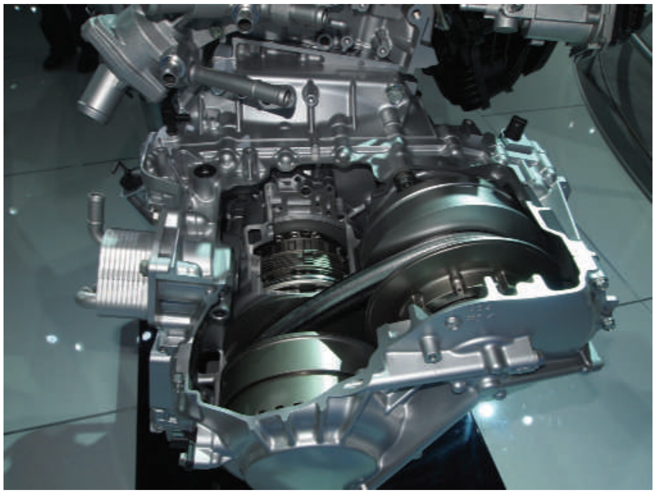


FIGURE 35–6 A CVT uses a belt and adjustable pulleys to change gear ratios according to conditions.

reluctance. It **(Figure 35–5)** may be mounted externally to the engine and connected to the crankshaft with a drive belt. They may also be mounted directly on the crankshaft between the engine and the transmission or integrated into the flywheel. Many hybrids place the motor/generators within the transmission or transaxle assembly.

Internal Combustion Engine

The engine used in most hybrids is a four-stroke cycle engine that burns gasoline. These engines are very similar to those used in conventional vehicles. The engine relies on advanced technologies to reduce emissions and increase overall efficiency. Many of the engines are Atkinson cycle engines.

In other countries where diesel fuel is commonly used, diesel hybrids are being tested. Diesel engines have the highest thermal efficiency of any internal combustion engine. Because of this efficiency, diesel hybrids can achieve outstanding fuel economy.

Transmissions

The transmission used in an HEV can be a normal transmission or one especially designed for the vehicle. Often a continuously variable transmission (CVT) is used, whose gear ratios change according to load **(Figure 35–6)**. In either case, the gear ratios are designed to allow the engine to run at its most efficient speed according to its current operating condition.

Stop-Start Feature

All hybrids have a stop-start system, as do some non-hybrid vehicles. These systems automatically turn off the engine when the driver applies the brakes and brings the vehicle to a complete stop. This prevents wasting energy while the engine is idling and can increase fuel economy by more than 5 percent, although that varies with the vehicle.

Although the engine is off, the heating and air-conditioning systems and basic electrical systems may continue to run using battery power. The engine is restarted automatically the moment the driver releases the brake pedal, or when the control system senses the need.

Normally, stop-start systems rely on new software for the engine control system, a more powerful battery, a powerful starter, various sensors, and an electric water pump.

Regenerative Brakes

Regenerative braking is the process that allows a vehicle to recapture and store part of the kinetic energy that would ordinarily be lost during braking. A vehicle has more kinetic energy when it is moving fast; therefore, regenerative braking is more efficient at higher speeds **(Figure 35–7)**. When the brakes are applied in a conventional vehicle, friction at the wheel brakes converts the vehicle's kinetic energy into heat. With regenerative braking, that energy is used to recharge the batteries.

In a regenerative braking system, the rotor of the generator is turned by the wheels as the vehicle is

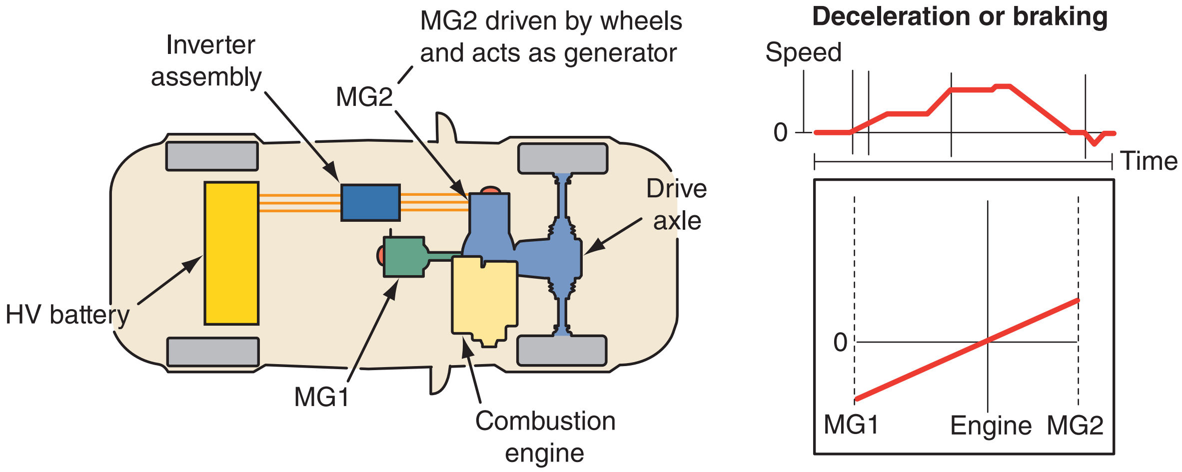


FIGURE 35–7 The power flow for a hybrid with two motor/generators during regenerative braking.

slowing down. The activation of the generator applies resistance to the drivetrain causing the wheels to slow down. The kinetic energy of the vehicle is changed to electrical energy until the vehicle is stopped. At that point, there is no kinetic energy. Regenerative braking can capture approximately 30 percent of the energy normally lost during braking in conventional vehicles.

In some hybrids, regeneration begins as soon as the driver's foot leaves the accelerator pedal, not just when the brake pedal is pressed. This allows for more regeneration.

With most hybrids, the control system changes the circuitry at the motor making it act as a generator. The motor now converts motion into electricity rather than converting electricity into motion. The captured energy is sent to the batteries.

Regenerative braking is not used to completely stop the vehicle. A combination of conventional hydraulic brakes and regenerative braking is used. Hydraulic, friction-based brakes must be used when sudden and hard braking is needed.

The amount of energy captured by a regenerative braking system depends on many things, such as the state of charge of the battery, the speed at which the generator's rotor is spinning, and how many wheels are part of the regenerative braking system. Most current HEVs are front-wheel drive; therefore, energy can only be reclaimed at the front wheels. The rear brakes still produce heat that is wasted.

Control System

The switching between the electric motor and gasoline engine is controlled by computers, as are other features of vehicle. The control systems are extremely complex. They have very fast processing speeds and real-time operating systems. The individual computers are linked together and communicate with each other through CAN communications **(Figure 35–8)**. The various computers include the electric motor controller, engine controller, battery management system, brake system controller, transmission controller, and electrical grid controller, and some systems also have 12- or 42-volt components.

A controller is used to manage the flow of electricity from the batteries and thereby controls the speed of the electric motor. A sensor located by or connected to the throttle pedal sends input regarding the pedal's position to the controller. The controller then sends the appropriate amount of voltage to the motor. The controller also looks at inputs from various other sensors to determine the current operating conditions of the vehicle. To provide precise control of the motor, the controller duty cycles the voltage to the motor, most controllers pulse the voltage more than 15,000 times per second.

Most of the electronics for a hybrid system are contained in a single, water- or air-cooled assembly. This unit may contain an inverter, DC-DC converter, boost converter, and air-conditioning inverter. During operation, these components generate a great amount of heat. This heat must be controlled to protect the circuits, especially the transistors.

An inverter may be part of the controller assembly or be a separate unit. The inverter **(Figure 35–9)** is a power converter that changes the high DC voltage of the battery to a 3-phase AC voltage for the electric motors. DC voltage from the battery is fed to

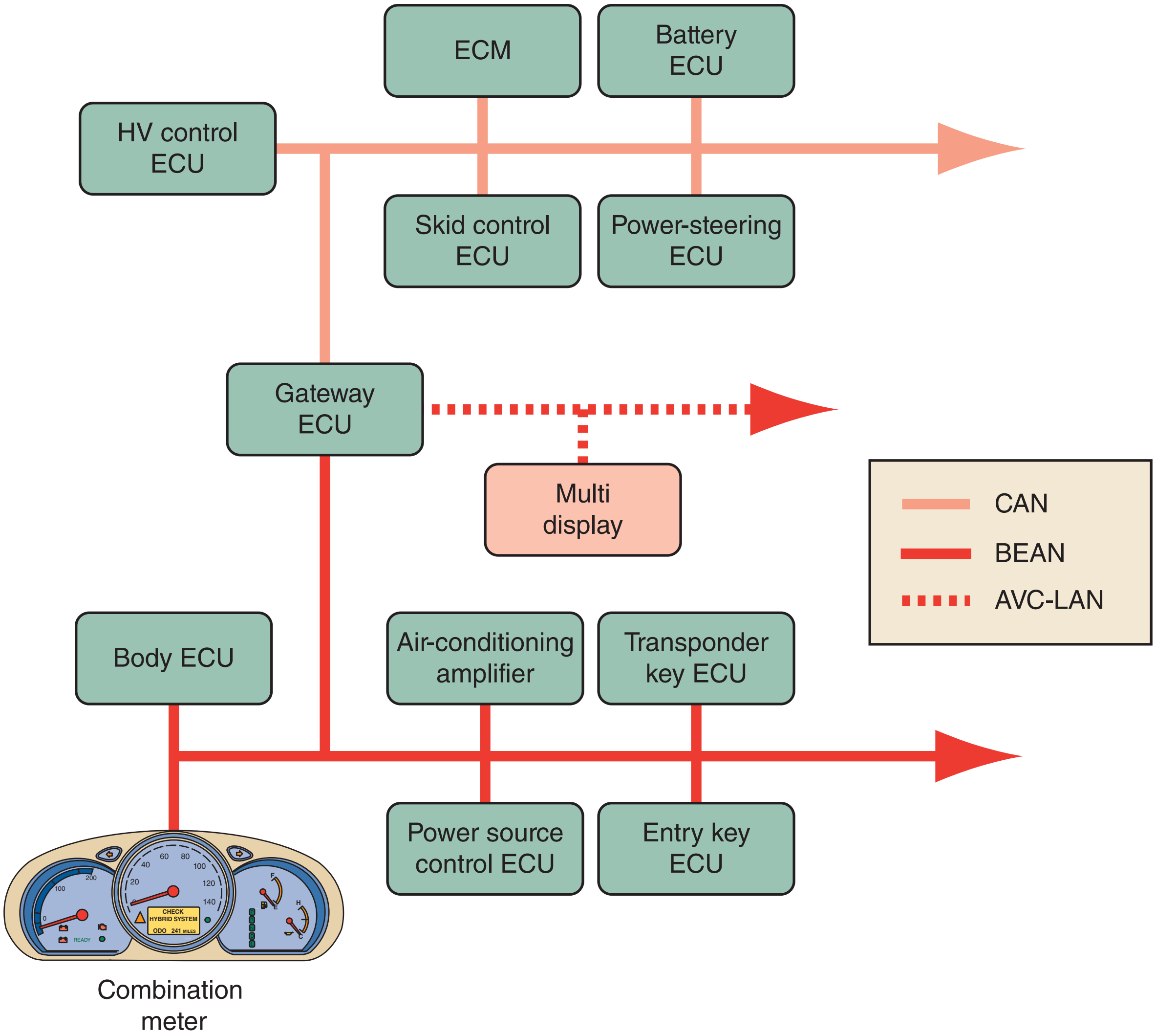


FIGURE 35–8 The individual computers in the control system are linked together and communicate with each other by high-speed "communication buses" known as the controller area network (CAN).

FIGURE 35–9 A cutaway view of an inverter.

the primary winding of a transformer in the inverter **(Figure 35–10)**. The direction of the current is controlled by an electronic switch (generally a set of isolated gate bipolar transistors or IGBTs). Current flows through the primary winding and then is quickly stopped and its direction reversed. This change of direction induces an AC voltage in the transformer's secondary winding. The inverter may also rectify the AC generated by the motor/generators so it can recharge the DC battery pack.

Most housings for the electronics also contain a converter, although it may be in a separate housing. A converter changes the amount of voltage from a power source. There are two types of converters, one that increases voltage, called a step up converter and one that decreases the voltage, called a step down converter. The latter is common in electric drive vehicles to drop some of the high DC voltage to the low voltage required to power accessories such

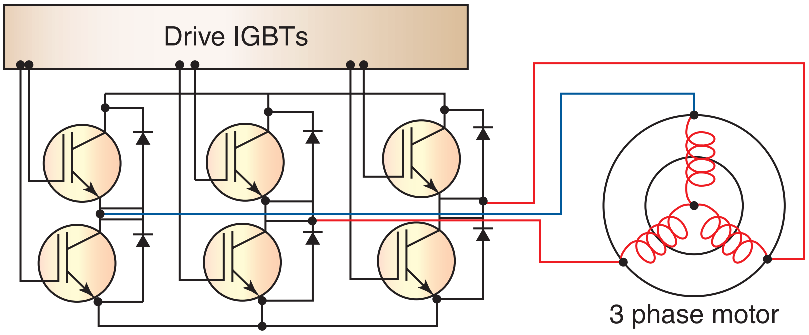


FIGURE 35-10 An electrical diagram of the connections to the motor through the IGBTs inside an inverter.

as sound systems, lights, blower fans, and the controller and to charge the 12-volt auxiliary battery.

Also, the available voltage may be increased (boosted) before it is sent to the motor. A boost converter can supply up to 500 volts to the motor. This increased voltage increases the power output of the motor.

Basic Systems

Many different layouts and systems are used in today's hybrid vehicles. Hybrids can be further defined by the location and purpose of the electric motor(s) in the system.

Belt Alternator Starter The least complex, but a commonly used system, is the **Belt Alternator Starter (BAS)** system. The BAS replaces the traditional starter and generator in a conventional vehicle. The motor/generator is located where the generator would normally be and is connected to the engine's crankshaft by a drive belt. When the engine is running, the drive belt spins the motor's rotor and the motor acts as a generator to charge the batteries. To start, or restart, the engine, the rotor spins and cranks the engine. Some BAS units also offer a small amount of engine assist.

Older BAS systems are typically connected to a 42-volt power source **(Figure 35–11)**, though newer systems operate at 115 volts. A belt tensioner is mechanically or electrically controlled to allow the motor/generator to drive or be driven by the belt. Some systems have an electromagnetic clutch fitted to the crankshaft pulley. When the engine is running, the clutch is engaged and the motor acts as a generator. When the vehicle stops,

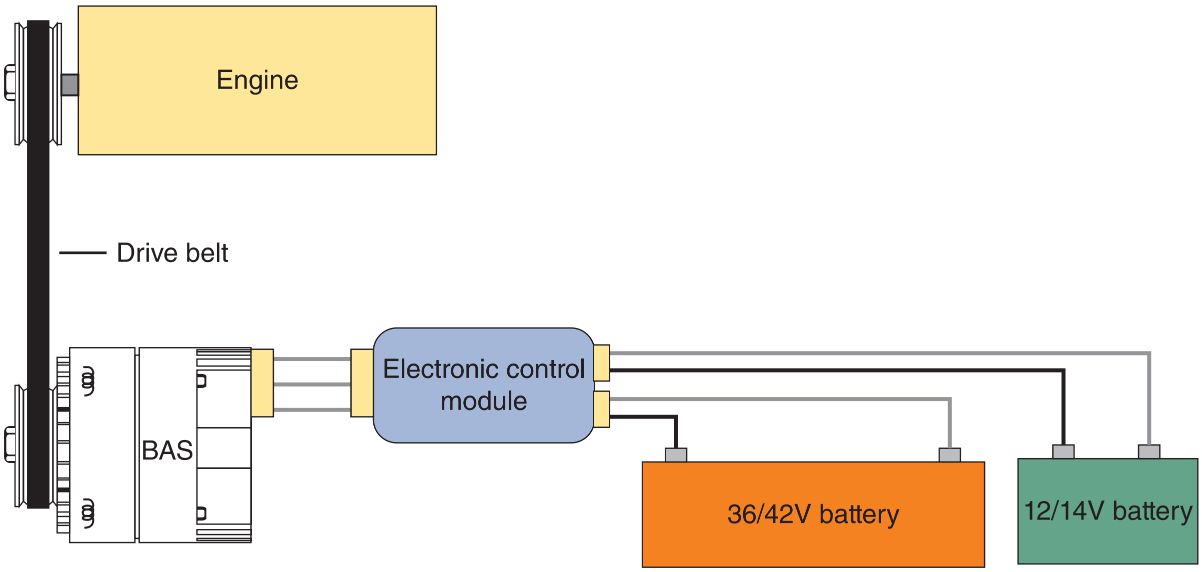


FIGURE 35-11 The layout for a typical BAS system.

the clutch disengages, and the unit is ready to act as the starting motor when the vehicle is ready to move again.

Integrated Starter Alternator Damper (ISAD) The **integrated starter alternator damper (ISAD)** system replaces the conventional starter, generator, and flywheel with an electronically controlled compact electric motor. Also called integrated motor assist (IMA), the unit is typically housed in the transmission's bell housing between the engine and the transmission **(Figure 35–12)**. The electricity generated by the unit is used to recharge the 12 volt and high-voltage battery; both of these are used to power the various vehicle systems. The IMA hybrid system is similar to the ISAD but has a larger electric motor and more electric power to help move the vehicle.

Power-Split System Currently, many full hybrid vehicles use a power-split system **(Figure 35–13)**. They are the foundation for series-parallel hybrids and are capable of instantaneously switching from one power source to another or combining the two. The power-split device functions as a continuously variable transaxle, although it does not use the belts and pulleys normally associated with CVTs. Also, the transmission does not have a torque converter or clutch. Rather, a damper is used to cushion engine vibration and the power surges that result from the sudden engagement of power to the transaxle. The unit is basically comprised of a planetary gearset and two electric motors. When used with high-output engines, the power-split unit also has an additional reduction planetary gearset.

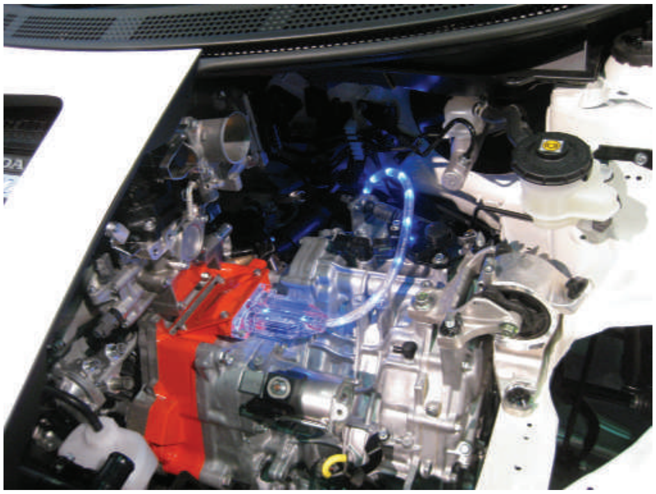


FIGURE 35-12 The red unit is an ISAD assembly sandwiched between the engine and transaxle.

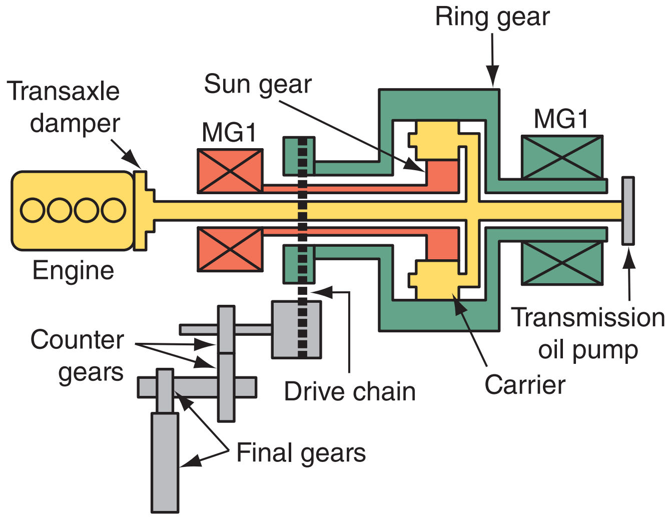


FIGURE 35-13 The layout of the main components connected to Toyota's power-splitting device.

GO TO Chapter 41 for a detailed discussion on power-split units and other hybrid transmissions.

Motors in Transmission This system relies on electric motors built into the transmission housing and connected to the transmission's planetary gearsets. Most of these systems are based on simple planetary gearsets coupled to two electronically controlled AC motors **(Figure 35–14)**. The gears work to increase the torque output of the motors and the engine. The result is a continuously variable transmission that responds to the needs of the vehicle. Some hybrids have a single motor within the transmission, while others have a motor at the transmission's input shaft and another on the output shaft.

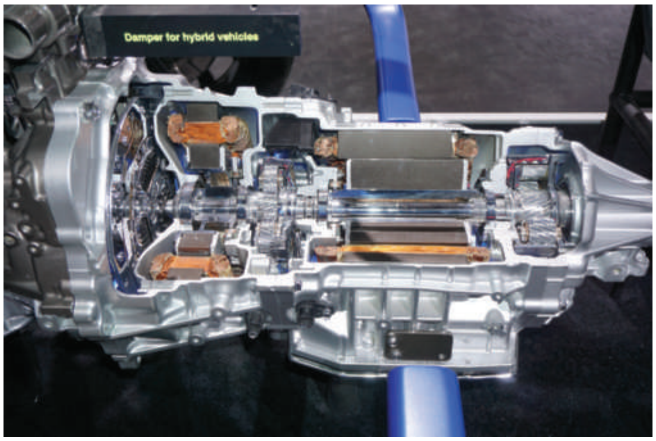


FIGURE 35-14 An automatic transmission fitted with two electric motors. They are located inside the two large drums.

Electric 4WD Some 4WD hybrids use an electric motor, differential, and rear transaxle housing to drive the rear wheels. This unit is not mechanically tied to the front drive axles; rather, its action is controlled by electronics. This allows the system to be capable of responding to operating conditions by varying the distribution of torque between the front and rear axles.

Accessories

In an HEV, the accessories are powered by either the battery or engine, depending on the model. Some systems, such as the radio, lights, and horn, operate the same way as they do in a conventional vehicle. Other systems, such as the power steering and power brakes, may be operated by small electric motors. It must be remembered that when working on HEVs, these auxiliaries and accessories may be powered by high voltage. Never attempt to work on these components (or the main propulsion system components) without thorough training that includes all safety procedures. Normally, most of the high-voltage components are clearly identified and the high-voltage cables are orange.

HVAC

The engine can be used to supply the heat so heating and defrosting systems are similar to those used in conventional vehicles. Some hybrids however have additional electrical heaters. These keep the passenger compartment warm when the engine is off.

HEV air-conditioning systems are identical to those used in a conventional vehicle, except a high-voltage motor may be used to rotate the compressor **(Figure 35–15)**. This increases the efficiency of the engine and allows for conditioned air when the engine is off. Compressors driven off the HV system require special servicing and refrigerant oils.

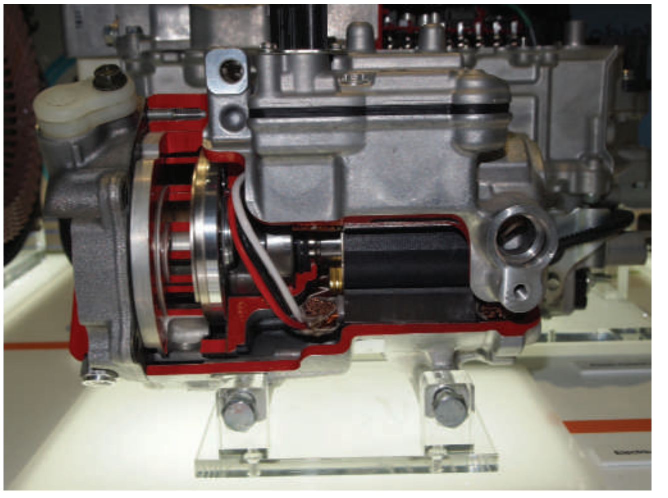


FIGURE 35–15 An electric A/C compressor for a hybrid vehicle.

> **GO TO** Chapter 55 for a detailed discussion on high-voltage A/C systems.

Power Brakes

Many power brake systems use engine vacuum and atmospheric pressure to multiply the effort applied to the brake pedal during braking. Because there is an engine in an HEV, there is a natural vacuum source. However, there is no vacuum when the engine is not running. Therefore some HEVs have an electrically powered vacuum pump fitted to the vacuum assist power brake system. Other hybrids have an electro-hydraulic brake system. An electric pump provides the necessary hydraulic pressure for a hydraulic brake booster.

Power Steering

Power-steering systems in HEVs are normally pure electrical and mechanical systems **(Figure 35–16)**. An electric motor directly moves the steering linkage. These systems are also very programmable and the energy consumed by the motor depends on the amount the steering wheel is turned. While driving straight, the motor may not run. However, when the steering wheel is fully turned, the motor is drawing its maximum current.

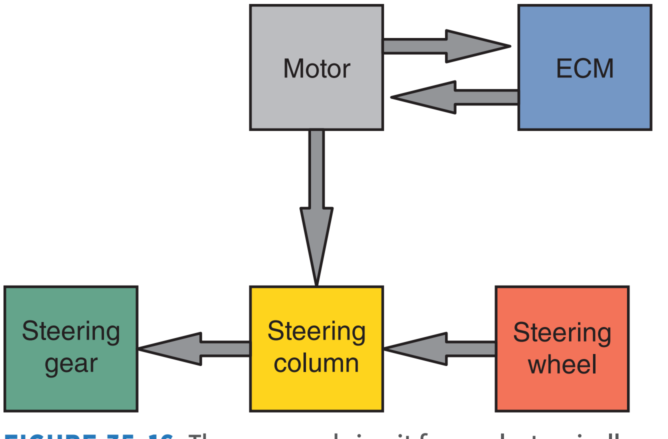


FIGURE 35–16 The command circuit for an electronically controlled power-steering system.

GM's Series Hybrids

The Chevrolet Volt **(Figure 35–17)** is a hatchback called an **extended range EV**. According to the SAE, this model should be classified as series or plug-in hybrid. Most of the time, the Volt acts as an EV or series hybrid. By combining the features of a battery operated electric vehicle and a series hybrid, you have an extended range EV. A smaller, shorter-range version is available as the Malibu Hybrid.
A similar vehicle, the Cadillac ELR, did not sell very well and was discontinued in 2016, while a new generation of the Volt was released. The drivetrain of the Volt is commonly referred to as the "Voltec" system.

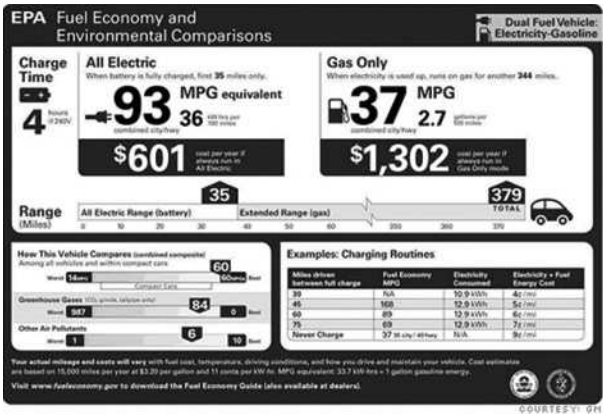
Both the first and second-generation Volts are powered by Li-Ion batteries and use an engine to run a generator, when necessary. The generator's output powers the motors when the battery's charge is low. The Volt can use the energy in the battery to power the drive wheels during the first 25 to 50 miles of operation. Once battery power is depleted, the engine turns on to provide the power to extend the driving range by up to 420 miles. Rather than rely solely on the generator to recharge the battery, the Volt uses the electrical grid to serve as the primary source for recharging.

The current Volt's fuel efficiency **(Figure 35–18)** is rated by the EPA as 106 mpg-e all electric /42 mpg gasoline only/77 mpg-e combined (electric + gasoline) **(Figure 35–19)**. The car is classified as an Ultra Low Emission Vehicle (ULEV) by the CARB. The only true exhaust emissions released occur when it is operating in the extended-range mode.

Powertrain

The second-generation powertrain has two AC permanent magnet electric motors—a 87 kW (117 hp) main traction motor and a 48 kW (54 hp) motor/generator plus a 1.5 liter 4-cylinder gasoline engine rated at 101 hp and lb-ft. of torque. The motors are powered by the energy stored in the battery pack or by the energy produced by the generator. The engine is primarily used to spin the generator. A planetary gearset and three clutches manage and distribute power from the motors and engine to power the wheels **(Figure 35–20)**.

FIGURE 35-17 A Chevrolet Volt, an extended range electric vehicle.



Courtesy of the U.S. EPA.

FIGURE 35-18 An EPA sticker for a Chevrolet Volt.

FIGURE 35-19 The dash display of current MPG for a Chevrolet Volt.

Battery

The Volt has a six-foot long 405 lbs (183 kg) 18.4 kWh Li-Ion battery pack. The pack has 192 cells **(Figure 35–21)** wired in series and parallel. The rectangular cells are separated into 7 modules of 24 and 32 cells. The first-generation battery had 32 cells, weighed 435 lbs (197 kg) and was rated for 16 kWh. The cells and modules are arranged around aluminum cooling fins to prevent hot or cool spots on the cells.

The Volt has a thermal management system to monitor and maintain the battery's temperature. The battery can be warmed or cooled by a liquid cooling circuit that is similar to the engine's cooling system.

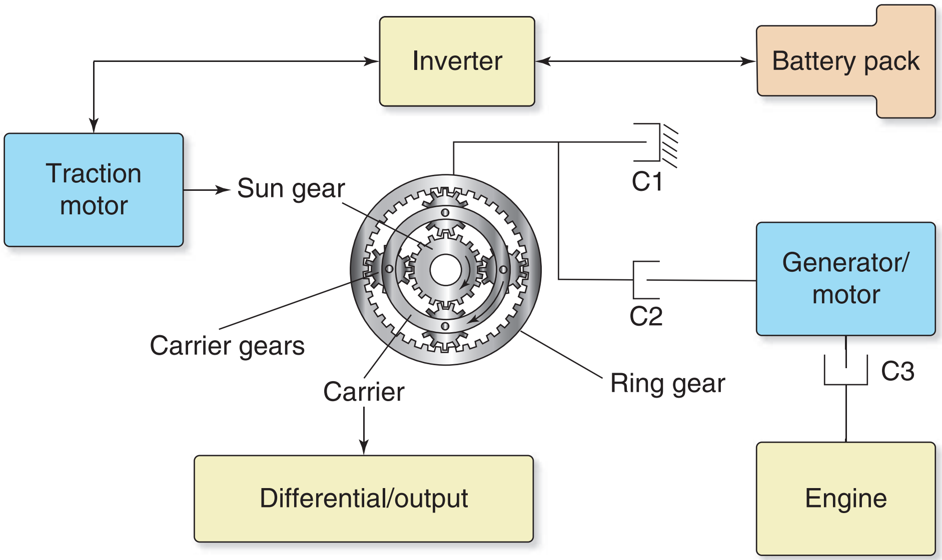
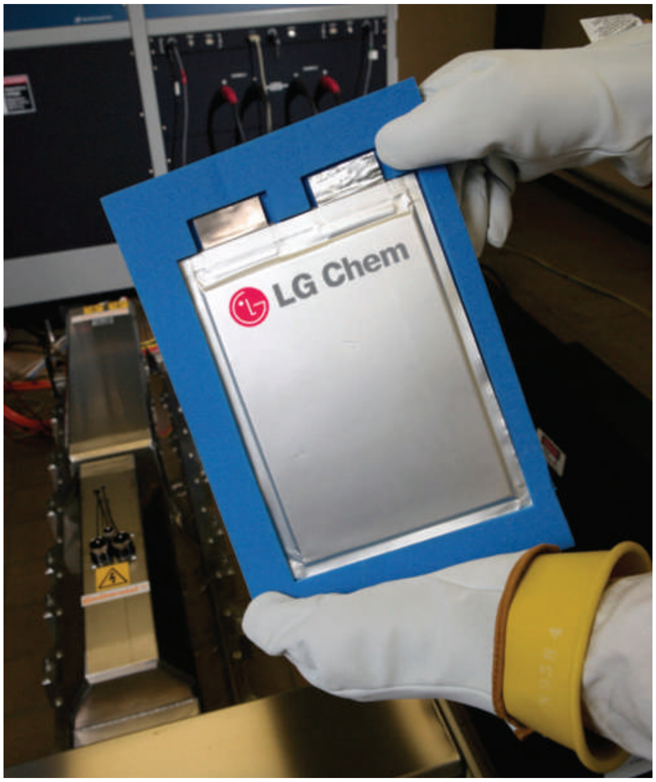


FIGURE 35-20 The main components of a Volt's powertrain.



Courtesy of LG Chem Power Inc. (LGCPI).

FIGURE 35-21 The Volt's battery pack consists of 288 of these Li-Ion cells.

The system can preheat the pack during cold weather and cool it in hot weather.

Because the energy in the pack is never completely depleted and therefore never receives a full charge, the life of the pack is extended. Of the total 18.4 kWh available, 14 kWh are used, an increase over the first generation of 25 percent. The management system allows the battery to only operate within a predetermined level SOC; once that level is reached, the engine starts to maintain a charge or provide power for the motors. It is important to note that the car has a normal 12-volt battery, in addition to the high-voltage battery pack.

Basic Operation

The drivetrain allows the Volt to operate as a pure electric vehicle. The distance it can travel on electricity alone is affected by many things including: the battery's SOC, road conditions, driving style, driver comfort settings (e.g., HVAC), and weather. Once the battery is mostly depleted, the engine starts and powers the generator and the car operates as a series hybrid.

While operating in the series mode at higher speeds and loads (normally above 30 miles per hour and/or under acceleration), the generator functions as a motor to aid the traction motor (MG-B). Also under particular conditions, the engine is mechanically linked to the output of the gearset and assists both electric motors to drive the wheels; therefore, the Volt can operate as a series-parallel hybrid when additional power is required.

The first-generation Volt's drive train includes the engine, motor/generator (MG-A), planetary gearset, three clutches (C1, C2, and C3), MG-B, and the power electronics unit. This unit has three IGBT inverters: one for each motor and one for an electric oil pump. MG-A, MG-B, and the engine are connected to the planetary gearset, this allows the unit to function as a variable speed transmission.

Power Mode	Charge Status	Operating Mode	Power Source
All-electric	Charge depleting	Low-speed, 1 motor (MG-B)	Battery
All-electric	Charge depleting	High-speed, 2 motors (MG-B + MG-A)	Battery
Extended range	Charge sustaining	Low-speed, 1 motor (MG-B)	Battery + engine driven generator
Extended range	Charge sustaining	High-speed, 2 motors (MG-B + MG-A)	Battery + engine driven generator; + supplemental torque from MG-A and engine

FIGURE 35–22 An overview of the different operating modes for a Volt and ELR.

MG-B is always connected to the sun gear and the final drive gears are always connected to the planetary carrier. The ring gear is either held stationary by a clutch or driven by MG-A or the engine. Two of the clutches are used to lock the ring gear or connect it to MG-A. The engine and MG-A are only connected to the gearset when the appropriate clutches are applied. The third clutch connects the engine to MG-A to provide an extended driving range.

The first-generation Volt has four basic power modes: all battery-electric (charge depleting), low and high speed, in which the battery is the only source of power for the electric motors; and extended-range (charge sustaining) low and high speed, in which the battery and engine work together to power the traction motor and to improve overall efficiency **(Figure 35–22)**.

The second-generation Volt uses the engine, MG-A, two planetary gearsets, clutches (C1, C2), a one-way clutch, MG-B, and the power electronics unit and has five power modes. The first four modes are the same as the earlier generation. The fifth mode is called a fixed ratio extended range mode where the engine is used to drive the wheels directly. Directly driving the wheels is more efficient under certain operation conditions than using MG-B to drive the wheels.

The second generation also has a new transmission with a slightly smaller MG-B that produces more torque than the first-generation motor. When the system is operating in extended range, there are three modes rather than the two in the original design. The new operating modes (low extended range, fixed ratio extended range and high extended range) increase efficiency, especially in city driving. In the low extended and high extended ranges, the output of the motors is combined with the output of the engine, making the system more efficient.

GM's Parallel Hybrids

GM used a BAS hybrid system in 2006 through 2008 on some Saturn models, 2009 through 2010 on Chevrolet Malibus, and recently in many Chevrolet and Buick models. Early systems were based on the dual-voltage of a 12V/42V battery pack.

The system's electronics monitor many operating conditions, and controls the operation of the motor/generator and the engine. The motor/generator can serve as the starter, assist motor, and generator. When working as a generator, it provides more than twice the output of a typical generator and is capable of providing 3,000 watts of continuous power.

During operation, the generator's control module can get very hot and excessive heat can destroy it. So there is a coolant pump to keep engine coolant circulating through the module when the engine is off during stop-start. That pump shares an electrical circuit with a second electric pump that keeps coolant circulating through the heater core when the engine is off and the vehicle is in the stop-start mode. A third pump is used to keep transmission fluid circulating in the transmission when the engine is off during stop-start.

General Motors eAssist

eAssist is available on late-model GM cars and select trucks. The system is based on the previously used BAS systems. However, the new system is more powerful and provides additional torque to the driveline during heavy loads and improved regenerative braking. As a result, the new system provides close to a 25 percent increase in fuel economy over previously used systems.

The BAS unit is connected by a drive belt to the engine's crankshaft. The BAS is a three-phase AC

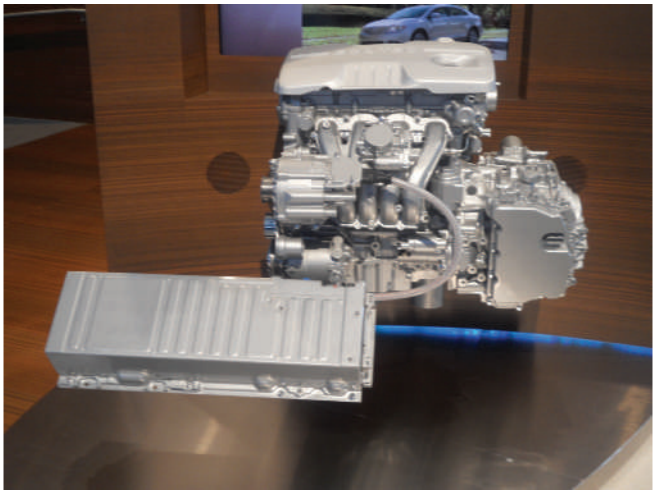


FIGURE 35–23 The main components for GM's BAS system.

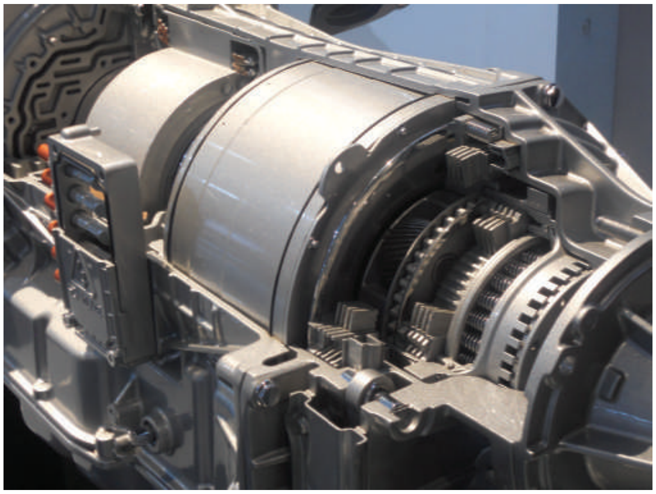


FIGURE 35–24 The motors and clutches inside a two-mode transmission.

induction motor powered by a 115 volt Li-Ion battery **(Figure 35–23)**. The air-cooled battery and its electronic controllers, along with a conventional 12-volt battery are housed in a single unit behind the rear seat. The motor can provide an 11 kW (15 hp and 79 lb-ft.) boost during acceleration. It can also recover 15 kW of electricity through regenerative braking to charge the battery.

GM Two-Mode Hybrid System

GM, BMW, and DaimlerChrysler (this company no longer exists) co-developed a **two-mode full hybrid system** that was used with gasoline or diesel engines. This idea claimed the fuel consumption of a full-sized truck or SUV can be decreased by at least 25 percent when it is equipped with this parallel hybrid system.

GM offers this technology in many of their vehicles, such as the Chevrolet Silverado, Chevrolet Tahoe, GMC Yukon, and Cadillac Escalade. The system works with a 300-volt NiMH battery pack and a two-mode transmission, called an electrically variable transmission (EVT).

The transmission has four fixed gear ratios but the motors can alter the gear ratios between each of those ratios. The system fits into a standard transmission housing and has three planetary gearsets coupled to two AC synchronous 60 kW motor/generators **(Figure 35–24)**. The gears work to increase the torque output of the motors. This combination results in a continuously variable transmission and motor/generators for hybrid operation. Multi-disc clutches are used to transition the transmission from one gear ratio to another **(Figure 35–25)**.

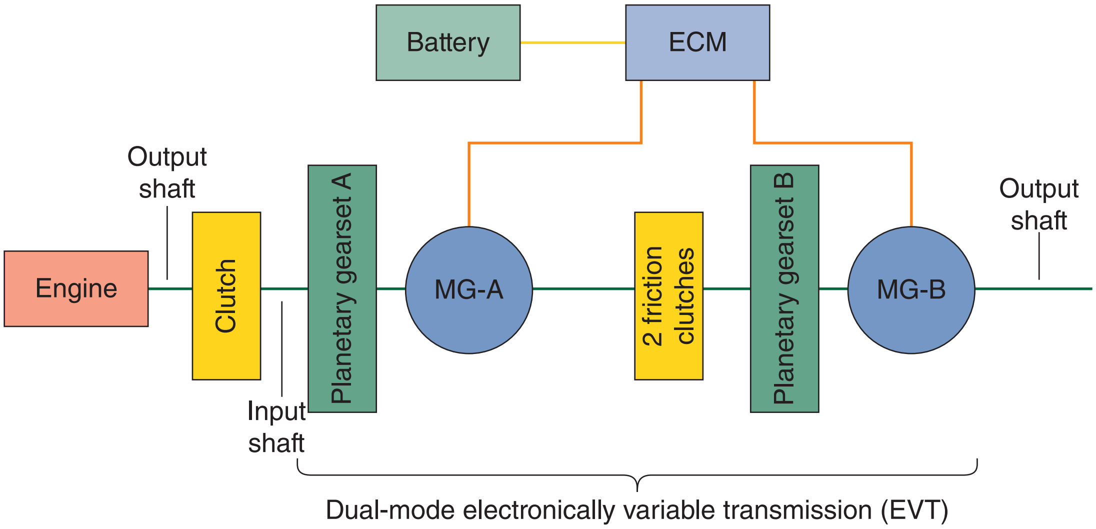


FIGURE 35–25 The two-mode system relies on two electric motors connected to planetary gearsets to move the vehicle or assist the engine during propulsion.

The control of the motors' speed relies on a relatively low voltage and current, which in turn means the inverter, converter, and controller can be made lighter and smaller. The NiMH battery pack has a nominal voltage of 300 volts and is contained in a housing equipped with a cooling circuit. The system's power electronics are located under the hood and have a unique temperature control unit.

Operation

The two-mode hybrid system can operate solely on electric or engine power or by a combination of the two. Electronic controls are used to control the output of the motors and the engine. Typically, when one of the motors is not providing propulsion power, that motor is working as a generator driven by the engine or by the drive wheels for regenerative braking.

The first operational mode is called the input split and the second is the compound split **(Figure 35–26)**. During the input split, the vehicle can be propelled by battery power, engine power, or both. This mode of operation occurs when the vehicle is slowly accelerating or cruising at slow speeds. When the control unit determines battery power is sufficient for the current driving conditions, the engine shuts off or some of its cylinders are deactivated. During this time, one motor moves the vehicle, while the other may be working as a generator to supply power for the traction motor or to recharge the battery. If the engine is commanded to start, the traction motor may shut down and the second motor can continue to operate as a generator if needed.

Mode two comes into play when pulling heavy loads, running at highway speeds, or during heavy acceleration. The electric motor(s) assist the engine to overcome the loads and the engine is set to provide full power. Current is no longer being generated and the vehicle is powered by gasoline and the battery.

Honda's IMA System

Most Honda hybrids use an ISAD system, called the IMA system **(Figure 35–27)**. Honda introduced their Insight in December 1999 and became the first manufacturer to offer hybrid vehicles in North America. With this introduction came a new technology, placing an

FIGURE 35–27 An underhood look at Honda's IMA system.

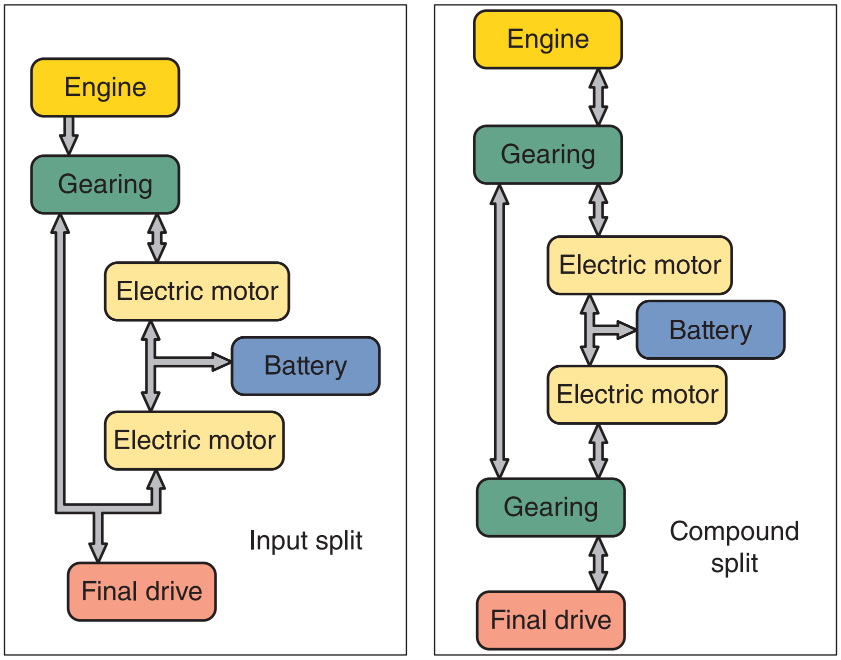


FIGURE 35–26 The flow of energy during the two operating modes.

electric motor between the engine and transmission. Since then, Honda has released many variations of this design and has offered many different hybrid models.

With this design, Honda is able to use a small efficient engine in a vehicle. The power deficiencies of the engine are overcome by a small, efficient electric motor. Through the years, this platform has been improved to allow the vehicle to be powered by the engine, electric motor, or both. Early Honda hybrids were assist only hybrids.

As time passed, Honda was able to use larger gasoline engines and more powerful electric motors, while continuing to decrease fuel consumption and exhaust emissions. Most current Honda hybrids are rated by CARB as an AT-PZEV and offer some of the best fuel economy numbers of all cars. The gains made in both areas are due to the use of improved aerodynamics, lighter construction materials, and other fuel saving technologies.

For 2018, Honda has the Accord Hybrid, Insight, and Clarity Plug-In Hybrid. The CR-Z was discontinued in 2016 and the Civic Hybrid was discontinued in 2015.

The Accord Plug-In Hybrid (PHEV) **(Figure 35–28)** represents a significant change in Honda's hybrid approach. An Atkinson-cycle 2.0-liter I-4 is used with two electric motors and a Li-Ion battery pack. The latter allows for plug-in charges to enable the car to travel up to 15 miles on battery power alone. This PHEV is rated at a combined rating of 115 MPGe by the EPA and the battery can be charged in about 3 hours when using a 120-volt outlet or less than 1 hour when using a 240-volt charger.

Since 2013, the IMA system in Accords has been replaced by a two-motor hybrid drive system, called the Two-Motor Hybrid Intelligent Multi-Mode Drive system. The hybrid has a 2.0-liter 143-hp four-cylinder engine, plus two electric motors one of

FIGURE 35–28 A Honda plug-in hybrid Accord.

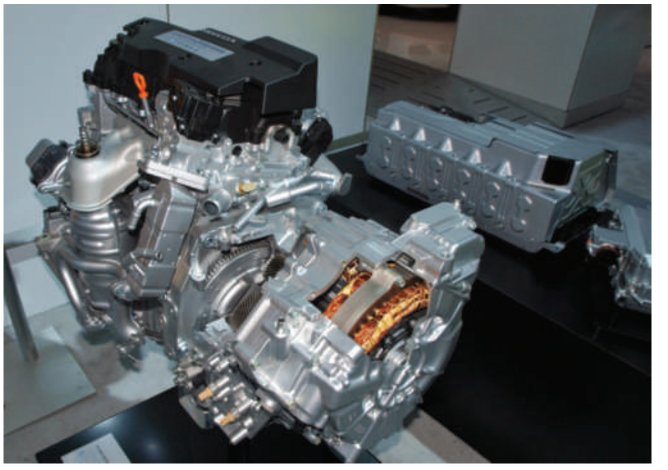


FIGURE 35–29 Honda's dual electric motor transaxle and powertrain.

which is used for propulsion and is capable of delivering 166 peak horsepower, and 226 pounds-feet of torque **(Figure 35–29)**. The second motor is used as a generator and also serves as the engine's starter. In addition to the generator, the battery is recharged through regenerative braking. Regeneration occurs as soon as the driver lets off the accelerator pedal, not just when the brake pedal is depressed.

Also to increase efficiency the system has a stop/start system as well as an electrically operated A/C compressor, water, and power steering pump. Battery power is supplied by a 1.3-kWh Li-Ion battery, which unlike a PHEV, cannot provide power for extended EV operation.

The system can run in three different propulsion modes: electric-only mode, gasoline-only mode, and gas-plus-electric mode. While in the electric-only mode, the vehicle operates by only electric power, which is good for low speed and load conditions. During the gasoline-only mode, a lock-up clutch connects the generator/motor and the electric drive motor to send engine power directly to the front wheels. During the gas-plus- electric mode, the engine runs to drive the generator and charge the battery. There is no direct connection between the engine and the drive wheels. The engine simply supplies the battery with replenished power to drive the wheels, once the battery power is depleted, the engine will start.

IMA

The IMA is positioned between the engine and the transaxle **(Figure 35–30)**. The synchronous AC motor has a three-phase stator and a permanent magnet rotor that is directly connected to the engine's crankshaft. There are three commutation sensors mounted

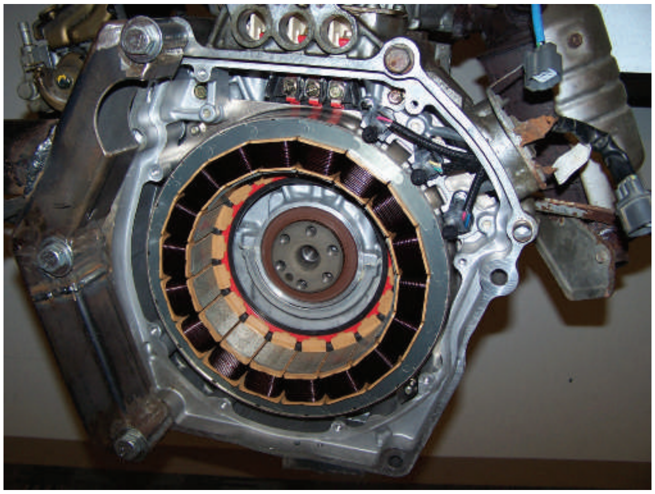


FIGURE 35-30 The IMA unit fits between the engine and the transaxle.

inside the motor/generator that give the control module information about the rotor's position.

The IMA in late-model Hondas is used to start the engine, both during initial start-up and during stop/start. Most have an additional 12-volt starter motor and 12-volt battery. These are used when the SOC of the high-voltage battery is low. The auxiliary starter is also used when the outside temperature is extremely low or if there is a problem with the IMA system.

In the basic system, when the driver depresses the accelerator, the IMA provides power assist to the engine **(Figure 35–31)**. As the engine overcomes the load, the motor is turned off and the car is powered only by the engine. While the car is cruising at a steady speed, the IMA can work as a generator to charge the battery and power the 12-volt system. The engine will not drive the generator unless there is need for charging.

Caution! Because the IMA motor/generator has a permanent magnet rotor, it ALWAYS generates electricity when the engine is rotating. Therefore, any time that the engine is spinning, the orange high-voltage cables could have high voltage. Keep away from them.

Some late-model hybrids have an electric motor inside the transaxle in addition to the IMA. This motor serves to provide electrical boost to the engine's output and transforms the transaxle into an electronic continuously variable transmission (E-CVT). The motor(s) are powered by a NiMH or Li-Ion battery pack.

Electronic Controls

The PCM is like the one used in a non-hybrid but it has been programmed to interact with the IMA system. The entire powertrain is monitored and controlled by the PCM through various CAN communication lines and sensors to provide the best efficiency and driveability.

Power to and from the motor/generator(s) are controlled by the Intelligent Power Unit (IPU), that is connected to the motor/generator by high-voltage cables. The IPU contains the Power Control Unit (PCU), control unit for the motor, motor power inverter, battery module, and a cooling system.

The PCU controls the flow of electricity between the IMA and battery pack. The Motor Control Module (MCM) controls the IMA, through the motor power inverter. The MCM monitors the state-of-charge of the

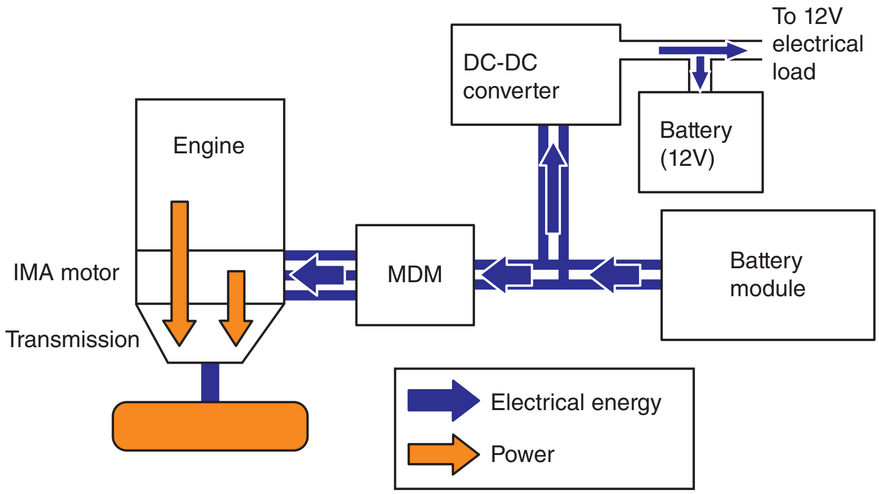


FIGURE 35-31 When the driver depresses the accelerator, the output of the motor supplements the engine's output to help acceleration.

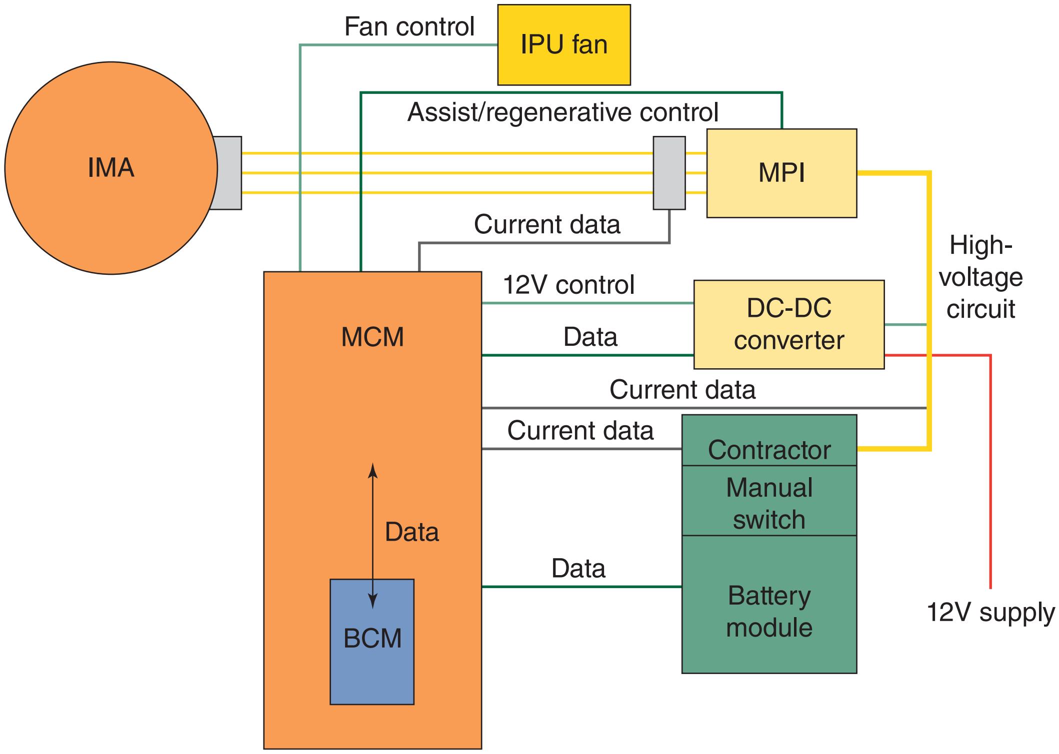


FIGURE 35–32 The basic control circuit for an IMA system.

battery pack and controls the IPU module fan. The MCM uses inputs of the batteries' voltage, temperature, and input and output current readings to determine the batteries' state of charge **(Figure 35–32)**.

The IPU is equipped with a cooling system mounted in the battery pack box **(Figure 35–33)**. Air is pulled into the battery module through the top of the tray behind the rear seats. The air passes over the heat sinks of the inverter, DC-DC converter, and A/C compressor driver before it is exhausted to the outside.

FIGURE 35–33 The battery box of a Honda HEV.

A revised battery box was required with the introduction of Li-Ion batteries. The module is fitted with temperature sensors and a cooling system run by the A/C system, outside air and a cooling fan. This system also cools the inverter, motor control module, DC-DC converter, and the heat sink for the air-conditioning compressor.

The A/C compressor is powered by the HV battery and controlled by the PCM.

Engine

The engines used with the IMA system have varied from a small three-cylinder engine to much larger V6s. The engines have incorporated many of Honda's fuel savings technologies, such as Variable Valve Timing and Lift Electronic Control (VTEC), intelligent Dual & Sequential Ignition (i-DSI), Variable Cylinder Management (VCM), and electronic throttle systems.

In addition to these, the construction of the engines includes many technologies to reduce internal friction such as low-friction pistons and roller rocker arms.

Transmission

Most of Honda's hybrids are equipped with either a manual transmission or a continuously variable

transmission (CVT). The manual transmissions are designed to be light, reduce power loss through friction, and make shifting easy. The CVT (Honda Multimatic) uses computer controlled drive and driven pulleys and a metal "push" belt running between the variable-width pulleys. The CVT constantly adjusts to provide the most efficient drive ratio possible depending on torque load.

Acura Hybrids Acura, the high-end brand of vehicles from Honda offers a line of hybrid vehicles. Most of their hybrids follow the same recipe as Honda hybrids; however, some are designed primarily for increased performance as well as fuel economy. These vehicles are all-wheel drive, full hybrids. The engine in these hybrids power the front or rear wheels with electric motors driving the additional front or rear drive axle. In some cases there is an additional electric motor in the transmission to assist the engine. When the rear axle is equipped with the electric motors, differential action is accomplished by electronically controlling the speed of the individual motors.

The new NSX Acura Hybrid **(Figure 35–34)** uses Honda's Sports Hybrid Super Handling All Wheel Drive (SH-AWD) technology. This system is fitted with a gasoline engine and two electric motors at the front wheels that operate independently to provide positive or negative torque to the wheels during cornering to improve vehicle handling. The system also has an additional motor between a dual clutch transmission and a mid mounted V6 engine.

For the 2013 and newer Honda Accord Hybrids, the IMA system has been replaced by a two-motor hybrid drive system. Called a transmissionless system, the Accord hybrid uses a 2.0-liter 143-hp four-cylinder engine, a 181-hp AC drive motor, and a secondary AC motor that is mainly used to generate electricity. The system has three driving modes: electric only, gasoline only, and a blend of the two. Electric-only mode provides EV operation under very limited conditions, such as when parking. Battery power is supplied by a 1.3-kWh Li-Ion battery, which unlike a PHEV cannot provide power for extended EV operation. When driving at highway speeds, the engine directly drives the wheels. A clutch locks the engine to an overdrive gear which turns the drive motor and the wheels. In the hybrid mode, the gas engine is used as a generator to provide electricity to the drive motor. The drive system reduces overall weight and friction, which according to Honda results in improved performance and fuel economy compared to other hybrid drive systems.

Toyota's Power-Split Hybrids

Since its introduction of a hybrid vehicle in 2000, Toyota (and Lexus) has offered many different hybrid models.

Toyota's approach to hybridization is a combination of series and parallel hybrid platforms. The system relies on two electric motor/generators, a power-split transaxle, and a high-voltage battery. The power-split device mechanically blends the output from the motors and an Atkinson cycle engine. This system **(Figure 35–35)** was called the Toyota Hybrid System (THS) when it was released, and the newer designs of the THS are called the Hybrid Synergy Drive (HSD) system. In all cases, the engine can power the vehicle or a motor/generator.

One motor/generator is primarily used to start the engine and recharge the battery pack after the

FIGURE 35–34 An Acura NSX hybrid.

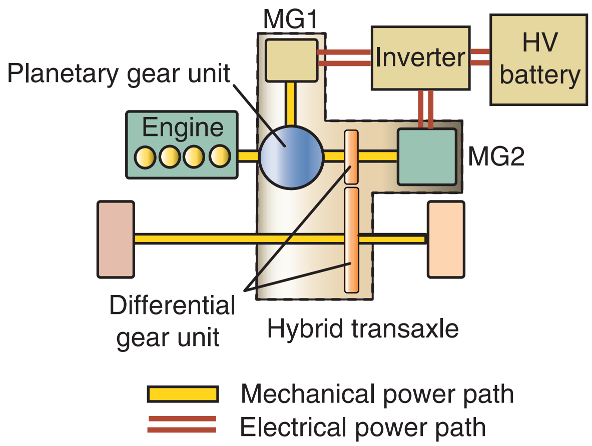


FIGURE 35–35 The THS uses a combination of two motive forces: an engine and electric motors.

FIGURE 35–36 A late-model Prius.

engine is running. The other motor/generator assists the engine while moving the vehicle or powers the vehicle for a short distance by itself. This is the traction motor and it can also work as a generator to provide for regenerative braking.

Recently Toyota has released different size variants of the original Prius **(Figure 35–36)**. Basically these versions are smaller or larger versions of the base model. As an example, the Prius V **(Figure 35–37)** has 50 percent more cargo space than the base model. The wheelbase of the V is longer and the overall length has been increased, it is also taller and wider. However, the powertrain in the Prius V is identical to that found in the base model.

Other Hybrids from Toyota Several hybrid cars are available from Toyota and Lexus. Lexus has hybrids across six products, from the Prius-based CT Hybrid to the performance-oriented LC Hybrid sports car. All of these except the LC Hybrid are based on the same architecture as the Prius. However the base engine, traction motor, and battery have been made more powerful to offset the increased weight of these cars over the Prius. The total power output from these hybrid systems ranges from 121 to 354 hp. The power split devices in the cars and Lexus SUVs equipped with larger engines have an additional planetary gearset to keep the speed of the electric motors low. The LC Hybrid uses a new longitudinal arrangement to keep its RWD sports car layout. Two electric motors still operate with a CVT transmission to operate as a Toyota hybrid in Normal or Eco driving modes. The addition of a four-speed automatic transmission placed after the output of the CVT makes the LC drivetrain unique. The automatic transmission reduces the speed at which the electric motors have to spin, increasing efficiency and driving feel. Between the electric motor, CVT, and four-speed transmission, the LC simulates the ten speeds of the conventionally powered LC's 10-speed gearbox. The system provides six e-ratios based on the operation of the electric motors and CVT plus the four fixed gear ratios of the automatic transmission.

FIGURE 35–37 A Prius V.

Battery

Most Toyota hybrids rely on a NiMH battery pack; they also have an auxiliary 12-volt battery that is the power source for the ECM, lights, and other systems. In 2016, Toyota began using lithium-ion batteries in some models. The battery module **(Figure 35–38)** contains the hybrid (HV) battery pack, battery ECU, and the System Main Relay (SMR). The module is positioned behind the rear seat, in the trunk. A service plug and main high-voltage fuse is inserted in the high-voltage circuit.

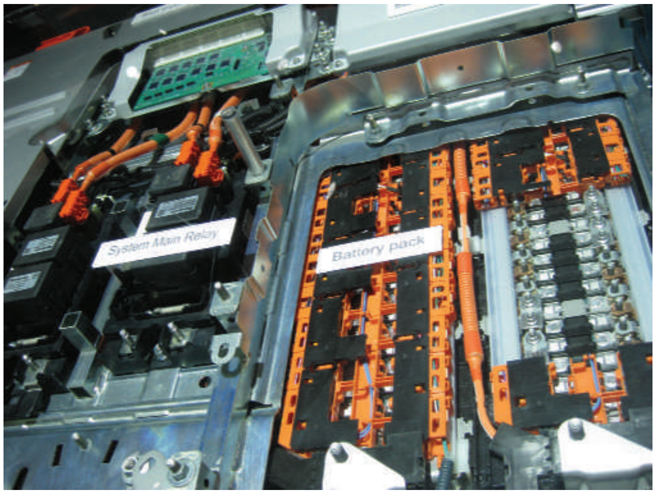


FIGURE 35–38 The main components inside a Toyota battery pack.

The fuse protects the circuit by opening if there is excessive current in the circuit. The service plug is used to disconnect or isolate the high-voltage circuit so that service can be performed on the circuit. The service plug is positioned in the middle of the battery modules. When removed, the circuit is open.

The nominal battery voltage varies with model and application. Late-model systems use a lower voltage battery than early vehicles, but these systems can boost the voltage up to 650 volts. This additional voltage reduces the required amount of current to power the motor(s). If the motors' power output in watts is held constant, the amount of current drawn by the motor is inversely increased or decreased with a decrease or increase in voltage. Therefore, if the voltage is doubled, the current will be reduced by half. Also, if the current to the motor is held constant and the voltage is increased, the motor's power will be increased.

Individual high-voltage cables **(Figure 35–39)** connect the battery pack to the inverter, the inverter to the motors, and the inverter to the air-conditioning compressor.

Operation

The basic operation of all generations of the HSD system is much the same. The HSD relies on an engine, a motor/generator that serves as the starter motor and a generator (referred to as MG1, Motor Generator 1), and a traction motor and generator (called the MG2, Motor Generator 2). The engine, MG1, and MG2 are connected to different members of a planetary gearset inside the power-split unit. MG1, MG2, and the engine control the output of that planetary gearset. This is how those respond to operating conditions:

- During initial acceleration, power from the battery pack to MG2 provides the energy to drive the wheels. While MG2 is powering the vehicle, the engine is off and MG1 rotates freely and does not operate as a generator.
- This continues until the battery's voltage drops, when the driver calls for rapid acceleration, or when battery's state of charge, battery temperature, engine coolant temperature, and the electrical load suggest a need for more battery energy, the engine will start. To charge the battery pack, MG1 is rotated by the engine through the planetary gears.
- When the system determines the engine should power the vehicle, the engine will start if it is not already running. Engine power is split according to the needs of the system. The amount of power sent to MG1 and the drive wheels is controlled by the system.
- When the vehicle is at a cruising speed, both the engine and MG2 may power the vehicle. If engine power is not needed to maintain the speed, the engine will shut down and the vehicle is powered by electricity alone. If the battery's SOC gets low during this time, the engine restarts to drive MG1.
- To overcome a heavy load, hard acceleration, climbing a hill, or passing another vehicle, both the engine and MG2 powers the car. MG2 receives energy from MG1 and the battery pack. This allows MG2 to work with full power. Once the vehicle returns to a normal cruising speed, battery power for MG2 is shut off and the battery is recharged by MG1.
- When the vehicle is decelerating, the engine shuts down. MG2 then becomes a generator driven by the vehicle's drive wheels, and regenerative braking begins. The vehicle's kinetic energy is used to charge the battery pack. Most of the initial braking force is the force required to turn MG2. The hydraulic brake system supplies the rest of the braking force and brings the car to a halt.
- When reverse gear is selected, MG2 rotates in a reverse direction. The engine remains off, as does MG1.

Electronic Controls

Needless to say, the coordination of the motors and engine requires very complex electronic control systems; these need to monitor operating and driving

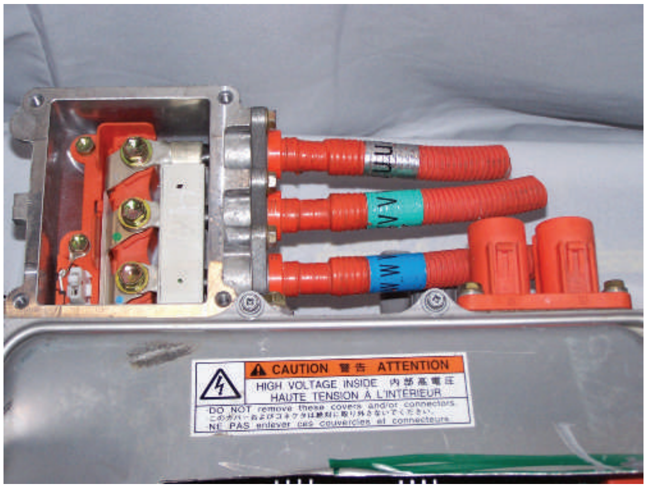


FIGURE 35–39 Individual high-voltage cables connect the inverter to the battery pack.

conditions and control current flow to and from the motor/generators. The ultimate control of the system is the responsibility of the Hybrid Vehicle Control Unit (HV ECU). This module receives information from sensors and other processors and in turn sends commands to a variety of actuators and controllers **(Figure 35–40)**. The ECU coordinates the engine's activity with the hybrid system. It starts and stops the engine as needed, as well as controls the operation of the engine. The HV ECU also makes sure there is proper phasing of AC to the motors. This circuit is connected between the motor/generator and the battery pack.

CAN communications are used to link various microprocessors together. The system runs continuous self-diagnostic routines. If a fault is detected, the unit stores a diagnostic code and controls the system according to data stored in its memory rather than current conditions (fail-safe mode) or it may shut down the entire system, depending on the malfunction.

The entire system is monitored by the ECU and the ECU memorizes all conditions and operating perimeters that are outside a specified range. Depending on the type and severity of the problem, the ECU will illuminate or blink the MIL, master warning light, or the HV battery warning light.

The MG ECU has final control of the inverter, boost converter, and DC-DC converter based on commands from the ECU. If the ECU detects a problem in the high-voltage circuit or if the transmission is placed in neutral, the inverter is turned off to stop the operation of the motor/generators.

Depending on the model and generation of the HSD system, the electronic controls may be located in a variety of places and the individual parts may have additional unique functions. Everything possible is done to keep the inverter assembly, MG1, and MG2 within a specified temperature by a cooling and heating system. In SUVs, the radiator for the inverter and motors is part of the engine's radiator, but is totally isolated from it.

Most late-model hybrids have a boost converter to provide up to 650 volts to MG2. This converter has an Integrated Power Module (IPM) that contains two Insulated Gate Bipolar Transistors (IGBT), a reactor to store the energy, and a signal processor.

Battery ECU The battery's ECU receives information about the battery's SOC, temperature, and voltage from various sensors. This information is then sent to the HV ECU, which controls MG1 to keep the battery pack at the proper charge. The battery ECU

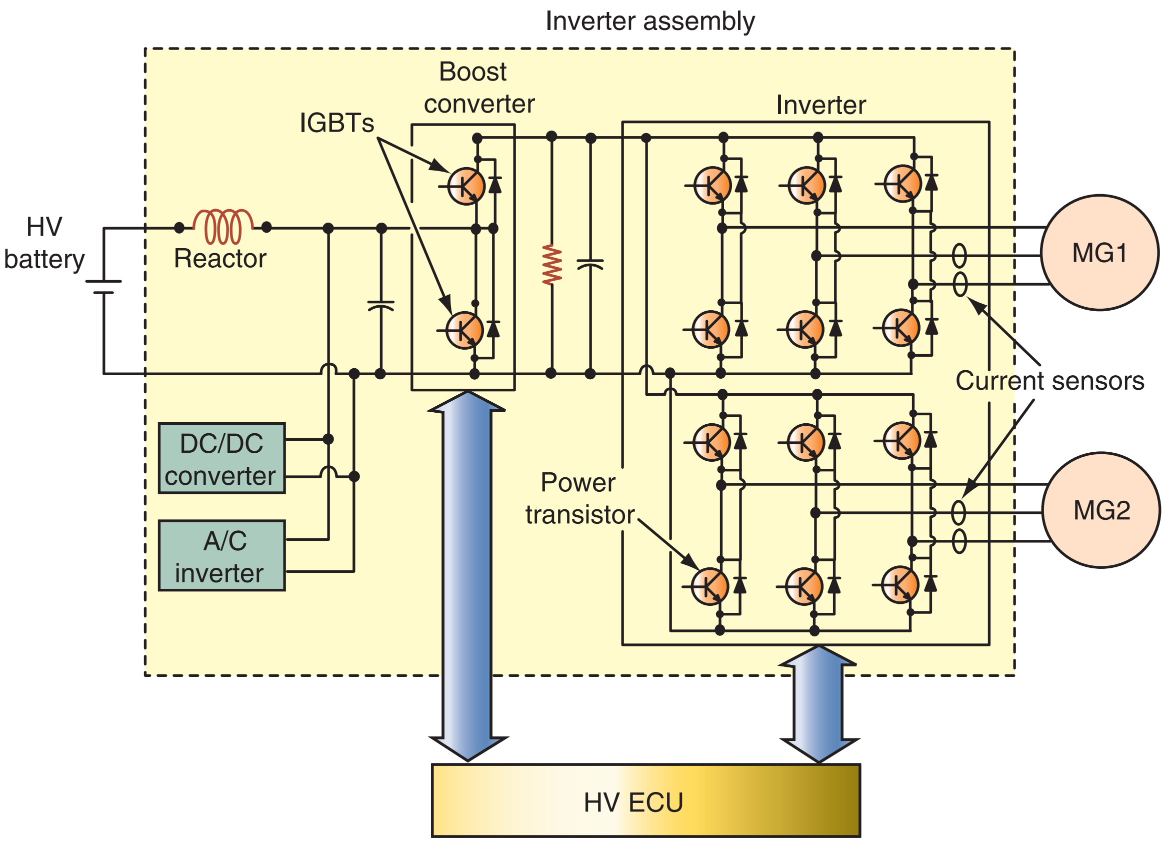


FIGURE 35–40 An electrical schematic for a THS vehicle.

also calculates the charging and discharging amperage required to allow MG2 to power the car. This information is also sent to the HV ECU, which sends commands to the ECM to control the engine's output. This continuous loop of information is done to maintain at least a 60 percent SOC at the battery.

The ECU also monitors the temperature of the batteries during the charge and discharge cycles, via three temperature sensors housed in the battery module and a temperature sensor in the air intake for the module. It also estimates the temperature change that will result from the cycling. Based on this information, it can adjust the battery's cooling fan or, if a malfunction is present, it can slow down or stop charging and discharging to protect the battery.

Regenerative Braking The skid control or "brake" ECU calculates the total amount of braking force needed to stop or slow down the car based on the pressure exerted on the brake pedal. This in turn determines how much regenerative braking should take place and how much pressure should be sent to the brakes through the hydraulic system. This information is sent to the HV ECU, which controls the regenerative braking of MG2.

The brake ECU also controls the hydraulic brake actuator solenoids and generates pressure at the individual wheel cylinders. The total amount of force applied to the hydraulic brake system is the total required brake force minus the force supplied through regenerative braking. The skid control ECU also controls the operation of the antilock brake system.

Motor/Generators

MG1 and MG2 are permanent magnet AC synchronous motors that can also function as generators **(Figure 35–41)**. The electric 4WD-i system used in SUVs has a permanent magnet AC synchronous motor/generator, called MGR, built into the rear drive axle assembly. Unlike conventional 4WD vehicles, there is no physical connection between the front and rear axles **(Figure 35–42)**. The aluminum housing of the rear transaxle contains the MGR, a counter drive gear, counter driven gear, and a differential. The final drive ratio in the rear drive axle is very low. This provides a large amount of torque to the rear wheels. The SUVs also have a stronger MG2 that is capable of higher rotational speeds. The power-split unit in these vehicles has been modified to include an additional planetary gearset (the Motor Speed Reduction unit). This gearset reduces the speed of MG2 and, thereby, increases the torque available at the front wheels.

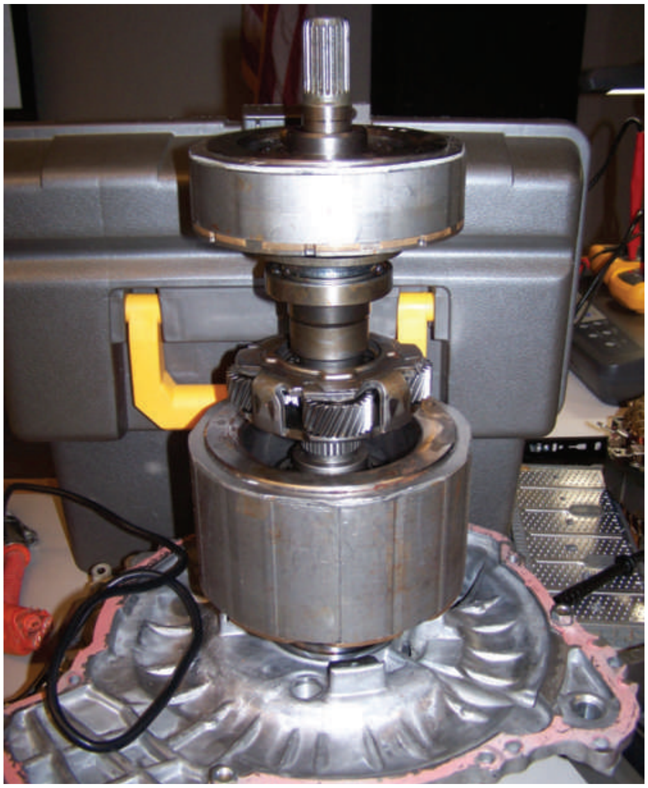


FIGURE 35–41 MG1 and MG2 are separated by a planetary gearset.

AC synchronous motors require a sensor to monitor the position of the rotor within the stator. It is necessary to time, or phase, the three-phase AC so it attracts the rotor's magnets and keeps it rotating and producing torque. AC creates a rotating magnetic field in the stator and the rotor chases that field. The control system monitors the position and speed of the rotor and controls the frequency of the stator's voltage, which controls the torque and speed of the motor. Toyota uses a sensor, called a **resolver**, to monitor the position of the rotor. The motors are also fitted with a temperature sensor. The ECU monitors the temperature of the motors and alters the power to them if there is evidence of overheating.

Power-Split Unit

The power-split device is also called the hybrid transaxle assembly. It functions as a continuously variable transaxle, although it does not use the belts and pulleys normally associated with CVTs. The variability of this transaxle depends on the action of MG1 and the torque supplied by MG2 and/or the engine.

Conventional final drive and differential units are used to allow for good handling and ample torque to drive the wheels. The transaxle does not have a

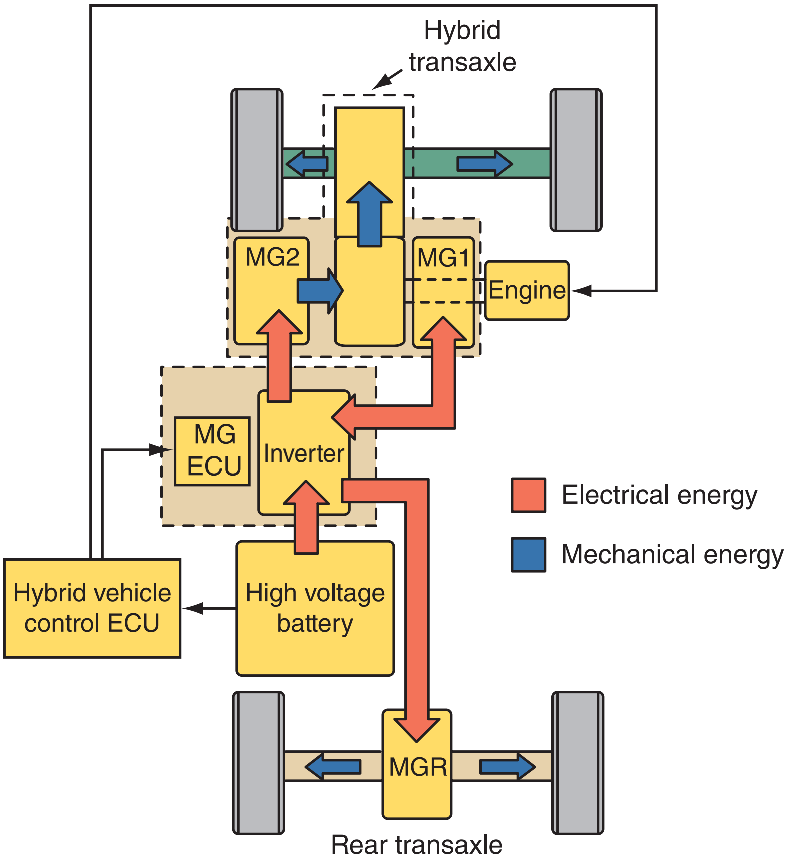


FIGURE 35-42 The rear axle is driven by an electric motor (MGR) and is not mechanically linked to the front drive axles.

torque converter or clutch. Rather a damper is used to cushion engine vibration and the power surges that result from the sudden engagement of power to the transaxle.

In the planetary gearset, the sun gear is attached to MG1. The ring gear is connected to MG2 and the final drive unit in the transaxle. The planetary carrier is connected to the engine's output shaft. The key to understanding how this system splits power is to realize that when there are two sources of input power, they rotate in the same direction but not at the same speed. Therefore, one can assist the rotation of the other, slow down the rotation of the other, or work together. Also, keep in mind the rotational speed of MG2 largely depends on the power generated by MG1. Therefore, MG1 basically controls the continuously variable transmission function of the transaxle.

Prius Plug-In

In 2012, Toyota released a plug-in version of the Prius **(Figure 35–43)**. The Prius Prime PHEV is based on the base Prius but is fitted with a 8.8 kWh Li-Ion battery pack. The pack allows the Prius to operate

FIGURE 35-43 Under the hood of a Prius plug-in hybrid.

as a pure EV for longer distances and at higher speeds. The estimated all-electric range is 25 miles, which results in an expected total range of 640 miles. The car is also capable of driving up to 62 mph while in the electric mode. The estimated fuel economy while operating as a gasoline-electric hybrid is 133mpge.

The battery pack sits under the rear cargo floor and includes a battery charger with 24-foot long

FIGURE 35–44 A charge nozzle into a Prius PHEV.

FIGURE 35–45 The battery pack for a Prius PHEV.

cables. The charger is designed for household current and can be plugged into any wall outlet. A full charge using a 120-volt AC outlet takes approximately 2.5 to 3.0 hours. The charging cables connect to the charging port located behind a door on the right-rear fender **(Figure 35–44)**. The port has LED lighting to allow for safe nighttime charging. The battery pack **(Figure 35–45)** has internal and external cooling fans to control heat. The inverter has also been reworked to be compatible with the new battery. Plus, the hybrid cooling system has a larger heat exchanger and higher capacity electric fans.

Ford Hybrids

In 2004, Ford released the Escape Hybrid. This was the first hybrid SUV and the first hybrid vehicle built in North America. The standard Escape Hybrid was front-wheel drive and an Intelligent 4WD system was optional. This option made the Escape the first 4WD hybrid. In 2006, Ford released a hybrid version of the Escape's cousin, the Mercury Mariner. These SUVs were full hybrids and featured a CVT transmission and stop-start technology, as well as the ability to be powered solely by battery power.

In 2010, Ford released a hybrid edition of its mid-sized car, the Fusion. Creating a hybrid system for the Fusion led to many changes in the system used in the Escape. These hybrid systems were based on a four-cylinder engine and two electric motors. The combined power output from the engine and the traction motor is the equivalent of 191 hp (142 kW).

Since the introduction of the Fusion Hybrid, the car has been redesigned **(Figure 35–46)** and two distinct hybrid models are available: the Fusion Hybrid and the Fusion Energi. The difference between the two models is that the Energi is a PHEV. Ford also released two hybrid versions of a new compact car, the C-Max **(Figure 35–47)**. Like the Fusion, hybrid and Energi models are available. Mechanically, Fusion and C-Max hybrids are identical. They are rated as Advanced Technology Partial Zero Emissions Vehicle (AT-PZEV) by CARB. They

FIGURE 35–46 A late-model Fusion hybrid.

FIGURE 35–47 A Ford C-max.

are also equipped with a high-output electric motor powered by a lithium-ion battery and an Atkinson-cycle gasoline engine. Both the Hybrid and Energi models have a projected 188 total system horsepower. With the introduction of these new hybrids, Ford discontinued the Escape Hybrid.

Lincoln MKZ This Lincoln hybrid is based on the Fusion hybrid and most of the mechanicals are the same with some upgrades. The hybrid is capable of all-electric driving up to 85 mph for short periods. The car is also equipped with Ford's SmartGauge with an interactive technology, called EcoGuide. This system provides real-time information to help a driver achieve maximum fuel efficiency.

Operation

The basic components and operation of Ford's hybrid system are very similar to what is found in Toyota hybrids. This has led many to conclude that Ford is simply buying the system from Toyota. This is not true. Due to the similarities and to avoid legal problems, Ford licensed some of the technology from Toyota and Toyota licensed some technology from Ford. Toyota does not supply hybrid components to Ford. Both Ford and Toyota state that Ford received no technical assistance from Toyota during the development of the hybrid system. Very simply, Aisin supplies the transmission used in the Ford hybrids and Toyota makes its own.

These are series-parallel hybrid vehicles **(Figure 35–48)**. Ford divides the operation of the hybrid system into three different modes: positive split, negative split, and electric modes. During the positive split (series) mode, the engine is running and driving the generator to recharge the battery or directly power the traction motor. The system is in this mode whenever the battery needs to be charged or when the vehicle is operating under moderate loads and at low speeds.

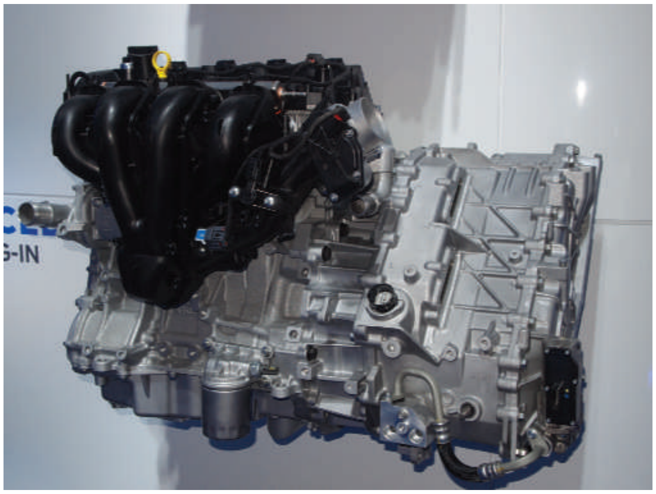


FIGURE 35–48 The engine and transaxle for a late-model Ford hybrid.

During the negative split (parallel) mode, the engine is running, as is the traction motor. The output of the traction motor tends to reduce the speed of the engine through the action of the planetary gearset. The engine's output is, however, supplemented by the power from the traction motor. During this mode, the traction motor can function as a motor or a generator, depending on the current operating conditions and the demands of the driver.

In the electric mode, the engine is off and the vehicle is propelled solely by battery power. This is the mode of operation when the battery is fully charged and during slow acceleration and low speeds, as well as when reverse gear is selected by the driver.

A feature of the Energi models is called the EV mode. There is a button that allows the driver to switch the vehicle between EV Now, Auto EV, and EV Later. Basically this switch allows the driver to select the power source for the vehicle—electric only, gasoline only, or a combination of gas and electric.

Motors

Two separate Permanent Magnet AC Synchronous motor/generators are used. One of these is primarily used as a generator but also serves as the starter motor for the engine and controls the activity of the transaxle. The other motor/generator is used to propel the vehicle during low-speed and low-load conditions and to assist the engine during hard acceleration, heavy loads, and/or during high-speed driving.

The operation of the two motors is ultimately controlled by the master control unit (the VSC), through inputs concerning speed and rotor position. The non-traction motor is powered by the battery pack, while the traction motor can be powered by the battery pack and/or the other motor/generator.

Controls

The vehicle system controller (VSC) is the primary control unit. Based on information from several other control units and inputs, it controls the charging, drive assist, and engine starting functions of the system according to current conditions. The VSC is part of the PCM.

The control system uses CAN communications and has diagnostic capabilities. The PCM monitors

the activity of the system and has direct control of engine operation. The VSC communicates with the other modules and receives inputs from the gear selector sensor, the accelerator pedal position sensor, the brake pedal position sensor, and many other inputs. Based on this information, the VSC manages the charging of the battery pack, controls the stop-start function, and controls the operation of the Transmission Control Module (TCM) that directly controls the operation of the motor/generators, and therefore controls the operation of the transaxle. This module is housed inside the transmission case.

Battery

Both models have a Li-Ion battery pack. However, the Energi has a more powerful battery pack (1.4 kWh vs. 7.6 kWh). The batteries in both models are located in the rear of the car **(Figure 35–49)**. These cars can travel up to 85 miles per hour on electric power alone.

The high-voltage lithium-ion battery pack in the Energi provides enough power to operate in all-electric mode for short commutes. Thanks to plug-in capability, the battery can be charged overnight using a 120-volt outlet. Or in less than 3 hours using a 240-volt outlet. The C-Max Energi has a range of more than 500 miles using the battery and engine.

When the connector cord is plugged into the Energi's charge port, located between the driver's door and front wheel, the port displays lights that indicate the battery's SOC. The port is surrounded by a light ring made up of four parts. When all four lights are illuminated, the vehicle has fully charged.

The hybrid and Energi's battery has a temperature management system. This system has an electric heater and a forced-air cooling system to keep

FIGURE 35–49 The battery pack in a Fusion hybrid.

FIGURE 35–50 The cooling system for the battery in a C-max hybrid.

the battery temperature within a specified range **(Figure 35–50)**. There are also two inertia-type switches, one in the front and the other in the rear, which can disconnect the high-voltage system if the vehicle is in an accident.

The Battery Energy Control Module (BECM) is housed in the battery pack and controls the activity of the battery. It receives commands from the VSC and sends feedback to the VSC to verify that the hybrid components are operating within the parameters set for the current condition of the battery. The battery is divided into modules. The voltage of each of the modules is constantly monitored, as is the current flow to and from them. There are eight temperature senses in each unit to help the BECM keep the battery pack within a specified temperature range. If the temperature is outside that range or if the voltage and current flow is outside their range, the BECM will order the PCM to set a fault code and the system will move to a default setting or shut down.

There is also a lead-acid 12-volt battery, located under the hood, to provide power for the various 12-volt systems of the vehicle. This battery is recharged by the DC-DC converter, also located under the hood.

Engine/Transmission

Current Ford hybrids are equipped with a 2.0-liter, four-cylinder, DOHC, Atkinson cycle engine. The early hybrids were equipped with a 2.5-liter, four-cylinder, DOHC, Atkinson cycle engine. The engine is coupled to an electronically controlled continuously variable transmission (eCVT).

The eCVT is based on a simple planetary gearset, like the Toyota's, the overall gear ratios are determined by the motor/generator. Ford's transaxle is different in construction from that found in the Prius. In a Ford transaxle, the traction motor is not directly connected

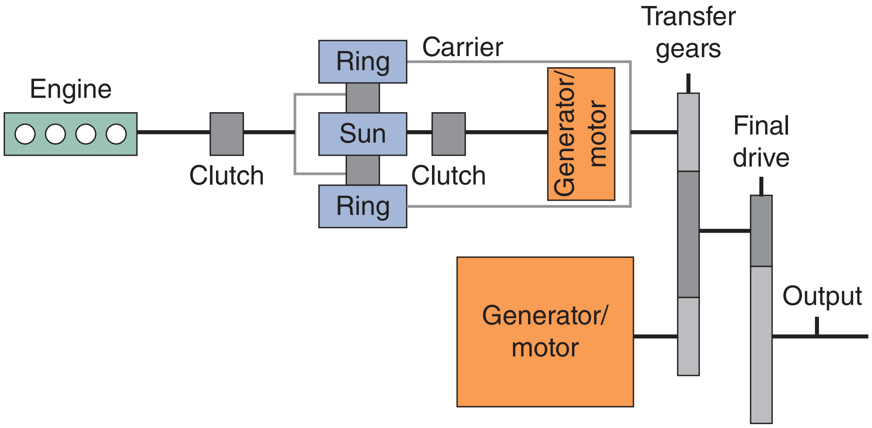


FIGURE 35–51 In a Ford hybrid transaxle, the traction motor is connected to the transfer gear assembly.

to the ring gear of the gearset. Rather it is connected to the transfer gear assembly **(Figure 35–51)**. The transfer gear assembly is composed of three gears, one connected to the ring gear of the planetary set, a counter gear, and the drive gear of the traction motor.

The effective gear ratios are determined by the speed of the members in the planetary gearset. They are controlled by the VSC through the TCM, which calculates the required ratio according to the information it receives from information from a variety of inputs.

The timing of the phased AC is critical to the operation of the motors, as is the amount of voltage applied to each stator winding. Angle sensors (resolvers) at the motors' stator track the position of the rotor within the stator. The signals from the resolvers also are used for the calculation of rotor speed. These calculations are shared with other control modules. The TCM monitors the activity of the inverter and constantly checks for open circuit, excessive current, and out-of-phase cycling. The TCM also monitors the temperature of the inverter and transaxle fluid.

Cooling System

The A/C system has two parallel refrigerant loops, one for the passenger compartment and the other for the HV battery. Both loops are connected to the same compressor and have their own shutoff valve. The system can cool the two zones independently.

The motor electronics (M/E) cooling system is completely separate from the engine's cooling system. The M/E cooling system cools the transaxle, motors, and the DC-DC converter. The system uses a PCM-controlled 12-volt coolant pump mounted near the bottom of the radiator to move the coolant through the system. The M/E system has a separate degas bottle that is part of an assembly that also includes the engine cooling system's degas bottle.

These vehicles have a PCM-controlled helper heater pump. This pump is located in series with the heater hose leading to the heater core. The pump is activated when the engine is off, such as during stop-start. This allows for some heat when the engine is not running.

Older models relied on an engine driven compressor. Since cooling the battery always has precedence over passenger comfort, the engine may turn on just to run the A/C. It is important to note that the A/C unit will not run unless the engine is running. When the driver selects the MAX A/C or defrost modes, the engine will run continuously and not shut down during normal stop-start conditions. Late-model vehicles have a high-voltage electric compressor. The use of an electric compressor allows the A/C to run anytime it is necessary, with the engine on or off.

4WD

Unlike the Toyotas with 4WD, the Escape and Mariner hybrids did not have a separate motor to drive the rear wheels. Rather, these wheels were driven in a conventional way with a transfer case, rear driveshaft, and a rear axle assembly. The 4WD system was fully automatic and had a computer-controlled clutch that engaged the rear axle when traction and power at the rear are needed. The system relies on inputs from sensors located at each wheel and the accelerator pedal, the system calculates how much torque should be sent to the rear wheels. By monitoring these inputs, the control unit can predict and react to wheel slippage. It can also make adjustments to torque distribution when the vehicle is making a tight turn; this eliminates any driveline shutter that can occur when a 4WD vehicle is making a turn.

Porsche and Volkswagen Hybrids

The same basic hybrid system is used in the Porsche Cayenne, Porsche Panamera **(Figure 35–52)**, and Volkswagen Touareg. Porsche continues to sell the Cayenne and Panamera E-Hybrid models but VW discontinued their hybrids in 2015. In 2014, Porsche introduced their plug-in hybrid Panamera, with a new engine and electric powertrain. The main difference between the various models is defined by the vehicle's intended purpose and the body style. Powertrain options include 2.9- and 3.0-liter turbocharged V6 engines and a 4.0-liter turbocharged V8. An electric motor is placed between the engine and an eight-speed automatic transmission. The engine and motor offer a maximum combined output of 416 hp to 680 hp. They are rated as super-low ULEVII vehicles by CARB.

If the vehicle is equipped with AWD, the "VW's 4 Motion," or similar, drive system with a Torsen center differential, front driveshaft and drive axle, and adaptive torque distribution capabilities is used.

For first generation vehicles, power for the electric motor comes from a 288V, 1.7 kWh NiMH battery pack. In electric only mode, the vehicles can be driven up to 30 mph and for about 1.2 miles. An engine management system monitors the driving conditions and SOC of the battery. Based on these inputs, it controls the engine and the motor. Later models have a larger 14 kWh battery, a more powerful electric motor, capable of reaching 86 mph and driving up to 31 miles with electric only.

FIGURE 35–52 A Porsche Panamera hybrid.

The vehicles have a clutch between the motor and the engine. This clutch provides a coasting feature that disengages the engine and motor from the driveline when the vehicle is operating with no-load and at speeds below 99 mph. This saves fuel by removing the engine's drag on the driveline while coasting, such as when going down hills.

The driver can manually disengage the clutch by pressing the "E Power" button. This disconnects the engine from the rest of the powertrain and allows the motor to power the vehicle by itself. This feature only works when the vehicle is moving at less than 53 mph and for only about one mile. After that, the battery's charge is too low to maintain the speed and the engine starts to propel the vehicle.

When the motor functions as a generator, it will charge the battery when the engine is in part-throttle mode and through regenerative braking. A battery management and cooling system monitors the battery's temperature to protect it from overheating. It also monitors the charge/discharge processes.

Systems that are usually driven by the engine, such as the A/C, power steering, and power brake, operate solely on electricity. Since they do not rely on the engine, they remain active when the car is running in electric mode or when it is coasting with the engine turned off.

VW Jetta Hybrid

The Jetta hybrid, which was discontinued in 2017, took a similar approach to other VW hybrids in that it connects the engine to the transmission with an electric motor. The engine, in this case, is a turbocharged engine connected to a 7-speed DSG automatic transmission. The use of a dual-clutch transmission is a first for a hybrid. The DSG uses a dry clutch pack, which reduces weight and improves efficiency by eliminating the power losses that come from the constant need to lubricate a wet-clutch or fill a torque converter.

The water-cooled 20 kW motor is rated at 27 hp with 114 lb-ft. torque and when combined with the engine, 170 hp and 184 lb-ft. of torque are available. Power for the electric motor is supplied by a 60-cell, 1.1-kWh Li-Ion battery pack located behind the rear seat. Like other VW Group hybrids, this system uses a clutch to decouple the engine from the drivetrain. This allows the engine to shut off and the car to coast on electricity at speeds up to 84 mph. Also, the driver can select an electric-only mode to provide for gasoline- and emission-free operation for up to 1.2 miles and a maximum of 44 mph. VW is also using this system in a diesel powered plug-in hybrid **(Figure 35–53)**.

FIGURE 35–53 A VW diesel powered plug-in hybrid.

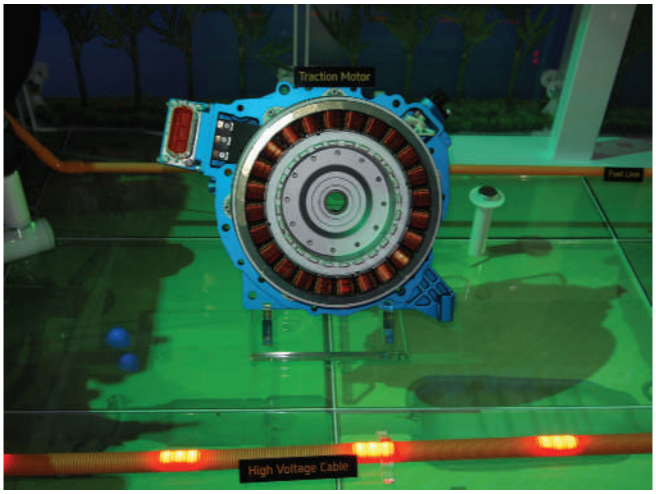


FIGURE 35–55 The ISAD assembly used in Hyundai and Kia hybrids.

Hyundai and Kia Hybrids

The Hyundai Sonata Hybrid **(Figure 35–54)** can go up to 75 mph propelled only by its electric motor. It has an EPA estimated fuel economy of 38 mpg in the city and 43 mpg on the highway. The combined power of the engine and electric motor for this parallel hybrid is 199 hp.

The electric motor **(Figure 35–55)** is sandwiched between the engine and a six-speed automatic transmission. The motor, called a transmission-mounted electrical device (TMED), replaces a conventional torque converter. The TMED is composed of two main assemblies: a 51 hp electric drive motor and a solenoid-activated clutch pack. The clutch allows the power from the engine, the electric motor, or both to pass through the transmission. The drive motor also serves as a generator for regenerative braking.

FIGURE 35–54 A Hyundai Sonata hybrid.

Hyundai also offers the Sonata as a plug-in hybrid. The plug-in has a 360-volt 9.8 kWh battery and a larger 67 hp electric motor. The lithium-ion polymer battery pack allows for up to 27 miles of electric-only driving and an EPA rating of 99 MPGe. Hyundai currently provides a lifetime warranty on the high-voltage battery for the original purchaser of the car.

Hyundai's latest hybrid, the Ioniq, is targeting the market currently dominated by the Prius family of hybrids. The Ioniq is a parallel hybrid with a 104-hp gasoline engine and a 43-hp electric motor driven by a 240-volt 1.56 kWh lithium-ion polymer battery. The system is claimed to be the most fuel-efficient car in its class, with an EPA combined rating of 58 mpg. A plug-in version of the Ioniq is expected to have a 60-hp electric motor and an 8.9 kWh battery pack allowing 27–37 miles of EV operation.

Kia Optima Hybrid and Plug-In Hybrid The Optima Hybrid uses the same 2.0 liter four-cylinder Atkinson cycle engine and electric motor found in the Sonata hybrid. The ISAD-type motor is connected to the engine and the six-speed automatic transmission by a wet clutch. The motor can provide up to 50 hp and 151 lb-ft. of torque. Electrical power is supplied by an air-cooled 270V Li-Poly battery. The car is capable of reaching about 62 mph in its full-electric mode. The EPA has rated the Kia's fuel economy at 39 mpg in the city and 42 mpg on the highway.

Nissan/Infiniti Hybrids

In an Infiniti M hybrid, later called the Q50, **(Figure 35–56)** the electric motor is sandwiched between the engine and a 7-speed automatic transmission. The engine can power the car with or without electrical assist. The 67 hp, 346V motor can power the car, assist the engine, start the engine, and serve as a generator. The engine and electric motor combine to produce about 360 hp. The car is EPA rated at 27 mpg in the city and 32 mpg on the highway.

The hybrid system, called "Infiniti Direct Response Hybrid," uses technologies developed for the Nissan Leaf electric vehicle, including the lithium-ion battery and electric motor. A 1.4-kilowatt Li-Ion battery pack is located under the trunk's floorboard. The battery pack is composed of laminated-cells to improve battery cooling.

Infiniti uses a single motor/generator, two clutches, and a standard seven-speed automatic transmission with no torque converter. The system is also called a parallel two-clutch (P2) system. The first of the two clutches is a dry clutch located between the engine and the motor. This clutch can couple and decouple the engine from the motor. This allows the engine to shut down anytime the accelerator pedal is released, such as during deceleration and coasting. The clutch eliminates the need for a torque converter and allows the full decoupling and shutting down the engine when there is adequate battery energy to power the vehicle solely by electricity.

The second clutch is a wet clutch at the rear of the transmission that allows the engine to turn the motor/generator to charge the batteries with the vehicle stationary.

The Q50 was last sold in 2015 and Nissan's last hybrid was the Altima, which used the Toyota hybrid system and was only available in very limited markets. The Altima Hybrid was ultimately discontinued. Future Altima Hybrids will use a system similar to that used in the Infiniti M.

FIGURE 35–56 An Infiniti M-series hybrid.

BMW Hybrids

Different BMW models are currently available as hybrids. The technology used in the models varies. BMW's 3 and 5 Series ActiveHybrids are full hybrids **(Figure 35–57)**. A 54 hp (40 kW) electric motor is sandwiched between the engine and an eight-speed transmission. The electric motor replaces the conventional starter and a belt-driven generator. When the motor is a generator, it recharges the battery mounted below the floor in the trunk.

The engine in the 3 and 5 Series hybrids is BMW's TwinPower Turbo, inline six-cylinder engine. The engine's efficiency (fuel economy and performance) is enhanced by the incorporation of the twin scroll turbocharger with Valvetronic, double-VANOS, and high-precision fuel injection. The engine and motor can provide a combined power output of 340 hp and 295 lb-ft. of torque.

A 120-volt Li-Ion battery is used and the car can move in the all-electric mode for up to a maximum speed of 37 mph. Electrical power is also available to assist the engine during heavy acceleration and heavy loads. The hybrid has both brake regeneration and auto start-stop systems.

The BMW X6 and 7 Series ActiveHybrids combines an engine with two electric motors inside a transmission. This transmission was co-developed with General Motors and the old DaimlerChrysler and is commonly referred to as a two-mode transmission. The transmission used in this hybrid is a seven- or eight-speed automatic that operates as an electronic continuously variable transmission.

The transmission has two synchronous AC motors, three planetary gearsets and four sets of

FIGURE 35–57 A look under the hood of a BMW Active Hybrid.

multi-disc clutches. The two electric motors serve as either a generator to charge the HV battery pack or power the hybrid with up to 91 hp. In all-electric driving, the hybrid can reach up to 37 mph and travel about 1.6 miles.

The transmission has two primary modes of operation: low and high speed. In each of these modes, one motor powers the hybrid while the other works as a generator. This is called the power split drive mode and allows the powertrain to run at continuously variable speeds to achieve maximum efficiency regardless of load or speed. To operate the transmission, the hybrid uses an HV battery pack, a power electronics unit with an integrated inverter, and high-voltage cables.

The intelligent energy management system consists of the Li-Ion battery, a 12-volt battery, and two on-board networks. There is a separate network for each of the power sources, but they are wired in parallel to each other. The 12-volt network contains all of the necessary components to operate and control the 12-volt systems in the car. The high-voltage network not only delivers to and receives high voltage from the motors, it also is used to operate and control other high-voltage systems, such as the air-conditioning compressor.

A 312V NiMH battery pack with a capacity of 2.4 kWh is installed in the rear of the vehicles. The battery pack is liquid cooled and works with the A/C system or the power-steering cooling system to control the battery's temperature. If the battery's temperature rises too much, the system will automatically turn on the A/C system. A control unit is part of the battery pack and constantly monitors current battery and power levels.

The engine is a 4.4-liter, V8 engine with Twin-Power turbo technology, piezo direct fuel injection, and the Double-VANOS variable valve timing system. The total available power output is 480 hp with 575 lb-ft. of torque.

BMW i3 and i8

BMW has developed two "i" cars that are sold in the United States. They use the prefix "i" for all vehicles that use electricity for mobility.

i3 The BMW i3 **(Figure 35–58)** is an extended range EV powered by a 125 kW (168 hp) electric motor that offers an 80 to 114 mile electric driving range. The i3 body, based on the 1 Series BMW, sits on an aluminum structure and in the center of the structure is a liquid-cooled 32 kWh lithium-ion battery pack. The traction motor is mounted to the front of the rear axle. To serve as a range extended, there is a 2-cylinder 600-cc gasoline generator that can recharge the battery pack while driving.

FIGURE 35–58 BMW's i3 hybrid.

An intelligent liquid heating/cooling system keeps the battery at its optimal operating temperature at all times, which helps to significantly boost the performance and life expectancy of the cells. The battery can be fully recharged in 4 hours using an installed outlet. If a DC-fast charger is used, an 80 percent charge can be achieved in around 30 minutes.

i8 The i8 is a plug-in hybrid that combines an electric drive system, fitted over the front axle with a three-cylinder engine producing about 220 hp (164 kW) and 221 lb-ft. (300 Nm) at the rear. The i8 is an all-wheel drive hybrid. The electric motor powers the front drive axles and the engine powers the rear wheels. The combined power output moves the car from 0 to 60 mph in about 4 seconds while providing 76 MPGe.

The body sits on an aluminum structure called the "DriveCell." Through the center of which is a liquid-cooled 7.1 kWh Li-Ion battery. Having the battery in this central position allows the car to have a low center of gravity, which enhances its handling.

Mercedes-Benz Hybrids

The Mercedes-Benz M- and S-classes have, for years, offered buyers a choice of hybrid and diesel-powered vehicles. The ML450 relies on two electric motors and a 275 hp 3.5L V6 Atkinson cycle gasoline engine to achieve an estimated 21 mpg around town and 24 mpg on the highway. This vehicle is classified as a full hybrid. Each of the motors is integrated into a

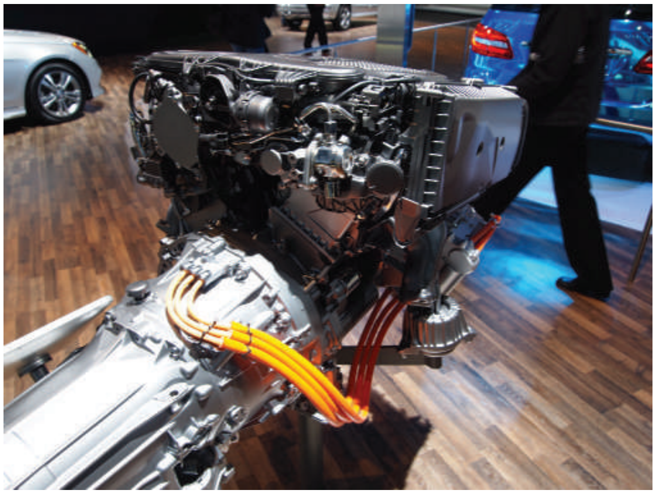


FIGURE 35–59 A two-mode transmission connected to a Mercedes-Benz V6 engine.

two-mode transmission **(Figure 35–59)**. The two-mode transmission was developed with other manufacturers and is commonly referred to as a two-mode transmission. Each electric motor has a specific purpose.

The motor positioned on the output shaft of the transmission has the primary purpose of moving the vehicle on electric power only. The second motor, located closer to the engine, provides the needed assist to the engine when needed. During parking and low speeds, the SUV runs on the electric drive only. The motors are powered by a liquid-cooled, 288-volt NiMH battery pack located under the rear cargo floor.

The S400 is classified as a mild hybrid. It has the Atkinson cycle 3.5L V6 engine used in the ML450. This was the first hybrid to use a Li-Ion battery. The battery powers a 20 hp electric motor. The motor/generator is contained within the torque converter housing, between the engine and transmission. Other than assisting the engine during times of need, the motor also helps to dampen drivetrain noise and vibration.

The 120-volt Li-Ion battery is located in the engine compartment. The battery is housed in a high-strength steel assembly with a separate cooling circuit, and its cells are separated by a gel that dampens jolts and vibrations. The 120-volt motor is designed to provide a large amount of torque during acceleration.

Since current flow to and from the battery can be as high as 150 amps, the battery has its own cooling circuit. In addition, a transformer in the right front wheel generates power to recharge the traditional 12-volt battery located in the vehicle's trunk.

It is important to note that since the oil pumps of most transmissions are engine-driven, an electric auxiliary oil pump is used to ensure the transmission is properly pressurized and lubricated when the engine is off.

E400 Hybrid

Mercedes recently released the E400 hybrid. The hybrid system used in this car is similar to the one used in the S-series. However, the E400 is considered a full hybrid and is capable of traveling over a half mile on electricity alone. A 27 hp electric motor is placed between a 302 hp, direct-injection, 3.5-liter V6 and seven-speed automatic transmission. The car also has its 0.8-kWh Li-Ion battery under the hood, next to the engine. The E400 Hybrid was last available in 2015 in the United States.

Mercedes currently offers S300, S400, S500 hybrids and the C350e Plug-in Hybrid. This model has a 2.0-liter turbocharged four-cylinder and 60 kW electric motor for a combined output of 275-hp and 51 MPGe. The C350e places the electric motor and a wet clutch between the engine and the seven-speed automatic transmission. The "SD" series hybrids rely on a two-mode transmission.

Maintenance and Service

Hybrid vehicles are maintained and serviced in much the same way as conventional vehicles, except for the hybrid components. The latter includes the high-voltage battery pack and circuits, which must be respected when doing any service on the vehicles. Manufacturers list the recommended service intervals in their service information and owner's manuals. Nearly all of the items are typical of a conventional vehicle. Care needs to be taken to avoid anything orange while carrying out the maintenance procedures.

GO TO Chapter 8 for guidelines on performing preventive maintenance on a hybrid vehicle.

For the most part, actual service to the hybrid system is not something that is done by technicians unless they are certified to do so by the automobile manufacturer. Diagnosing the systems varies with the manufacturer, although certain procedures apply to all. Keep in mind that a hybrid has nearly all of the

basic systems as a conventional vehicle and they are diagnosed and serviced in the same way.

Before performing any maintenance, diagnosis, or service on a hybrid vehicle, make sure you understand the system found on the vehicle and try to experience what it is like to drive a normal operating model. These vehicles offer a unique driving experience, and it is difficult to say what is working correctly if you do not have firsthand seat experience.

Safety Issues

Hybrid systems rely on very high voltages. Always follow the correct procedures for disarming the high-voltage system before performing any service on or near the high-voltage circuits. This is important for all services, not just electrical. Air-conditioning, engine, transmission, and body work can require services completed around and/or with high-voltage systems. If there is any doubt as to whether something has high voltage or not, or if the circuit is sufficiently isolated, test it before touching anything.

High-voltage circuits are identifiable by size and color. The cables have thicker insulation and are colored orange. The connectors are also colored orange. On some vehicles, the high-voltage cables are enclosed in an orange shielding or casing; again the orange indicates high voltage. In addition, the high-voltage battery pack battery and other high-voltage components have "High Voltage" caution labels **(Figure 35–60)**. It is important to remember that high voltage is also used to power some vehicle accessories. Avoid all orange colored cables, connectors, and wires unless you have disconnected the high-voltage power source and know what you are doing.

FIGURE 35–60 A high-voltage warning label.

Precautions

- Always precisely follow the correct procedures. If a repair or service is done incorrectly, an electrical shock, fire, or explosion can result.
- Systems may have a high-voltage capacitor that must discharge after the high-voltage system has been isolated. Make sure to wait the prescribed amount of time (about 5–10 minutes) before working on or around the high-voltage system.
- Move the key and/or key fob a good distance away from the vehicle before starting any service.
- After removing a high-voltage cable, cover the terminal with vinyl electrical tape.
- When working on or near the high-voltage system, even when it is de-powered, always use insulated tools.
- Never leave tools or loose parts under the hood or close to the battery pack. These can easily cause a short.
- Never wear anything metallic, such as rings, necklaces, watches, and earrings, when working on a hybrid vehicle.
- Alert other technicians that you are working on the high-voltage systems with a warning sign such as "high-voltage work: do not touch."
- Keep in mind that the engine can start and stop on its own if it is left in the idle stop mode. Make sure the READY light in the instrument panel is OFF.
- If the vehicle needs to be towed into the shop for repairs, make sure it is not towed on its drive wheels. Doing this will drive the generator(s) to work, which can overcharge the batteries and cause them to explode. Always tow these vehicles with the drive wheels off the ground or move them on a flat bed.
- In the case of a fire, use a Class ABC powder type extinguisher or very large quantities of water.
- When checking for trouble codes, if DTC P3009 or P0AA6 are present, make sure you use caution when working on the HV system. P0AA6 indicates there is decreased resistance in the HV insulation and DTC P3009 suggests there is a short in the HV circuit.

Gloves

Always wear safety gloves during the process of de-powering and powering the system back up again. These gloves must be class "0" rubber

FIGURE 35-61 Blow up an insulated glove and attempt to roll it up to check its integrity.

FIGURE 35-62 A pair of lineman's gloves covered with leather work gloves.

lineman's gloves; rated at 1,000 volts. The condition of the gloves must be checked before each use. Make sure there are no tears or signs of wear. All gloves, new and old, should be checked before they are used **(Figure 35–61)**.

GO TO Chapter 6 for more information on hybrid vehicle tools.

The insulated gloves must be sent out for testing and recertified by an accredited laboratory every 6 months. If recertification is not possible, new gloves should be purchased. After recertification, the laboratory marks the date of certification on each rubber glove. Used gloves should be stored in their natural shape and protected from physical damage, in a cool, dark, and dry location.

Keep in mind; these insulating gloves are special gloves and not the thin surgical gloves you may be using for other repairs. You should never expose these gloves to petroleum products. Degreasers, detergents, and hand soaps may contain petroleum and should not come in contact with the gloves. Also, to protect the integrity of the insulating gloves, as well as you, while doing a service, wear leather gloves over the insulating gloves **(Figure 35–62)**. However, never use the leather gloves without the insulating gloves when working on HV systems.

Buffer Zone When working on a high-voltage system, it is best to keep anyone who is not part of the service away from you and the car. This can be accomplished by creating a buffer zone around the car. The outside edges of the zone should be at least three feet away from the car. Orange cones should be placed to define the outer boundaries of the zone. If the vehicle is sitting unattended, it should be marked off with "do not enter" tape, along with the cones.

Safety Hook If a "hot" high-voltage cable is loose and you cannot safely turn off the power to it, use a fiberglass reach pole and hook **(Figure 35–63)** or a dry board to move or remove the wire. The reach

FIGURE 35-63 A fiberglass safety hook.

FIGURE 35–64 Most hybrid engines require the use of a very light engine oil.

FIGURE 35–65 A coolant reservoir for an inverter.

pole can also be used to push or pull someone away from the wire.

Maintenance

The engines used in hybrids are modified versions of engines found in other models offered by the manufacturer. Other than fluid checks and changes, there is little maintenance required on these engines. However, there is less freedom in deciding the types of fluids that can be used and the parts that can replace the original equipment. Hybrids are not very forgiving. Always use the exact replacement parts and the fluids specified by the manufacturer.

Typically, the weight of the engine oil used in a hybrid is very light **(Figure 35–64)**. If the weight is increased, it is possible that the computer system will see this as a problem. This is simply caused by the extra current needed to turn over the engine. If the computer senses very high-current draw while attempting to crank the engine, it will open the circuit in response.

Special coolants are required in most hybrids because the coolant not only cools the engine, but may also cool the inverter assembly. Many hybrids have a complete and separate cooling system for the HV battery and electronics. Cooling the inverter is important, and checking its coolant condition and level is an additional check during preventative maintenance **(Figure 35–65)**. The cooling systems used in some hybrids feature electric pumps and storage tanks. The tanks store heated coolant and can cause injury if you are not aware of how to carefully check them. The battery cooling system may need to be serviced at regular intervals. There is a filter in the ductwork from the outside of the vehicle to the battery box. This filter needs to be periodically changed. If the filter becomes plugged, the temperature of the battery will rise to dangerous levels. In fact, if the computer senses high temperatures it may shut down the system.

A normal part of preventative maintenance is checking the power steering and brake fluids. Some power-steering systems have a belt-driven pump, some have an electrically-driven pump, and others have a pure electric and mechanical steering gear. Each variety requires different care; therefore always check the service information for specific information before doing anything to these systems. Also, keep in mind that some hybrids use the power-steering pump as the power booster for the brake system.

Batteries

Most hybrids have two separate battery packs. One is the high-voltage pack and the other is a 12-volt battery **(Figure 35–66)**. The high-voltage battery pack supplies the power to start the engine, assist the engine during times of heavy load, and in full hybrid it supplies the energy to move the vehicle without the engine's power. The battery pack is the one that is most associated with the hybrid system. The 12-volt battery is associated with the rest of the vehicle, such as the lights, accessories, and power equipment. The 12-volt battery also supplies the power for the electronic controls that monitor and regulate the operation of the hybrid system. If this power source is not working correctly, the hybrid system will not. Therefore, this low-voltage power source should never be ignored when working on a hybrid or a conventional system.

FIGURE 35-66 This warning label states there are two separate batteries.

The procedure for de-powering and isolating the high-voltage system is very important and not very difficult. However, each manufacturer has its own procedure that must be followed in the order presented. Make sure you are following the correct procedure for the specific vehicle you are working on. With the correct information and following the procedures, you can safely work on a hybrid vehicle. The following procedure has steps common to many hybrid vehicles but is not specific to any manufacturer or model and should not be used in place of the correct service procedures.

Because of the advanced electronics in hybrids, steps must be taken after reconnecting or installing a battery. The regenerative braking system needs to relearn the initial position of the brake pedal. After the battery is reconnected, slowly depress and release the brake pedal one time. The engine also needs to relearn its idle and fuel trim strategy. If this is not done immediately after reconnecting the battery, the engine will idle and run poorly until it sets up its strategy. A typical procedure begins with turning off all accessories and starting the engine. The engine is idled until it reaches normal operating temperature, then it should be allowed to run at idle for 1 minute. After that time, the air conditioning is turned on and the engine again is allowed to idle for at least 1 minute. Now the vehicle should be driven for about ten miles. All manufacturers have their own sequence for doing this, so be sure to follow their procedure.

PROCEDURE

1. Remove the key from the ignition switch. If the vehicle has a "smart" key, turn the smart key system OFF. This may be done by applying pressure to the brake pedal while depressing the start button for at least 2 seconds. If the READY lamp goes off, continue. If it does not, diagnose the problem before continuing.
2. Disconnect the negative (–) terminal cable from the auxiliary 12-volt battery. This should turn the high-voltage system off, but does not complete the de-powering process.
3. Move the carpeting from the floor in the trunk or the rear of the vehicle.
4. Make sure you are wearing insulated gloves and reach in at the location of the disconnect plug at the battery box.
5. Unlatch the lever on the plug and pull the lever down. Then remove the service plug from the battery module.
6. Put the service plug in your toolbox or elsewhere to prevent others from reinstalling it before the system is ready or while you are working on the vehicle.
7. Put electrical insulating tape over the service plug connector.
8. Wait at least 5 minutes before proceeding or doing any work on or around the high-voltage system.
9. Prior to handling any high-voltage cable or part, check the voltage at the terminals. There should be less than 12 volts.
10. If a high-voltage cable must be disconnected for service, wrap its terminal with insulating tape to prevent a possible short.
11. When the service plug is reinstalled, make sure its handle is in the upright position; failure to do this may result in a loose plug that may set diagnostic trouble codes (DTCs).

Recharging Recharging the high-voltage battery pack is best done by the vehicle itself; however, there are times when it may be necessary to recharge the battery in the shop. Doing this is not a typical procedure. Chances are your shop will not have the correct charger. For example, many hybrid batteries require a special charger that is not sold to its dealerships. If there is a need for one, the dealership must contact the regional office and have one delivered and only someone from that office is allowed to

operate it. This charger has the normal connections plus a cable to power the battery's cooling system. The charger is designed to bring the battery pack to a 40 to 50 percent state-of-charge within 3 hours. This is enough to start the vehicle and allow the engine to bring the battery back to full charge.

PHEV Charging Methods All plug-in hybrids have a specific procedure for recharging the battery. Normally the battery pack can be charged by a 120- or 240-volt outlet. The required charger can be built into the battery pack or connected externally. For example, a Volt is equipped with a 120-volt charger **(Figure 35–67)** that plugs into a household wall outlet; this allows the battery to receive a full charge in 10 to 12 hours. The charger is located in the trunk along with the tire emergency repair kit. One end of the charger's cord has a fuel nozzle type plug that fits into a charge port located on the left side of the car.

When the charging plug is connected and all is well, the green indicators on the charger will illuminate. If the red indicators are flashing, the battery cannot be charged. A flashing red light can mean one of the following: the AC voltage is out of range, the AC outlet does not have a proper safety ground, or there is a fault in the charge cord or charger.

FIGURE 35–67 The Chevrolet Volt has an auxiliary 120V battery charger in its trunk.

Jump-Starting If the vehicle will not start, several things can be the cause. Like conventional vehicles, it must have fuel and there must be ignition, intake air, compression, and exhaust. Before proceeding with a no-start diagnosis, make sure the immobilizing system is working properly. If the auxiliary or high-voltage battery is discharged, the engine will not start nor will the vehicle be able to operate on electric power only. Manufacturers have built in ways to jump-start these vehicles, if and when the batteries go dead. The basic connection from a booster battery to the dead battery is the same but the connecting points may be different and there are certain precautions to consider when jump-starting. There are also separate procedures for jump-starting with the low- and high-voltage systems. Some hybrids have a control that must be activated before attempting to jump-start it.

Battery Cooling System Filter Normally, the battery has its own cooling system. The control module monitors the temperature of the cells and activates fans and/or the rear air-conditioning system when the temperature rises. The cooling system draws in outside air. Within the ductwork for that vent, there is an air filter that requires periodic replacement. If the filter is dirty or restricts airflow, the battery can overheat.

Diagnostics

It is important that you have good information when diagnosing driveability problems. The problem can be caused by the hybrid system, engine, or transmission. Determining which system is at fault can be difficult. On some hybrids, it is possible to shut down the hybrid system and drive the vehicle solely by engine power. On others, such as the Toyota and Ford hybrids, this is not possible. If electric power can be shut off and the vehicle still drives poorly, the problem is the engine or transmission. If it is not possible to shut down either power source, your diagnosis must be based on the symptom and information retrieved with a scan tool.

With hybrids, it is often difficult to control the operation of the hybrid system so certain tests can be conducted. Ford has built into its control system, two scan tool controllable modes for diagnostics. The engine cranking mode allows the engine to crank without the engine starting. During this mode, the TCM orders the starter/generator to rotate the engine at 900 to 1,200 rpm.

FIGURE 35–68 An example of some of the displays and warning lamps on a hybrid vehicle.

Ford also offers a running diagnostic mode. In this mode, the engine will run until it is ordered to stop by the scan tool or the ignition is turned. In normal operation, the engine will not idle for very long without being shut down by the system. Therefore when diagnostics require that the engine is idling, the engine running mode allows for this.

All warning lamps in the instrument panel should be checked **(Figure 35–68)**. If any of these remain on after the engine is started, the cause should be identified and corrected before continuing with diagnosis. Lastly, a scan tool should be used to retrieve any fault codes held in the computer's memory. In many cases, a manufacturer-specific scan tool is required to test hybrids. Follow the prescribed sequence for retrieving and responding to all DTCs.

The scan tool also allows for some active tests that enable you to excite or disable certain outputs so their operation can be monitored. These "inspection modes" can crank the engine to conduct a compression test, turn the traction control on and off, and turn the inverter on and off. The value of these modes is the ability to isolate systems, which will definitely help in diagnosis. The scan tool is also used to reset or calibrate the electric motor's rotor.

Test Equipment

To test high-voltage systems you need a DMM **(Figure 35–69)** and, of course, a good pair of insulating gloves. Although the high-voltage system can be isolated from the rest of the vehicle, high voltage is still at and around the battery pack and inverter.

The DMM used to diagnose a hybrid vehicle is not the same meter you would use on a conventional vehicle. The meter used on hybrids, electric vehicles, and fuel-cell vehicles must be classified as a

FIGURE 35–69 A CAT III DMM is a must for diagnosing the high-voltage systems.

category 3 or 4 (CAT III or CAT IV) meter. There are four categories for low-voltage electrical meters, each built for specific purposes and to meet certain standards. Low voltage, in this case, means voltages less than 1,000 volts.

Warning! When using a CAT III or CAT IV meter, make sure the meter's leads are also rated for high voltage. Also, make sure the meter's probes have safety ridges or finger positioners. These help prevent physical contact between your fingers and the probes.

Another valued tool during diagnosis is an **insulation resistance tester**. This meter is not one commonly used by automotive technicians, but should be for anyone who might service a damaged hybrid vehicle, such as doing body repair. These meters check for voltage leakage from the insulation of the high-voltage cables **(Figure 35–70)**. Minor leakage

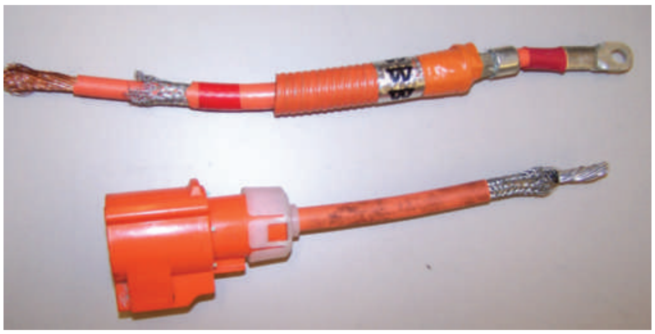


FIGURE 35–70 An insulation resistance tester (megger meter) is used to check the insulation of high-voltage cables.

can cause hybrid system-related driveability problems. This meter should also be a CAT III meter.

To check the insulation, the approximate system voltage should be selected on the meter and the probes placed at their test position. The meter is measuring the insulation's effectiveness and not its resistance. The meter will display the voltage it detects and any voltage is not good and the cable should be carefully examined.

Air Conditioning

Most hybrids are equipped with air-conditioning systems with either a belt-driven or an electrically powered A/C compressor. The electrical units are powered by high voltage and all precautions should be taken to work safely with these units. Always wear lineman's gloves when inspecting or servicing high-voltage air-conditioning systems.

The refrigerant oil used in all electrically operated compressors must meet the specifications given by the manufacturer. In nearly all cases, the oil is synthetic and non-conductive and able to insulate the various electrical parts of the compressor from each other. The most common is **Polyvinyl ether (PVE) oil**. The use of the regular refrigerant oil (PAG) can cause the destruction of the compressor **(Figure 35–71)**.

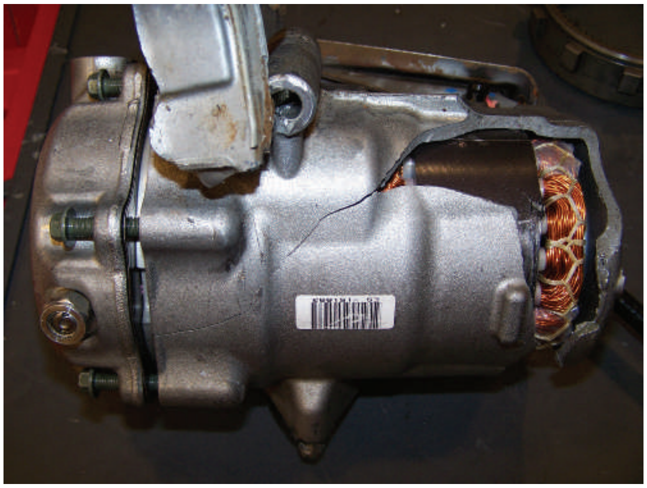


FIGURE 35–71 This is what can happen to a compressor if the wrong refrigerant oil is used.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2017	**Make:** Chevy	**Model:** Volt	**Mileage:** 11,054	**RO:** 16412
Concern:	Service charging system warning lamp is displayed and the charging connector shows orange instead of green when connected to vehicle.			
The technician confirms the warning message and finds several fault codes stored for the high-voltage system.				
Cause:	Found blown 15 amp fuse in the high voltage battery disconnect relay assembly. Confirmed issue related to bulletin #16185.			
Correction:	Per service bulletin, replaced 15 amp fuse and high-voltage relay, reprogramed PCM. All codes cleared and vehicle operates normally.			

KEY TERMS

Belt alternator starter (BAS)
Category 3 or 4 (CAT III or CAT IV)
Extended range EV
Full hybrid
Insulation resistance tester
Integrated starter alternator damper (ISAD)
Lineman's gloves
Plug-in hybrid electric vehicles (PHEVs)
Polyvinyl ether (PVE) oil
Resolver
Two-mode hybrid system

SUMMARY

- Any vehicle that combines two or more sources of power is called a hybrid. Current HEVs have a gasoline engine and one or more electric motors.
- In a series hybrid, the engine never directly powers the vehicle.
- Many hybrid vehicles are parallel types and rely on power from an electric motor and the engine.
- A series-parallel hybrid can run on just the engine, just the batteries, or a combination of the two.
- Plug-in hybrid electric vehicles (PHEVs) are full hybrids with larger batteries.

- Regenerative braking is the process that allows a vehicle to recapture and store part of the kinetic energy that would ordinarily be lost during braking.
- A controller looks at inputs from various sensors to determine the operating conditions of the vehicle and manages the flow of electricity to control the speed of the motor.
- An inverter is a power converter that changes the high DC voltage of the battery to a three-phase AC voltage for the electric motors.
- The Belt Alternator/Starter System (BAS) replaces the traditional starter and generator in a conventional vehicle and is connected to the engine's crankshaft by a drive belt.
- The integrated starter alternator damper (ISAD) system replaces the conventional starter, generator, and flywheel with an electronically controlled compact electric motor housed in the transmission's bell housing between the engine and the transmission.
- A power-split unit has a planetary gearset and two electric motors and is capable of instantaneously switching from one power source to another or combining the two, while functioning as a continuously variable transaxle.
- Some hybrid systems are based on the presence of one or more motors inside a conventional transmission.
- Some 4WD hybrids use an electric motor, differential, and rear transaxle housing to drive the rear wheels.
- HEV air-conditioning systems are identical to those used in a conventional vehicle, except a high-voltage motor may be used to rotate the compressor.
- The Chevrolet Volt and Cadillac ELR are called extended range EVs but can be also classified as series or plug-in hybrids.
- General Motors eAssist system is based on a BAS system and can provide additional torque to the driveline during heavy loads.
- A two-mode full hybrid system fits into a standard transmission housing and has three planetary gearsets coupled to two AC synchronous 60 kW motor/generators. This results in a continuously variable transmission and motor/generators for hybrid operation.
- Most Honda hybrids use an ISAD system, called the Integrated Motor Assist (IMA) system in which a small efficient engine in a vehicle and the power deficiencies of the engine are overcome by the electric motor.
- Toyota's approach to hybridization is a combination of series and parallel hybrid platforms. The system relies on two electric motor/generators, a power-split transaxle, and a high-voltage battery.
- The basic components and operation of Ford's hybrid system are very similar to what is found in Toyota hybrids; however, each manufacturer uses a unique design to accomplish the same thing.
- Porsche Cayenne, Porsche Panamera, Volkswagen Jetta, and Volkswagen Touareg hybrids are based on an ISAD system.
- The Hyundai Sonata and Kia Optima hybrids have an electric motor sandwiched between the engine and transmission and a BAS unit for stop-start.
- The Infiniti M hybrid is also a basic ISAD system but has two clutches; one is a dry clutch located between the engine and the motor and the other is a wet clutch located at the rear of the transmission.
- BMW's 3 and 5 Series ActiveHybrids are based on the ISAD system.
- The BMW X6 and 7 Series ActiveHybrids use the two-mode hybrid system.
- The Mercedes-Benz M hybrid is based on a two-mode transmission.
- The Mercedes-Benz S hybrid is a mild hybrid with an ISAD. The same platform is used in their E400 full hybrid.
- Hybrid systems rely on very high voltages. Always follow the correct procedures for disarming the high-voltage system and pay strict attention to the stated precautions before performing any service on or near the high-voltage circuits.
- Always wear lineman's gloves rated at 1,000 volts during the process of de-powering and powering the system back up again.
- The condition of the gloves must be checked before each use. Make sure there are no tears or signs of wear.
- When working on a high-voltage system, keep anyone who is not part of the service away from you and the car by creating a visual buffer zone around the car.
- If a "hot" high-voltage cable is loose and you cannot safely turn off the power to it, use a fiberglass reach pole and hook or a dry board to move or remove the wire. The reach pole can also be used to push or pull someone away from the wire.

- The cooling system in many hybrids is comprised of several independent cooling loops; each of these must be maintained.
- Recharging the high-voltage battery pack is best done by the vehicle itself; however, there are times when it may be necessary to recharge the battery in the shop. To do this, a special charger is required.
- To test high-voltage systems you need a CAT III DMM.
- An insulation resistance tester should be used to check the effectiveness of all HV cables.

REVIEW QUESTIONS

Short Answer

1. What are the basic components of a belt alternator starter hybrid system?
2. What are the main reasons that a mild hybrid consumes less fuel than a conventional vehicle?
3. The Prius PHEV offers many advantages over the basic Prius, how is that possible?
4. In a Toyota Prius, what members of the planetary gearset are connected to the motor/generators and the engine?
5. How often must insulated lineman's gloves be tested and recertified?
6. Nearly all hybrids have less powerful engines than typical nonhybrids. What feature of a hybrid provides power to allow the engine to overcome heavy loads?
7. What is the purpose of a typical inverter?
8. On hybrids with a separate cooling system for the inverter and other electronics, what needs to happen if air is trapped in the cooling system?
9. List five common sense safety rules that should be followed when working on a hybrid vehicle.
10. During diagnostics the DTC P3009 is displayed. What does this indicate?

True or False

1. *True or False?* All hybrids that have an electric motor inside the transmission have at least two.
2. *True or False?* The Hyundai Sonata Hybrid uses BAS and ISAD systems.

Multiple Choice

1. After isolating the high-voltage system, what is the minimum time you should wait before beginning to work on or around the hybrid system?
   a. 1 hour
   b. 30 minutes
   c. 15 minutes
   d. 5 minutes
2. Which of the following statements about the high-voltage circuits in a Honda Hybrid is NOT true?
   a. All of the high-voltage cables are covered in orange sleeves for easy identification.
   b. You should always follow the disarming of the high-voltage systems before performing any service work on or near the high-voltage circuits.
   c. There is a main switch on the instrument panel that is used to disconnect the battery module from the rest of the car.
   d. There are three large capacitors in the MDM that will take at least 5 minutes to discharge after the switch is turned off.
3. Which of the following is the least likely to decrease fuel consumption of a hybrid vehicle?
   a. Low-rolling resistance tires
   b. Increased aerodynamic drag
   c. Stop-start systems
   d. Lighter and less powerful engines

ASE-STYLE REVIEW QUESTIONS

1. Technician A says an insulation resistance tester measures voltage. Technician B says an insulation resistance tester measures the effectiveness of a wire's insulation. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. When working on a high-voltage system, it is best to keep anyone who is not part of the service away from you and the car by creating a buffer zone around the car. Technician A makes sure the outside edges of the zone are at least one foot away from the car. Technician B places orange cones to define the outer boundaries of the zone. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

3. Technician A says a mild hybrid has stop-start, regenerative braking, and electric motor assist available when the engine needs added power to overcome the load. Technician B says a full hybrid has stop-start, regenerative braking, electric motor assist, and can be driven by only electricity. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
4. Technician A says diesel engines can be used in a hybrid powertrain. Technician B says a gasoline engine is normally used in hybrid powertrain. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. While discussing working on hybrid vehicles: Technician A says to make sure that the high-voltage system is shut down and isolated from the vehicle before working near or with any high-voltage component. Technician B says that when working on or near the high-voltage system, even when it is de-powered, always use insulated tools. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. While discussing the DC-DC converter used in most hybrids: Technician A says that it changes some of the DC voltage from the battery module to an AC voltage for the electric motors. Technician B says that it provides the power to operate the car's 12-volt electrical system and accessories. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. While discussing regenerative braking: Technician A says the regenerative system can completely stop the vehicle in order to generate a maximum amount of electricity. Technician B says since most hybrids are FWD vehicles, the rear wheels are designed to claim the most kinetic energy. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. Technician A says PVE refrigerant oil is commonly recommended for electric A/C compressors. Technician B says PAG refrigerant oil can be used in many electric A/C compressors. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. Technician A says Ford hybrid SUVs with 4WD have an additional motor in the rear axle. Technician B says Ford's Energi models are plug-in hybrids. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While discussing the other classifications for the extended range EV, the Chevy Volt: Technician A says it can be called a plug-in hybrid. Technician B says it can be called a parallel hybrid. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

CHAPTER 36

ELECTRIC VEHICLES

Today, there are only a few pure battery electric vehicles (BEVs) manufactured by the major automobile companies. However, nearly all are planning to release new BEVs in the near future **(Figure 36–1)**. Market resistance has resulted from short drive ranges and high cost. However, today's battery technologies and other efficiencies allow BEVs to have longer ranges than in the past. The purchase price of BEVs has also decreased, which makes BEVs a bit more practical today.

OBJECTIVES

- Describe the major systems that make up a BEV.
- Describe the purpose and function of a battery control system.
- Explain the differences between conductive and inductive battery charging.
- Describe some precautions that should be followed when troubleshooting and repairing an electric vehicle.
- Describe the basic configurations for the power train in a fuel cell vehicle.
- Describe the major components of a fuel cell vehicle.
- Explain how a fuel cell works.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2012	**Make:** Nissan	**Model:** Leaf	**Mileage:** 41,058	**RO:** 16603
Concern:	Customer states driving range decreased significantly in last few weeks.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

FIGURE 36–1 An Audi "e-tron," which is an electric concept car.

A Look at History

Electric drive vehicles have been around for a long time. Early automobiles were mostly electric or steam powered. "Steamers" were the most common until the late 1800s.

In 1900, 38 percent of the cars sold were electrically powered; the others ran on steam or gasoline. Starting the engine and changing gears were the most difficult things about driving a gasoline-powered vehicle. Electric drive vehicles did not need to be manually cranked to get going and had no need for a transmission or change of gears. These were the primary reasons the public accepted electric drive over the gasoline vehicles. However, the internal combustion engine became popular because it allowed a vehicle to travel great distances, achieve a decent high speed, and was much less expensive to buy.

Let us take a quick look at some interesting developments of electric vehicles throughout history. It is said that the first practical electric vehicle was made either by Thomas Davenport in the United States or by Robert Davidson in Edinburgh, Scotland in 1842. Both vehicles had non-rechargeable batteries and, therefore, had a limited driving range and most consumers did not want them.

In 1865, the storage battery was invented and then further improved in 1881. More significantly, between the years 1890 and 1910, battery technology drastically improved with the development of the modern lead-acid battery by Henri Tudor in 1881. In 1909, Thomas Edison perfected his nickel-iron battery and marketed it to automakers, and electric vehicle popularity grew and reached its peak in 1912.

In 1904, Henry Ford overcame some of the common objections to gasoline-powered cars and, thanks to assembly line production, offered gasoline-powered vehicles at very low prices ($500 to $1,000). The cost of electric vehicles was much higher and rising each year.

Further advances made to a gasoline vehicle, such as an electric starter, and the availability of gasoline provided cheap and more practical transportation. For the most part, electric drive vehicles were a thing of the past from 1920 to 1965.

The U.S. Congress introduced bills, in 1966, recommending the use of electric vehicles as a way to reduce air pollution. Subsequent laws put mandates on auto manufacturers to clean up exhaust emissions. The initial result of these laws was altering the basic engine with a variety of emission controls many of which adversely affected fuel economy and performance. This forced the manufacturers to look into alternative ways to provide transportation.

In 1973, the price of gasoline drastically increased as the result of an Arab oil embargo. The rising cost led to increased attention to the development of electric drive vehicles.

The U.S. Congress passed into public law the Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976. One objective of the law was to work with industry to improve batteries, motors, controllers, and other hybrid-electric vehicle components. The goal was to double fuel efficiency in all vehicles.

In 1990, CARB adopted a requirement that 10 percent of all new cars offered for sale in California in 2003 and beyond must be zero-emission vehicles (ZEVs). But in 1998, CARB modified those requirements. The change allowed manufacturers to satisfy up to 6 percent of their ZEV requirement with automobiles that qualify as partial ZEVs. Today, only FCEVs running on pure hydrogen and BEVs qualify as ZEVs.

In 1991, the United States Advanced Battery Consortium (USABC) began a project that would lead to the production of a battery that would make electric vehicles a viable option for consumers. The initial result was the development of the nickel-metal hydride (NiMH) battery. This battery can accept three times as many charge cycles as lead acid, and can work better in cold weather.

In 1996 GM began to lease its EV1, the first modern electric car. Its range was 70 to 100 miles. An upgraded version with an NiMH battery was available 3 years later with 100 to 140 miles of range. By 1998, a few electric vehicles were made available (but very few were purchased or leased) in the United States, including Honda's EV Plus, GM's EV1 and S-10 pickup, Ford's Ranger pickup, and Toyota's RAV4 EV.

In 2003, CARB ended its initiative to require zero-emission vehicles. GM, along with Toyota and others, formally ceased production of electric vehicles. However hybrid and electric vehicle development did continue without the mandate. For example:

- From 2004 to present many hybrid vehicles have been produced and are being sold at great numbers.
- In 2008, the Lotus Elise-based, Lithium Ion Tesla Roadster went on sale.
- In 2010, Chevrolet introduced an "extended range" BEV called the Volt, this car was named car of the year in 2011.
- In 2010, Nissan released a BEV called the Leaf and some mid-sized hybrids. Also, Mitsubishi released a BEV called the Mi-MEV.
- In 2011, many new BEVs and plug-in hybrids were introduced including the TESLA Model S; Honda Fit; Ford Escape, Fusion, Focus, and C-MAX; Smart ED; and Toyota Prius Plug-in and a Tesla-powered Toyota RAV4.
- As of 2018, the BMW i3, Chevy Bolt, Fiat 500e, Hyundai Ioniq, Kia Soul EV, Tesla Model X and Model 3, all BEVs or plug-in hybrids, are available and more are planned. All of these will make the near future the busiest years in electric cars since early in the twentieth century.

Zero-Emissions Vehicles

BEVs use electrical energy stored in batteries to power the traction motors **(Figure 36–2)**. BEVs have zero emissions. The only emissions related to a BEV are those released when coal, oil, or natural gas are used in power plants to generate the electrical energy required to recharge the batteries. The use of hydroelectric, wind, sunlight, or other renewable sources to generate electricity would eliminate all emissions associated with EVs. It is impossible to have zero emissions from an internal combustion engine.

Fuel cell electric vehicles (FCEVs) are also zero-emission electrically-powered vehicles but they rely on hydrogen as the fuel. There is no infrastructure for dispensing hydrogen, although fuel reformers can be used to extract hydrogen from other fuels. The use of reformers does cause the release of some emissions.

Advantages

With a BEV, there is the convenience of being able to "fill up" at home, eliminating the need to go a gasoline station. There are also some remote charge stations available in a few states **(Figure 36–3)**. The cost to refuel is very low; typically it costs less than $4.00.

Because of the limited range, BEVs are ideal for commuting or traveling within a limited area. Studies have shown that 80 percent of commuters travel fewer than 40 miles per day; this is well within the range of most BEVs.

Cost

The initial cost of a BEV tends to be higher than a conventional vehicle. This is due to their limited availability and the cost of the batteries. Current estimates put the cost of a typical EV battery at $10,000 to $15,000. New batteries developed to extend the range of a BEV are, unfortunately, more expensive. However, as more BEVs are produced and sold, their cost should decrease. The initial cost of an EV is reduced by a federal tax break that lowers the cost by $7,500, and some states offer further subsidies.

The motor in an EV has few moving parts. The armature or rotor of the motor is the only moving

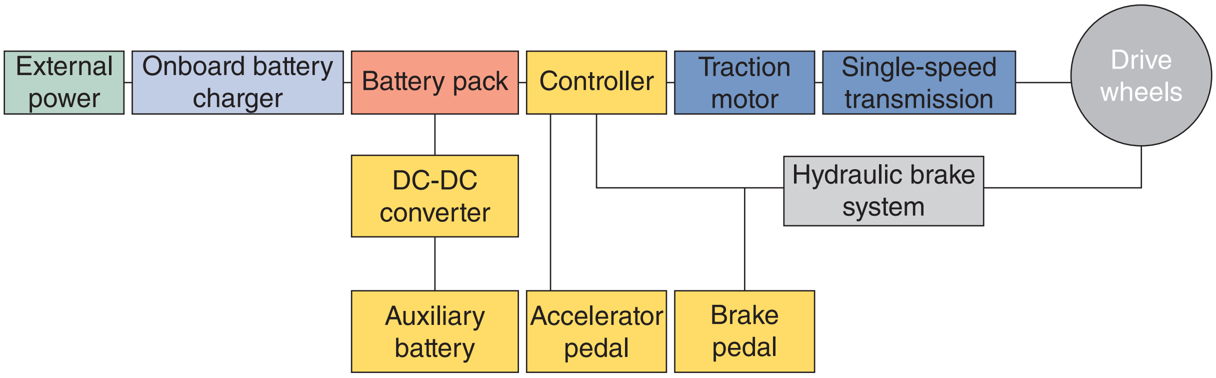


FIGURE 36–2 The major components of a BEV.

FIGURE 36–3 An example of a public charger for EVs.

part. An engine has hundreds of moving parts, each requiring clean lubrication and are subject to wear. The rotor in a motor is normally mounted on sealed bearings and requires little, if any, additional lubrication throughout its life. The controller and battery charger are electronic units and require little or no maintenance. The batteries also are sealed and maintenance free. All of these reasons explain why a BEV has very low maintenance costs.

The true cost of driving a BEV depends on the cost of electricity per kilowatt/hour (kWh) and the efficiency of the vehicle. Actual operating costs are reduced by making the cars lighter, more aerodynamic, and with less rolling resistance.

Disadvantages

Perhaps the biggest disadvantage of a BEV is the limited driving range. The typical usable range between recharging the batteries is 50 to 150 miles. Although some new battery designs have extended this range, long-distance travel in a BEV is still not practical for everyone. Although newer BEVs have extended ranges, for example the Tesla P100D model can cover 315 miles on a full charge and the Chevy Bolt will go more than 200 miles on a full charge. It is important to understand that a battery's size and amount of power it stores does not directly determine the range of an EV. Remember, the smallest, lightest, and most aerodynamic electric vehicles will provide the longest range, with the same battery.

Long recharge times are also a problem. In addition to the recharge times, there is a problem of where they can be recharged. If the owner is at home, the charger can be connected to the electrical system of the house. Most EV manufacturers offer special home charging stations that shorten the required charge time.

Major Parts

The basic systems in a BEV are a high-voltage battery pack, battery management system, the motor(s) and supporting system, 12-volt system, converter and/or inverter, and the driver's displays and controls **(Figure 36–4)**. The propulsion system has a traction motor that provides the power to rotate the drive wheels and a controller to control the power output of the motor. The 12-volt system supplies the electrical power for the vehicle's accessories, such as the radio and lights. An inverter and converter are required to convert AC to DC and DC to AC electricity. A converter is used to reduce the system's high voltage in order to charge the 12-volt battery and to provide power to the low-voltage systems.

Energy and Power

You may recall that energy is the ability to do work and power is the rate at which work is done. A common automotive expression of power is horsepower. Although this term is used when discussing the motor in an electric vehicle, the correct way to express power is using the term kilowatt. One kilowatt (kW) is the international unit to measure power (not only electrical); a kilowatt is 1,000 watts. One kW equals 1.34 horsepower and 746 watts equals 1 horsepower. Therefore, a 149 kW motor can provide about 200 hp. Electric motors provide a maximum torque when it is spinning at zero rpm. So, it is very hard to compare the power output of an electric motor to a gasoline-powered engine that produces a maximum amount of torque at a much higher engine speed **(Figure 36–5)**.

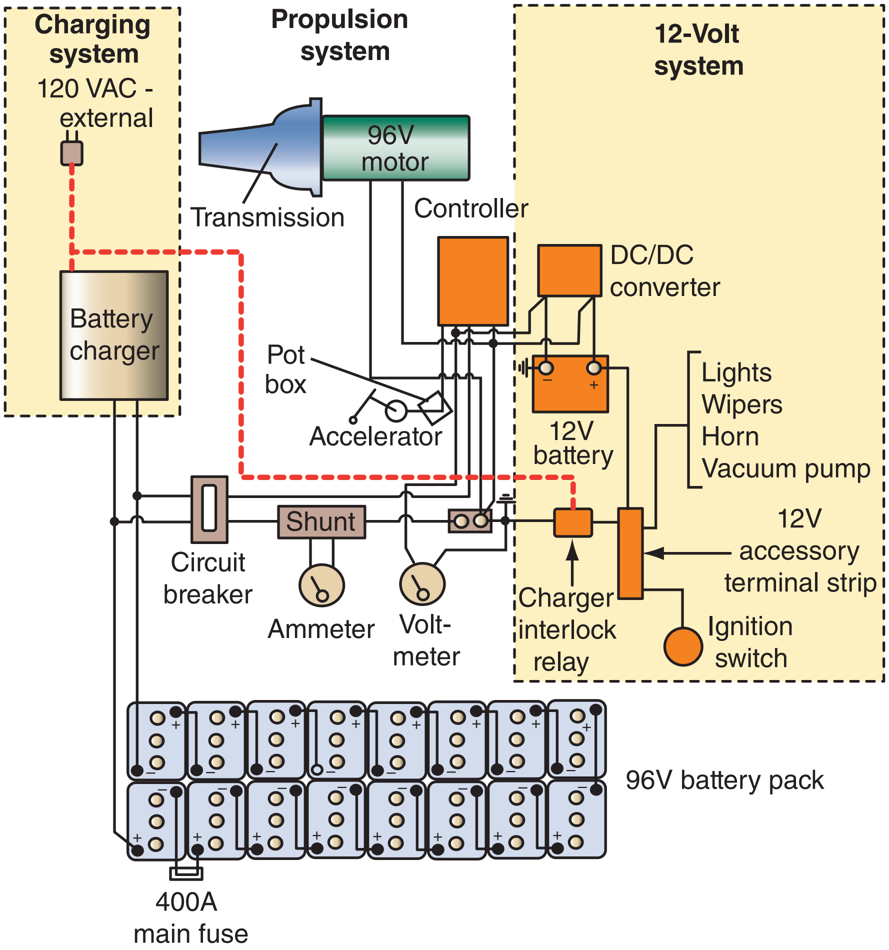


FIGURE 36–4 A basic wiring diagram of an electric vehicle.

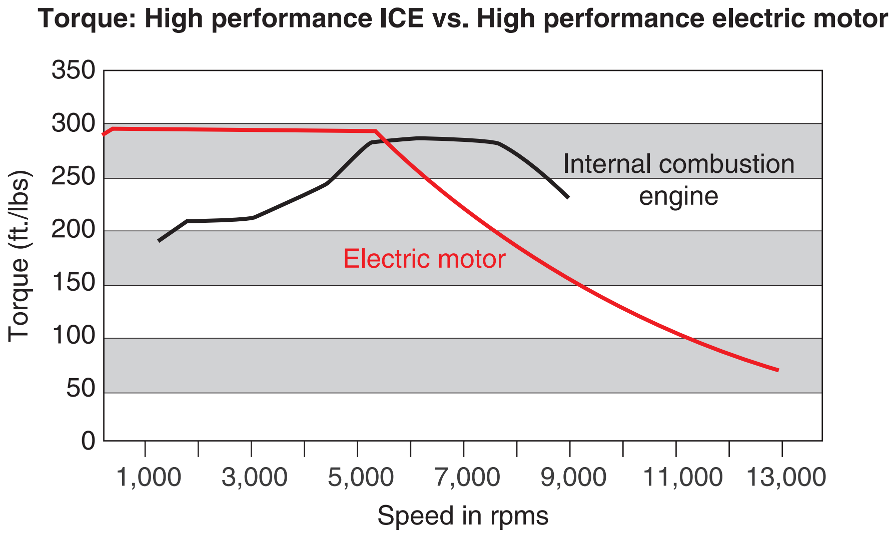


FIGURE 36–5 A comparison of the amount of torque produced by a gasoline engine and an electric motor.

The power rating of an electric motor (or gasoline engine) indicates how quickly energy can be changed into work, such as during acceleration. An electric motor relies on the energy stored in a battery or some other source. The amount of energy available is expressed in kilowatt hours (kWh). Kilowatt hours express what can be accomplished by 1 kilowatt acting for 1 hour. For example, when a light bulb with

a power rating of 100W has been on for 1 hour, it has used 100 watt-hours (0.1 kWh). This is the same amount of energy used to keep a 50W light bulb on for 2 hours.

When comparing systems and the available power of a battery, it is important that a battery's rating is looked at in regards to the system's voltage. If a battery has a rating of 100 amp-hours and the battery provides 12 volts, the amp-hours should be multiplied by the voltage to determine the total energy available. In this case, the energy source can provide 1,200 watt-hours (1.2 kWh).

So if we look at a 300 V battery pack rated at 24 kWh, the battery can provide 80 amps at 300 volts for 1 hour. Keep this in mind when looking at the ratings of batteries and battery chargers. Also, do not be fooled by the manufacturers' estimates.

Nissan says the 24 kWh pack in a Leaf provides for a 100-mile drive range. That means 240 watts are needed to provide enough energy for 1 mile of travel. So, theoretically the battery should supply enough energy for 100 miles of travel. This number is close to what the EPA has estimated as the driving range of the Leaf **(Figure 36–6)**.

The traction motors are either AC or DC motors and are specifically designed for this use. Most production BEVs use AC motors and FCEVs and many conversion EVs use a DC motor. The latter is a consequence of cost. DC motors can be powered directly by the batteries, whereas AC motors require inverters to change the DC voltage stored in the batteries into the AC required by the motors. FCEVs have a DC motor because the electricity generated by the fuel cell is not AC; therefore, there is no need for an inverter or other similar conversion equipment.

The cost of high-voltage batteries has declined through the years. For example, the Nissan Leaf has a 24 kWh battery. If batteries cost $1,000 per kWh, the battery in a Leaf would cost $24,000 and would

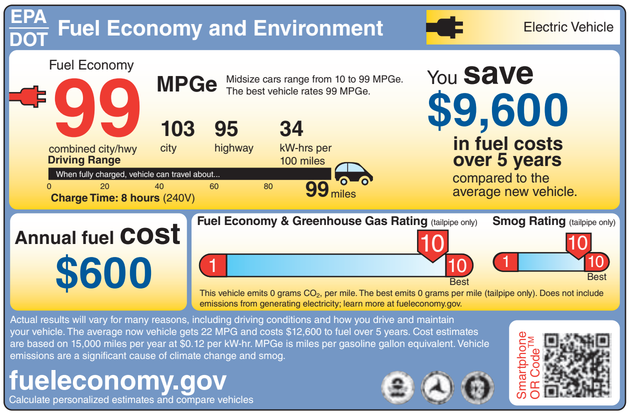


FIGURE 36–6 The new Monroney sticker for electric vehicles.

make it nearly impossible for Nissan to sell the car for $32,800 before incentives. At $400 per kilowatt hour, the battery would only cost $9,600. This has been a focus of the U.S. Department of Energy that has set a goal of providing car batteries for $250 a kilowatt hour.

Electric Motor

In most EVs, there is no transmission because the rotary motion, or torque, of the motor can be applied directly to the axle drive gears. A motor is capable of providing enough torque throughout its speed range to move the vehicle without torque multiplication. With an electric motor, instant torque is available at any speed. The entire rotational force of a motor is available the instant the accelerator pedal is pressed. Peak torque stays constant to nearly 6,000 rpm, and then it begins to slowly decrease. An electric motor produces the most torque when it is operating at high speeds.

The wide torque band eliminates the need for multi-speed transmissions. There is no need for a reverse gear either, since switching the polarity of the stator will cause the rotor to turn in reverse. The absence of a typical transmission saves weight and makes the power train much less complex.

Controller

The controller in a BEV controls the voltage and current to the traction motor(s) in response to the driver's input. The controller may also reverse the current flow to the motor when reverse gear is selected.

In electric vehicles with DC motors, a simple variable-resistor-type controller can be used to regulate the speed of the motor. With this type of controller, full current and power is drawn from the battery all of the time. At slow speeds, when full power is not needed, a high resistance in the resistor reduces current flow to the motor. With this type of system, a large percentage of the energy from the battery is wasted as an energy loss (heat) at the resistor. High speeds are the only time all of the available power is used.

Modern controllers for AC motors adjust motor speed through pulse width modulation (PWM). Pulse width is the length of time, in milliseconds, that a component is energized. Controllers rely on transistors to rapidly interrupt the flow of electricity to the motor. High electrical power (during high speed, acceleration, and/or heavy loads) is available when the intervals for the stopping of current flow are short. During slow speeds, little power is needed and the intervals of no current flow are longer **(Figure 36–7)**.

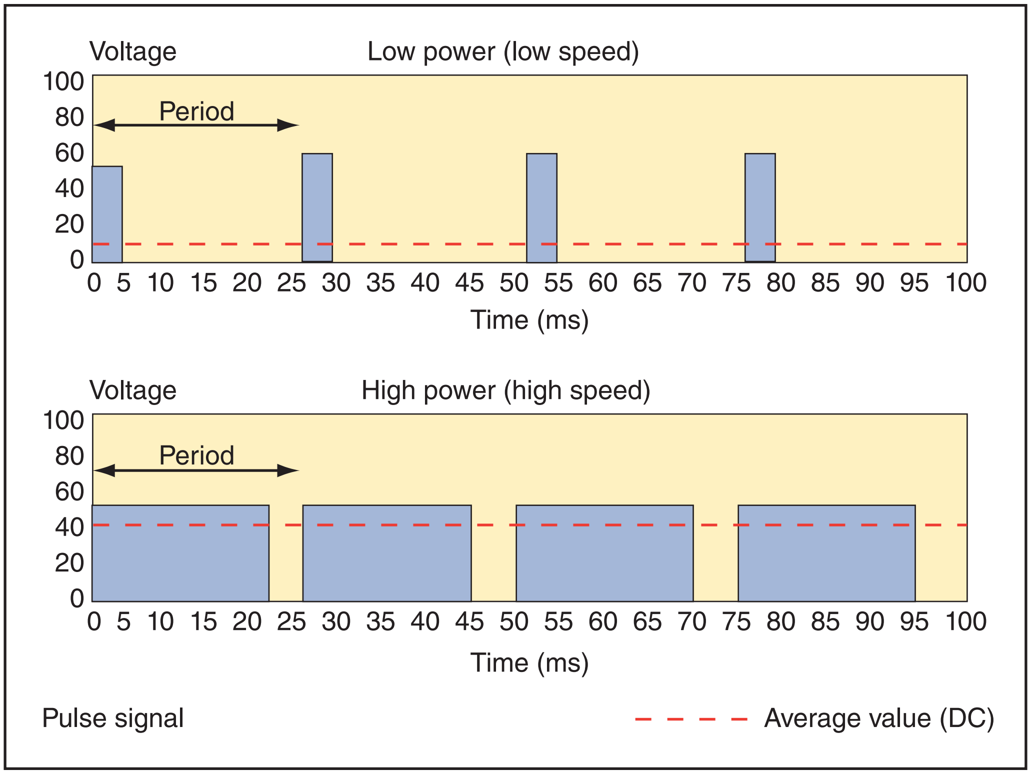


FIGURE 36–7 An explanation of pulse width modulation at low and high speeds.

Inverter/Converter

Remember, a storage battery holds only DC voltage. An AC power inverter converts the battery's DC voltage into three-phase AC voltage to power the traction motor. The output voltage varies according to the demands of the driver and the vehicle. Normally the inverter is controlled by an electronic control module. The output from a typical inverter is constantly being calculated using input signals from the accelerator pedal, the motor's shaft speed sensor, the motor's direction sensor, and the brake pedal.

The inverter is liquid-cooled and the heat from the inverter can be used to supplement the passenger compartment's heater to save energy. This is done automatically whenever the controls are set for heat.

Battery Charging

Refueling a BEV simply means charging the batteries. Recharging involves connecting a battery charger to a source of electricity and connecting the charger to the battery pack. Battery chargers **(Figure 36–8)** may be internal (in the vehicle) or external (at a fixed location). There are advantages and disadvantages to both. An on-board charger allows the batteries to be recharged wherever there is an electrical outlet. The disadvantage of on-board chargers is their added weight and bulk. To minimize this, manufacturers normally equip the vehicles with low power chargers that require long charge times. External chargers, however, force the driver to charge the batteries at specific locations but offer more power and decrease the time required to charge the batteries. Some BEVs with off-board chargers also have a convenience charger. These on-board chargers plug into standard 110-volt outlets and allow the driver to recharge batteries wherever electricity is available.

Most EVs have an on-board charger that uses a rectifier circuit to transform AC from the electrical grid to DC, which is necessary for recharging the battery pack. The rectifier can only handle a certain amount of power and develops a great amount of heat while it is changing AC to DC. Rectifiers can be built to handle more power and heat, but they would cost quite a lot. Based on these concerns, most conventional charging stations in North America and Japan are based on 240V/30A service. This power level seems to be a safe limit for the rectifiers. But, charging at these levels takes several hours to recharge the battery pack. The required time varies with the size and type of battery and battery charger.

A solution to these problems is to use an external charging station capable of delivering DC directly to

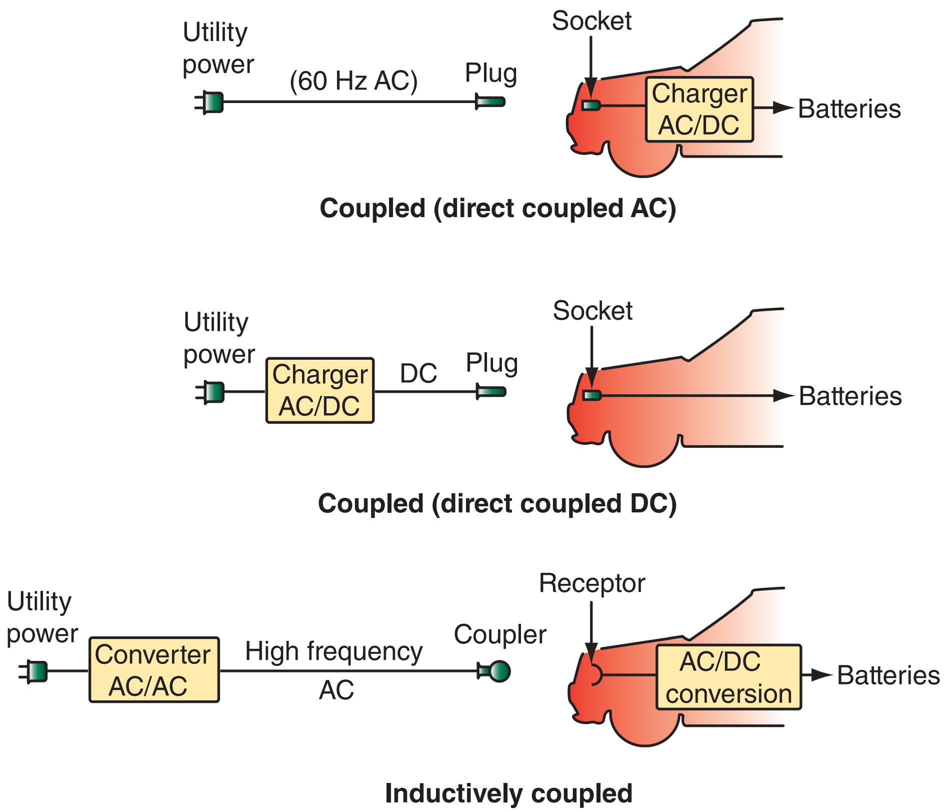


FIGURE 36-8 EV battery chargers may be internal (onboard) or external (offboard).

VOLTAGE TYPE	CHARGE LEVEL	MAX. VOLTAGE	PEAK CURRENT
AC	1	120 VAC	16A
AC	2	240 VAC	32A (2001)/ 80A (2009)
DC	1	450 VDC	80A
DC	2	450 VDC	200A
DC	3	600 VDC	400A

FIGURE 36-9 Current standards for the various charging levels.

the vehicle's battery pack. Doing this would call for dedicated chargers at permanent locations. These new chargers may be able to recharge a battery in less than 20 minutes. They use sophisticated electronics to monitor the cells and regulate the charging voltage and current. Being able to quickly charge the batteries would certainly make an electric vehicle more practical. The charging setup using high voltage and high-current is called a DC Fast Charge and is also referred to as level-3 charging **(Figure 36–9)**.

Charger to Vehicle Connectors

There are two basic ways a BEV is connected to an external source of electricity for charging. One is the traditional plug, called a conductive coupling. The coupling is plugged into a receptacle on the vehicle where it connects into the wiring for the batteries. The other type of coupling is called an inductive coupling.

Inductive charging transfers electricity from a charger to the vehicle using magnetic principles. To charge the batteries, a weatherproof paddle is inserted into the vehicle's charge port **(Figure 36–10)**. The paddle and charge port form a magnetic coupling. The external charging unit sends current through the primary winding inside the paddle. The resulting magnetic flux induces an alternating current in the secondary winding, which is in the charge port. The connection is basically a transformer with the primary winding in the paddle and the secondary winding in the vehicle. The induced AC is then converted to DC (within the vehicle) to recharge the batteries.

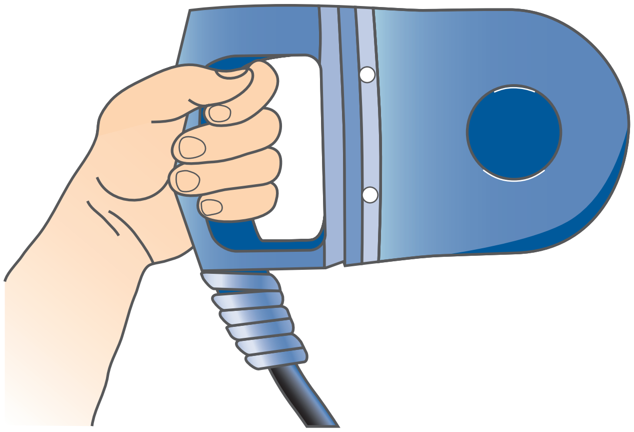


FIGURE 36–10 An inductive charging connector (paddle).

There is no metal-to-metal contact between the charge paddle and the charge port of the vehicle. This system provides a safe and easy-to-use way to recharge the batteries.

Inserting the paddle begins the charging process. The insertion of the paddle completes a communication link between the charger and the vehicle. The charger displays what percent of charge remains in the batteries and an estimate of the time needed to fully charge the batteries.

This link also allows the charging unit to enter into self-diagnostics and prevents the vehicle from being driven while the paddle is inserted in its port. If the charging cable becomes damaged or cut, power will shut off within milliseconds. The charging process ends immediately after the paddle is removed from the port.

Conductive Charging With a conductive charger, a connector safely makes the link between the power supply and the vehicle's charge port. The connector makes a weatherproof direct electrical connection to the vehicle's charge port. The connector has multiple pins that carry data. This data is used to control the action of the charger based on the conditions of the battery pack. External chargers are available in many different sizes and can be wall or pedestal mounted.

Conductive charging can be accomplished with a fuel nozzle looking connector called the ODU **(Figure 36–11)**. The connector has many round male pins that mate to female ends in the vehicle. Similar to adding fuel to the vehicle, the connector is placed into an opening on the vehicle and refueling or recharging can take place.

Recharging Standards and Regulations

Like nearly everything designed for an automobile, there are standards and regulations that pertain to charging a high-voltage battery pack. The most recognized standard is the North American standard for electrical connectors for electric vehicles as defined by the Society of Automotive Engineers (SAE). This standard is referred to as the "SAE Surface Vehicle Recommended Practice J1772, SAE Electric Vehicle Conductive Charge Coupler." Basically this standard covers the basic physical, electrical, communication protocol, and performance requirements for an EV's conductive charge system and coupler. The purpose of the standard is to ensure EVs from different manufacturers will not need special or unique chargers or charging connectors.

FIGURE 36–11 An ODU connected to an electric vehicle.

Early electric vehicles like GM's EV1 used inductive charger couplers. These were replaced with conductive couplers, in 2001, according to the new SAE J1772 standard initiated by the California Air Resources Board (CARB). AVCON manufactured a rectangular connector compliant with the SAE J1772 specification and was capable of delivering up to 6.6 kW of electrical power. The AVCON conductive interface **(Figure 36–12)** was also used by the Ford Ranger EV truck and the Honda EV Plus. The connector had a rectangular charging head that plugged into an AVCON inlet mounted on the vehicle. Many public EV charging stations, funded by the CARB, relied on conductive AVCON charging connections.

In 2008, CARB proposed changes to the 2001 CARB regulations that were aimed at higher charging current than the AVCON could handle. This led to the design of a new connector that would be used starting in 2010. As a result all AVCON charging stations were converted to the new J1772 or phased out starting in 2011.

With the advent of improved chargers, and the desire to charge with AC and DC voltage, new specifications for the J1772 ODU have been released.

Courtesy of AVCON Corporation.

FIGURE 36–12 An AVCON charging connector.

Using AC and DC at the same time to charge a battery is faster than the previous regulated process. Therefore the new J1772 standards allows for a single inlet in the vehicle and a single plug to be used for both AC and DC charging. The new J1772 standard incorporates AC Levels 1 and 2 (up to 80 amps), and DC Levels 1 and 2 (up to 200 amps).

The new "combo" connector is similar to the first-generation J1772 plug but also has pins to fit into the lower portion of the inlet. The first-generation J1772 plug fits into the upper part of the inlet, while DC charging takes place across two dedicated pins across the bottom of the connector. Above these pins is a round receptacle that has five pins **(Figure 36–13)**. These pins complete the circuit from the electric grid to the vehicle through AC power Line 1 and AC power Line 2 pins and a designated ground pin. The two other pins are for Proximity Detection and the Control Pilot. The Proximity Detection feature prevents the car from moving while it is connected to the charger. The Control Pilot is the communication line used to transfer information between the charger and vehicle in order to safely and efficiently charge the battery. When the male and female halves of the connector are not mated, there is no voltage at the pins, and charging does not begin until it is commanded by the vehicle.

FIGURE 36–13 The female connections for a SAE J1772 connector.

This combination connector allows for DC-fast charging and has been endorsed by Audi, BMW, Chrysler, Daimler, Ford, General Motors, Porsche, and Volkswagen. Their goal is to provide a way for consumers to charge their EVs in 15 to 20 minutes.

CHAdeMO Protocol The new SAE standard offers a number of advantages over the competing CHAdeMO standard **(Figure 36–14)**. However, CHAdeMO (short for "charge and move") is already well established in Japan, and is also used by most existing vehicles and chargers in the North American market. In spite of CHAdeMO's current dominance, there is strong support for J1772.

The connector currently used for DC-fast charging on the Nissan Leaf and Mitsubishi i vehicles

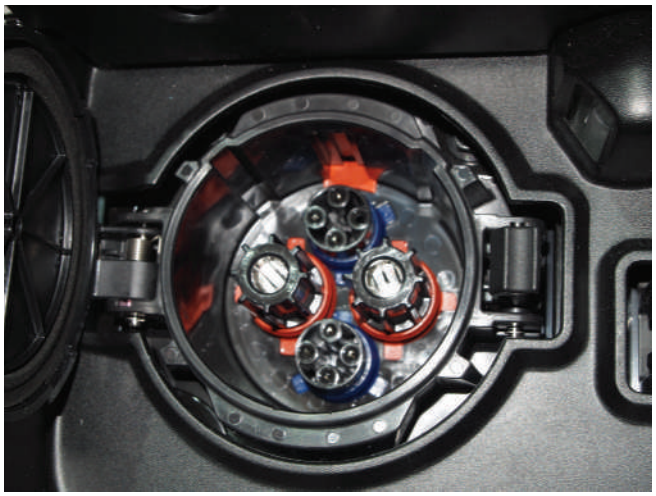


FIGURE 36–14 A CHAdeMO on-vehicle connector.

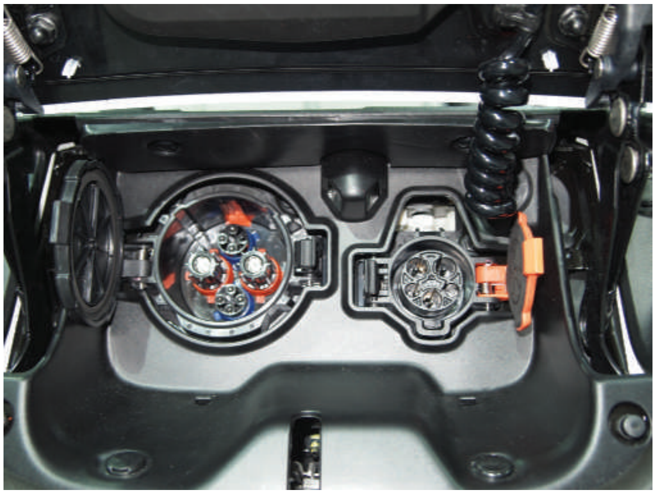


FIGURE 36–15 The Nissan Leaf has receptacles for a CHAdeMO and SAE J1772 connector.

is based on the CHAdeMO standard. Some Asian EV models have two vehicle electric inlets, one for CHAdeMO DC charging and one for J1772 AC charging **(Figure 36–15)**.

Charging Precautions

There are three primary things that affect the required time to recharge the batteries: the current state of charge of the battery, the chemicals used inform the cells of the battery, and the type of charger used.

Each EV has a specific charging procedure. These procedures vary with the type of charger, charger coupling, and battery. Always follow the procedure for the vehicle being worked on. The following are some general guidelines to follow:

- Make sure the gear selector is in the park position and the parking brake is applied before charging.
- Before charging, make sure the motor switch is off and the key is removed.
- To avoid getting an electric shock, never operate the charger with wet hands.
- Avoid charging under high temperatures or direct sunlight.
- Never touch the terminals of the conductive terminals on the vehicle or coupler; you may get an electric shock.
- Do not modify the charge coupler.
- The charge coupler should be firmly installed without any tension on the cable.
- If the charge coupler is damaged, repair or replace it as soon as possible.
- Make sure water, dirt, or other foreign objects do not enter the charge port on the vehicle.
- Do not disconnect the charge coupler until the batteries are fully charged, unless it is necessary to prematurely stop charging.

Accessories

Some systems, such as the radio, lights, and horn, operate the same way as they do in a conventional vehicle. Other systems, such as the power steering and power brakes, require additional small electric motors, which have an impact on the vehicle's driving range. Because all accessories and auxiliary systems operate on electricity, their electrical power needs reduce the capacity of the battery.

HVAC

To meet federal safety standards, all vehicles must be equipped with passenger compartment heating and windshield defrosting systems. Vehicles with an internal combustion engine use the heat of the engine's coolant to warm the passenger compartment. In a BEV, there is no engine and therefore there is no direct source for heat. The heat must be provided by an auxiliary heating system. Some electric vehicles use an electric resistance heater with a fan.

Other BEVs have liquid heaters. Water, or a mixture of water mixed with ethylene glycol, is held in a tank. The liquid in the tank is kept heated by a resistive heating element submerged in the tank. When the driver turns on the heating system, a small pump circulates the heated liquid through a heater core in the passenger compartment. A fan moves air over the core to provide heated air.

BEV air-conditioning systems also have a significant impact on the driving range. In many cases, the air-conditioning system uses a high-voltage motor to rotate the compressor. Obviously, the energy used to power the air conditioning puts a drain on the battery pack. The amount of energy consumed by the air-conditioning system depends on how often it is used, the outside temperature, and the selected temperature for the passenger compartment.

Power Brakes

Many power brake systems use engine vacuum and atmospheric pressure to multiply the effort applied to the brake pedal during braking. Because there is no engine in a BEV, there is no direct vacuum source. However, normal vacuum assist power brake

systems can be used if fitted with an electric vacuum pump. These pumps are similar to those used on diesel engine vehicles. The pump may be connected to a storage tank. The tank reduces the time the pump needs to operate and therefore minimizes the effect the pump has on driving range.

Another type of power brake system uses hydraulic pressure, from a pump, to reduce the pedal effort required to apply the brakes. Some BEVs use an electric pump to provide the necessary hydraulic pressure **(Figure 36–16)**. These systems are called electro-hydraulic brake systems. Because both types of power brake systems for BEVs operate on electrical power, brake boost is available at all times.

Power Steering

Hydraulic pressure is often used to reduce steering effort. This pump can be driven by an electric motor, which is how some BEVs are equipped. The control for the pump can be programmed to provide more assist at lower speeds, and less at higher speeds. The system can also be programmed to only run the pump when it is needed; this reduces the effect power steering has on the driving range. These systems are called electro-hydraulic steering systems.

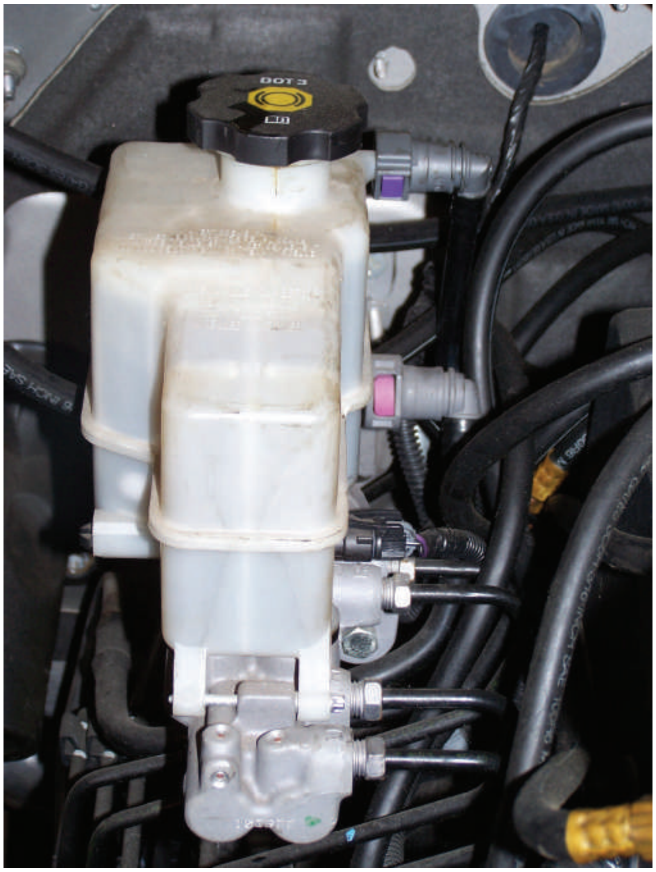


FIGURE 36–16 The master cylinder and pump assembly for an electro-hydraulic brake system.

Many power steering systems are purely electrical and mechanical systems. An electric motor moves the steering linkage. These systems are programmable and the energy consumed by the motor depends on the amount the steering wheel is turned. While driving straight, the motor may not run. However, when the steering wheel is fully turned, the motor is drawing its maximum current.

Driving a BEV

Driving a BEV is like driving any other vehicle but with some notable exceptions. There is still a steering wheel, a brake pedal, and an accelerator pedal. A BEV typically has adequate acceleration and can travel at highway speeds. The biggest difference for the driver is that attention must be paid to the consumption of energy. Failure to minimize consumption and carefully plan travel routes can lead to reduced power and a need to recharge the batteries at inconvenient locations or times. If the batteries are not charged, the vehicle will not move. Also, one of the things most drivers notice is the lack of engine noise. BEVs run silently and this has been a concern since pedestrians cannot hear an approaching BEV.

Starting

The biggest adjustment a driver needs to make when preparing to drive a BEV is starting it or getting it ready for action. A BEV has no noise or vibration when it is ready to go. The driver must look at the instrument cluster to determine it is ready. Make sure the gear lever is in the PARK position and that the parking brakes are on. The accelerator should never be depressed during starting.

The ignition (motor) switch has several positions. One is "lock," during which the traction motor is off and the steering wheel is locked. The key can be removed only at this position. "Accessories" allows some accessories to work but the traction motor is off. "START" actually gets the traction motor ready to work, and "ON" is the normal position for driving. Never leave the switch in the ON position when the vehicle is not in use.

To turn on the traction motor, turn and hold the motor switch to START with the brake pedal depressed until the READY light in the instrument cluster comes on **(Figure 36–17)**. On some vehicles, a buzzer will sound when this happens. Once the READY lamp is lit, the motor switch can be released

FIGURE 36–17 The instrument panel displays for a typical EV.

to allow it to move to the ON position. At this point, the traction motor will run when the accelerator is depressed and all accessories are ready to operate. If the READY light does not illuminate during the start process, there is a problem with the traction motor or its circuit, or the auxiliary battery is discharged.

Driving and Braking

Most BEVs have a single-speed automatic transmission and the gearshift lever has five positions **(Figure 36–18)**. Normally the shift lever can only be shifted out of "P" when the motor switch is in the ON position. When moving out of "P" into "D" or "R," the brake pedal must be depressed. It is important that the accelerator is not depressed when shifting gears. Doing this can cause the vehicle to unsafely and quickly move and can cause damage to the motor. Once the shift lever has been moved and with the brake pedal still depressed, the parking brake can be released.

To begin moving, press the accelerator. Drive normally with the realization that the accelerator is the only thing that controls vehicle speed. When the accelerator is released, vehicle speed will decrease because the wheels are now turning the motor that just became a generator.

The Chevy Bolt, and other BEVs, has a paddle behind the steering wheel that allows the driver to slow down without applying the brake pedal. When the paddle is engaged, the kinetic energy of the moving vehicle is converted to electrical energy to charge the battery. Also the Bolt offers one-pedal operation. When the vehicle is operating at low speeds and the driver lets off the accelerator, the vehicle will slow down while the motor/generator charges the battery. To back the car up, bring the vehicle to a complete stop. Then depress the brake pedal and move the shift lever into the "R" position. It is important to keep in mind that a BEV can accelerate just as quickly in reverse as it does in drive. However, it is more difficult to steer any vehicle in reverse therefore the accelerator should be gently pressed when backing up.

To park and shut down the vehicle, come to a complete stop. Then apply the parking brake. While depressing the brake pedal, move the shift lever to the "P" position. Now turn the motor switch to the LOCK position and remove the key.

FIGURE 36–18 The gear shifter positions for an EV.

Maximizing Range

The driving range of a BEV is reduced by cold weather (requiring use of heater), warm weather (requiring use of the air conditioner), and the condition and age of the battery. There are certain other things a driver can do to extend the range and the life of the batteries.

- Avoid high-speed driving. Maintain a moderate speed on highways.
- Avoid driving up inclines.
- Avoid frequent speed increases or decreases. Attempt to drive at a steady pace.
- Avoid unnecessary stopping and braking.
- Avoid full throttle acceleration, accelerate slowly and smoothly.

- The vehicle should be well maintained, including proper tire inflation pressure.
- Unnecessary weight in the vehicle will shorten the driving range.

Ford Focus

The Ford Focus Electric **(Figure 36–19)** uses a 23 kWh, liquid-cooled lithium-ion battery pack that provides an all-electric range of about 100 miles (160 km). It relies on a synchronous PM electric motor rated at 107 kW (143 hp) and 184 ft.-lb of torque. The motor's output is transferred to the front wheels through a single-speed transmission.

The L-shaped battery pack is located under the rear seat and between the rear wheels. The battery uses a liquid cooling and heating thermal management system to precondition and regulate the temperature of the battery. The thermal management system heats or chills a coolant before passing it through the battery's cooling system.

The Focus has a 6.6 kW on-board charger. A full recharge is possible after 3 to 4 hours. This requires plugging into Ford's 240 volt, 32 amp Level 2 home recharging unit with a J1772 connector **(Figure 36–20)**. The Focus also is equipped with a 120-volt cord that allows the charger to be connected to a standard household outlet. At 120 volts, the battery pack can be recharged in close to 20 hours.

The instrument cluster allows the driver to monitor energy consumption. There is a smartphone application that allows the driver to remotely track the car's charging status.

Ford also provides a 2.5 kilowatt rooftop solar panel system through the solar system manufacturer Sun Power. The solar panels can produce an average of 3,000 kWh annually, theoretically enough to accommodate a customer who drives 12,000 miles a year.

FIGURE 36–19 A Ford Focus EV.

FIGURE 36–20 An at-home high-voltage charger for a Focus EV.

The charging port is in the left front fender **(Figure 36–21)**. The port illuminates when the charger's cord connector is plugged into the charge port. A blue light indicates GO and that the charger is connected and charging.

FIGURE 36–21 The charging port on a Focus is on the left front fender.

Nissan Leaf

The Nissan Leaf **(Figure 36–22)** is a true ZEV with zero tailpipe emissions. It is rated at 106 MPG-e for city driving and 92 MPG-e on the highway and 99 MPG-e for combined city and highway driving. The Leaf is equipped with an AC synchronous motor that can provide up to 107 hp (80 kW) and 207 pounds-feet of torque to the front drive wheels.

The EPA estimates the driving range for a Leaf with a full battery is 73 miles (117 km), although Nissan advertises a range of 100 miles (161 km). There are many things that can explain the discrepancy but those will not be discussed here; simply look at the things that affect driving range and you will find the reasons why the two disagree.

Power from the motor moves through a single speed reducer-type transmission. But through electronic controls, there are two optional forward drive modes: Drive and Eco. Drive provides quicker acceleration, but uses a great amount of the battery's reserve. Eco extends the driving range by limiting acceleration and reducing the power to the climate control system. It also provides additional brake regeneration, causing the car to decelerate more rapidly, but also adding electrons to the battery.

The battery is a 24 kWh lithium manganese (Li-Ion) that is capable of delivering up to 90 kW of power. The battery pack **(Figure 36–23)** is made up of 48 modules and each module contains four laminated flat cells, arranged in three stacks. The 192 stacked laminar cells have lithium manganate cathode. The battery weighs about 660 pounds (272 kg), and is located under the floor pan directly beneath the front and rear rows of seats. The battery pack is air cooled (and heated when necessary) to protect the cells.

Charging time varies with the type of charging used. Customers can purchase a 240V home charging station through Nissan. Some Leaf models

FIGURE 36–22 A Nissan Leaf.

FIGURE 36–23 The battery pack in a Leaf.

have a Quick Charge Port with a 3.3 kW on-board charger. With this charger, the battery can be fully recharged by a 220/240 volt 30 amp within 8 hours.

The Leaf's charging port at the front of the car has two charging inlets **(Figure 36–24)**. One is a standard J1772 connector for Level 1 and 2 recharging. The other is a Level 3 DC connector that uses the CHAdeMO protocol.

The Leaf also has an auxiliary 12-volt lead-acid battery that provides power for the basic systems and accessories in the car, such as the sound system, headlights, and windshield wipers. An interesting touch is that some models of the Leaf have a small solar panel on the rear spoiler **(Figure 36–25)** to help trickle charge this auxiliary battery.

Telematics The Nissan Leaf uses an advanced telematics system called Carwings. Carwings is

FIGURE 36–24 The Leaf's charging port at the front of the car and the two charging inlets.

FIGURE 36–25 The solar panel built into the spoiler on some models of the Leaf.

FIGURE 36–26 The "carwings" display in a Leaf.

connected any time the car is within the range of a cell tower and provides information to the driver, such as the car's position, remaining range, and the location of charging stations available within that range. The system also monitors and compiles information about distances traveled and the amount of energy consumed **(Figure 36–26)**. It also provides daily, monthly, and annual reports of those and that information can be viewed on the car's digital screens. Through Carwings, cell phones can be used to remotely turn on the air conditioner and heater and reset all charging functions.

Pedestrian Sounds Because BEVs emit very little noise while they are moving, the Leaf is programmed to emit digital warning sounds, one for forward motion and another for reverse, to alert pedestrians, the blind, and others that it is moving close to them. This is called the Vehicle Sound for Pedestrians (VSP) system. This sound system moves from 2.5 kHz at the high end to a low of 600 Hz, which makes it audible for all age groups. The sound stops when the Leaf reaches 19 mph and begins again when the Leaf slows to less than 16 mph. The VSP system is controlled by a computer and synthesizer and the sound is emitted from a speaker in the driver's side front wheel well.

Mitsubishi i-MiEV

The Mitsubishi i-MiEV (*Mitsubishi innovative Electric Vehicle*) is an EV hatchback **(Figure 36–27)**. The car has a permanent magnet synchronous motor mounted on the rear axle. The water-cooled 49 kW motor can provide 66 hp and 145 pound-feet of torque. The motor is placed above the rear axle and the 16 kWh lithium-ion battery pack and the motor control unit is under the floor. The motor's output is sent to the rear wheels through a single-speed fixed reduction transmission.

The EPA initially rated this Mitsubishi capable of providing a combined fuel mileage rating of 112 MPG-e. The estimated driving range in the city is 98 miles (158 km).

The 16 kWh SCiB battery pack uses lithium-titanate oxide in the anode, which provides increased safety and decreased charging times. The battery pack is made up of two 4-cell modules placed vertically at the center of the pack and ten 8-cell modules placed horizontally, these are connected in series. These 88 cells provide 330V.

FIGURE 36–27 A Mitsubishi i-MiEV (Mitsubishi innovative Electric Vehicle).

It is estimated that it takes 22 hours to recharge the battery with a 110-volt power supply and 7 hours with 220 volts. And, if the Level 3 480-volt quick-charging station with CHAdeMO charging technology is available, the battery can be recharged to about 80 percent of full capacity in about 15 minutes, about 50 percent in 10 minutes, and about 25 percent in 5 minutes. This is much less than the required charge time for a typical Li-Ion battery charged under the same conditions. The SCiB also generates little heat while recharging, eliminating the need for a complex system, and power robbing system, to cool the battery module.

The system offers three distinct driver-selected drive modes: "D," "Eco," and "B." Each has been designed to provide the best performance for different driving conditions. D mode is the default position and is the best mode for driving on highways and interstates. The Eco mode limits the motor's output to increase the range by decreasing the amount of power available for acceleration. The B mode adds more regenerative braking when the car is coasting to a stop or braking on downhill stretches to more aggressively recharge the battery.

After 10 years on the market, the Mitsubishi i-MiEV is no longer being sold in the United States. The car had a 66 HP engine with 145 lb-ft of torque, combined with the electric motor, it offered reasonably good economy and performance, but the public did not clamor to it, so Mitsubishi dropped it.

Tesla

Tesla Motors, based in California, is an independent auto manufacturer. Their automotive focus is manufacturing high-technology EVs. The company has been strongly supported by its founder and other investors, and is dedicated to providing fun and practical EVs. This effort was further helped by the U.S. government when Tesla was granted investment dollars.

Elon Musk is the co-founder and CEO of Tesla. In addition to electric vehicles, Tesla also manufactures large batteries and solar products. Musk is also the CEO of SpaceX, which was founded to revolutionize space technology. SpaceX craft has brought supplies, many times to the international space station. Musk was also the co-founder and CEO of PayPal, an internet payment system. Musk is currently working on several alternative transportation systems and vehicles, including electric semitrucks and a hyperloop mass transit system.

Tesla's first car made available to the public was its Roadster. The Tesla Roadster was a BEV it based on a Lotus Elise. It had a 248 hp (185 kW) 3-phase 4-pole AC induction motor powered by a 53 kWh lithium-ion battery. The roadster relied on a single speed transmission. The EPA's estimated range for the roadster was 244 miles.

Recently, SpaceX launched a Tesla roadster into space. Driven by a "spaceman," the car was supposed to orbit Mars but overshot that orbit and was heading into an asteroid belt outside Mars. No one knows how long the roadster will survive out there, but it is sort of cool that an automobile is out there in space.

Tesla calls its battery pack the Energy Storage System (ESS). This battery has 6,831 lithium-ion cells arranged into sheets and bricks. Each brick has 69 cells connected in parallel and each sheet has 9 bricks connected in series. Each of the cells is similar to those used as batteries for laptop computers. The battery weighs 990 pounds, stores 56 kWh of electric energy, and can deliver as much as 215 kW of power. Coolant is pumped continuously through the ESS when the car is running.

Model S The Tesla Model S **(Figure 36–28)** is a full-sized four-door sedan engineered and produced by Tesla Motors. The Model S is a high-performance electric sedan. Much of the technology used in the Roadster has been used in the Model S. The motor is an AC induction motor that can provide up to 416 hp and 443 lb-ft. of torque.

There are various models and options, each provides various power and driving range options, up to a 100 kWh option, rated at 335 miles (539 km). The

FIGURE 36–28 A Tesla Model S.

Tesla Model S is available in seven models: 60, 60D, 75, 75D, 90D, 100D, and P100D. The digits refer to the kilowatt hours capacity of the model's battery, while the "D" denotes the dual-motor, all-wheel-drive models. In Dual-motor models, up to 779-hp is available from the two motors to drive the four wheels.

Recently, Tesla has introduced two new models: the Model X and Model 3. The Model X is an SUV with 4WD, seating for up to 7 adults and a driving range of up to 295 miles. It can also accelerate to 60 mph in less than 3 seconds. One unique feature of the Model X is the "Falcon Wing" rear doors. These doors are designed to allow easy access to the second and third row seats. The doors move up and out of the way providing a large opening to the rear seats. The Model 3 is smaller and more affordable than the Model S. After this model was announced, thousands of buyers put a down payment on one before they drove or saw one.

The Model S comes with everything needed to plug into the most common 120V and 240V outlets. A full battery recharge requires less than 4 hours (or at a rate of 62 miles or 100 km range per hour) when charged with 70 amps and 240 volts. Using a 120V charger, 5 miles of travel is gained for every hour of charging and a full recharge requires about 48 hours. The Tesla uses a proprietary charging connector, but an adapter is available through Tesla that allows recharging with a J1772 connector. The system controls temperature and voltage of the battery pack by monitoring more than 100 sensors.

A 50 percent charge in 30 minutes is possible with a Tesla Supercharger **(Figure 36–29)**. These Superchargers are exclusive to Tesla and will not charge other EVs. Until early 2017, there was no cost to Tesla owners for using these chargers; Tesla pays for the electricity, which mostly justifies this proprietary arrangement. For vehicles purchased or delivered after early 2017, tiered charging costs are applied based on location and the amount of charging. These charging stations are positioned in various locations across the United States with the heaviest concentrations along the Northeast and on the west coast.

To charge the battery, all the driver needs to do is move toward the driver's side taillight holding a connector, press the button, and a triangle opens to reveal the charge port. There is a light ring around the charging port. The color of the light signifies status of the recharging process. In the center console there is a display that shows the charging status and gives a summary of the driver's past performance in regards to efficiency and other information **(Figure 36–30)**.

FIGURE 36–29 Tesla's Super Charging Station in use.

FIGURE 36–30 The display in the center console of a Model S.

Honda Fit EV

The car is powered by a 123 hp 189 lb-ft. PM motor. This motor is also used in Honda's FCEV, the Clarity. The motor with a single speed reduction transmission is located at the front of the car **(Figure 36–31)**. One of the drive axles passes through the motor's rotor hollow shaft to connect to the drive wheel. The Fit's 20 kWh SCiB lithium-ion battery is located below the car's floor. This required that the car's chassis be raised nearly two inches.

A J1772 charging connector is behind a flap in front of the driver's door **(Figure 36–32)**. The connector feeds power to the 6.6 kW on-board charger.

FIGURE 36–31 An under-hood look at the powerplant of a Honda Fit EV.

This connection allows for recharging the battery in about 3 hours when using a 240V source. Honda has selected Leviton as the vendor to provide a home charging station.

A unique feature of the Fit EV is its brake system. Normal braking, or the feel of the brake pedal, is totally simulated. The Fit EV attempts to come to a stop using only regenerative braking. The system does provide normal friction braking to bring the car to a complete halt and during hard braking. However, even during those conditions braking is computer controlled (brake-by-wire). In the brake system's hydraulic system, there is a fast-reacting electric motor that pressurizes the fluid at the brake calipers. This brake setup maximizes the amount of electricity generated during braking to help extend the driving range of the car.

Chevy Bolt EV

The 2017 Chevrolet Bolt EV is a low-cost electric vehicle **(Figure 36–33)**. The Bolt's permanent magnetic drive motor has an offset gear and shaft that allows for an EPA-estimated 238 miles of range. The motor is capable of producing up to 266 lb.-ft. (360 Nm) of torque and 200 hp (150 kW) of power. Combined with a 7.05:1 final drive ratio, the Bolt can accelerate from 0 to 60 mph in less than seven seconds.

It has a 60 kWh lithium-ion battery pack that is placed under the floor. The battery is made up of 288 cells and weighs 960 lbs. (435 kg). The nickel-rich lithium-ion battery chemistry improves the battery's

FIGURE 36–32 The charging port's door is in front of the driver's door on a Honda Fit EV.

FIGURE 36–33 A Chevy Bolt EV.

heat resistance. An active thermal management system circulates a liquid to maintain the battery's temperature during extremely hot and cold operating conditions.

As standard equipment, the battery has a charging cord to connect to a 120 V source and a 7.2 kW onboard charger. When the charger is connected to a 240 V source, the battery can be recharged to provide up to 50 miles of driving in less than 2 hours of charging. The Bolt also offers an optional DC Fast Charging system using a standard SAE Combo connector. This connector allows the car to be fast charged at a Combined Charging System station. With this, the battery can be recharged to provide up to 90 miles within 30 minutes. All Bolts come with a ChargePoint® card that allows access to thousands of public charging stations.

BMW i3 & i8

The BMW i3 **(Figure 36–34)** is a compact electric car with an additional model that has a range expander engine. The base i3 has a 170 hp (lb-ft @ rpm) AC synchronous electric motor and a 33 kWh Li-ion battery and a base price of $44,450. The i3 with the range extender has a base price of $51,500. The two cylinder engine used as a range extender provides additional power, when needed, but is there only to charge the battery when the battery's state of charge is low.

The i3 has a single speed transmission with a final ratio of 9.7:1; this allows the car to accelerate from 0 to 60 mph in less than 8 seconds. The i3 charges in approximately 4.5 hours, using a 240 volts and 32 ampere charger. Of course, the i3 uses brake regeneration to help charge the battery.

FIGURE 36–34 A BMW i3.

The i3 with the range extender will only start the engine when the battery charge level is below 7 percent, the engine will power the motor/generator to recharge the battery. Doing this, the driving range of the car is increased. The engine only drives the generator/motor and never directly powers the car's wheels.

The BMW i8 is an AWD plug-in hybrid that looks and acts like a sports car. The base price of an i8 is $143,400. The powertrain of an i8 includes an AC electric motor; a 7.1 kWh Li-ion battery, and BMW's 1.5 liter, turbo 3-cylinder. The engine can provide 228-hp and 236 lb-ft of torque and the electric motor can provide 129-hp and 184 lb-ft of torque, together they are able to provide a total of 357 hp and 420 lb-ft of torque. The i8 plug-in hybrid can accelerate from 0 to 60 mph in 4.2 seconds. A two-speed transmission is connected to the electric motor and a 6-speed automatic transmission is connected to the engine.

Basic Diagnosis

Diagnosis of BEV concerns can be simpler than diagnosing concerns on a conventional vehicle because there are fewer components. However, most manufactured BEVs have complex electronics that are unique.

Manufacturer-supplied checklists are especially helpful when deciding what should be known about a particular problem and repair **(Figure 36–35)**. In the vehicle's service information, there may be symptom-based diagnostic aids. These can guide you through a systematic process. As you answer the questions given at each step, you are guided to the next step.

When these diagnostic aids are not available or prove to be ineffective, good technicians conduct a visual inspection and then take a logical approach to solving the problem.

Precautions

During diagnosis and repair of a BEV always keep in mind that the vehicle has very high voltage. This voltage can kill you! Therefore, always adhere to the safety guidelines given by the manufacturer. Keep in

CUSTOMER PROBLEM ANALYSIS CHECK

EV CONTROL SYSTEM Check Sheet	Inspector's Name ________

Customer's Name		Model	
Driver's Name		Model Year	
Date Vehicle Brought in		Frame No.	
License No.		Odometer Reading	km miles

Problem Symptoms	☐ READY does not turn ON ☐ Vehicle does not move ☐ Poor acceleration ☐ Noise ☐ Vibration ☐ Harshness ☐ Smoke is rising ☐ Smell of or the likes burn ☐ Other ________

Date Problem Occurred		
Problem Frequency		☐ Constant ☐ Sometimes (times per day/month) ☐ Once only ☐ Other ________
Condition When Problem Occurred	Weather	☐ Fine ☐ Cloudy ☐ Rainy ☐ Snowy ☐ Various/Other ________
	Outdoor Temperature	☐ Hot ☐ Warm ☐ Cool ☐ Cold (approx. ____°F/ ____°C)
	Place	☐ Highway ☐ Suburbs ☐ Inner City ☐ Uphill ☐ Downhill ☐ Rough road ☐ Other ________
	Traction Motor	☐ Just after starting vehicle (min.) ☐ Standing with READY ON ☐ Driving ☐ Constant speed ☐ Acceleration ☐ Deceleration ☐ Other ________

Condition of MIL	☐ Remains on ☐ Sometimes lights up ☐ Does not light up
DTC Inspection	☐ Normal ☐ Malfunction code(s) (code) ☐ Freeze frame data ( )

FIGURE 36–35 A checklist for inspecting and road testing a BEV.

mind the same concerns stated in the chapters dealing with any high-voltage system should be adhered to now.

GO TO Chapters 8, 18, and 35 for the procedures for working with and around high-voltage systems.

Self-Diagnostics

The vehicle's control system has a built-in self-diagnostic system. When a fault is detected, the computer will store that information and may illuminate the Malfunction Indicator Light (MIL) on the instrument panel. The faults held in the computer's memory can be retrieved as Diagnostic Trouble Codes (DTCs). To retrieve these codes:

PROCEDURE

1. Measure the voltage of the auxiliary battery. If the voltage is lower than specifications, recharge it before continuing with your tests.
2. Inspect all fuses, fusible links, wiring harness, connectors, and ground in the low-voltage circuit. Repair them as necessary.
3. Connect the hand-held scan tool to the Data Link Connector (DLC) on the vehicle.
4. Turn the motor switch to the ON position and make sure the MIL is lit. If the MIL does not light, check for a burnt bulb, a bad circuit fuse, or an opening in the circuit. Again, correct the problem before proceeding. The MIL should go off when the READY lamp lights. If the MIL stays on, the computer has found a problem and related information is stored in its memory. Turn the motor switch to the OFF position.
5. Make sure the scan tool is set up for the vehicle being tested.
6. Turn the motor switch to the ON position and turn the scan tool on. Check for DTCs and freeze frame data and record all codes and data displayed on the scan tool. Refer to the manufacturer's reference to determine what the DTCs indicate.
7. Following the correct procedures, verify the concern, and repair the problem. After completing any repair of the motor or related parts, erase the DTCs retained in the computer's memory with the scan tool. Then test it again to make sure the fault is no longer present.

Reduced Range

If you have a customer with an EV that is experiencing reduced driving range, do not forget that conditions that can cause reduced fuel economy in a standard car or truck can cause a reduction in range for an EV. Check the following:

- Inspect the vehicle for additional weight, such as from leaving heavy items in the trunk or cargo areas.
- Make sure the brake system is operating properly and that neither the service brakes nor parking brake are sticking on.
- Ensure the vehicle has the correct tires and that they are inflated to the proper pressure.
- Inspect the underside of the vehicle for damaged or missing covers that can affect airflow underneath the vehicle.

Fuel Cell Vehicles

Fuel cell electric vehicles (FCEV) are the result of many years of research and development on electric and hybrid vehicles. They share many of the same technologies but differ greatly in the source of energy used to power the electric motors that are used to move the vehicle. Although the U.S. Department of Energy has announced that it will no longer fund fuel cell research and development, the manufacturers who have been exploring the possibilities say they will continue.

The technology is not new, nor is it unproven; NASA (National Aeronautics and Space Administration) has been using this technology in its spacecraft for years. Fuel cells provide the energy for the various electronic devices on-board the spacecraft. A fuel cell vehicle is much like a battery-operated electric vehicle. It operates like one and has many of the same characteristics: Electricity powers a motor to drive the vehicle, the vehicle operates very quietly, and the output of CO2 and other harmful emissions is zero.

FCEVs have electric motors, but the immediate energy source for those motors is not necessarily batteries. Some FCEVs use an ultra-capacitor in place of a battery pack. Regardless of where the energy is stored, all FCEVs rely on the DC voltage generated by an on-board fuel cell assembly. That energy can directly power the DC motors or be sent to the storage device **(Figure 36–36)**. An external energy source is not required to refill the electrical storage unit; however, the fuel used in the fuel cell must be refilled. Pure water and heat are the only emissions from a fuel cell. Fuel cells can continue to work until the fuel supply is depleted. In other words, the driving range of a fuel cell vehicle is largely dependent on the amount of fuel it can carry.

Hydrogen

Fuel cell vehicles use hydrogen as their fuel or energy source. Hydrogen is only found in compound form, such as in water, which is a combination of hydrogen and oxygen. Fossil fuels are combinations of carbon and hydrogen, which is why they are called hydrocarbons.

Due to its atomic structure, hydrogen is full of energy and is used to make reformulated gasoline, ammonia

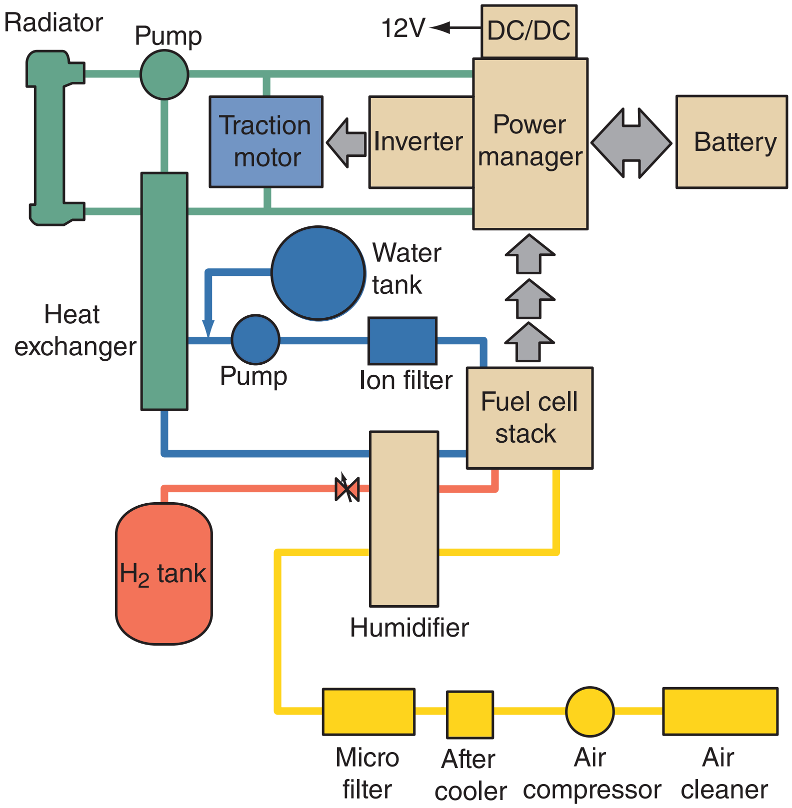


FIGURE 36–36 The basic layout for a fuel cell vehicle.

for fertilizer, and many different food products. Hydrogen contains more energy per weight than any other fuel, but contains much less energy by volume.

The auto industry has long used the energy released by separating hydrogen from a substance and recombining it with oxygen for many years. In a gasoline-fueled engine, gasoline is forced (by heat) to combine with oxygen. The result is combustion, which releases energy. That energy is used as mechanical energy. In a fuel cell, the same basic thing happens, but the chemical energy is released as electrical energy.

The Practicality of FCEVs

A major obstacle in the practicality of a fuel cell vehicle is the absence of an infrastructure for supplying pure hydrogen. Hydrogen production is commonly done, but it is very costly. It can be extracted from water, fossil fuels, coal, and biomass by a process that pulls hydrogen out of its bond with another element or elements. Currently it costs much more to produce hydrogen than it does to produce other fuels, such as gasoline. This, again, is an obstacle and the focus of much research.

The two most common ways hydrogen is produced are steam reforming and electrolysis. **Steam reforming** is the most common way used to produce hydrogen. About 95 percent of the hydrogen available today is produced this way. High-temperature steam is used to extract hydrogen from natural gas or methane **(Figure 36–37)**. Methane is the simplest of all hydrocarbons and is readily available. It is also the primary component of natural gas, which is found in oil fields, natural gas fields, and coal beds. Steam reforming is the most cost effective way to produce hydrogen. However, it relies on fossil fuels to create the steam and uses a fossil fuel as the source for hydrogen. Therefore, it does not reduce our dependence on fossil fuels and releases emissions during the process.

A cleaner, but more costly, method for producing hydrogen is **electrolysis**. In this process **(Figure 36–38)**, electrical current is passed through water. The water then separates into hydrogen and oxygen. The hydrogen atoms collect at a negatively-charged cathode and the oxygen atoms collect at the positively-charged anode. Producing hydrogen by electrolysis costs approximately ten times more than using steam reforming. However, the process does result in pure hydrogen and oxygen.

Hydrogen In-Vehicle Storage

Another big challenge for FCEVs is the storage of hydrogen. To be practical, any vehicle must have a decent driving range of at least 300 miles (483 km).

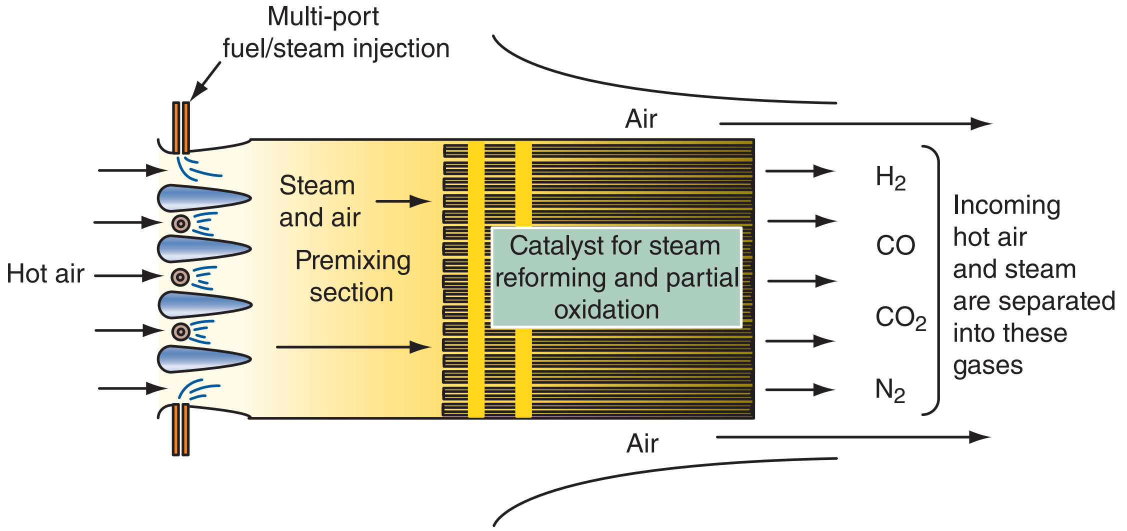


FIGURE 36–37 Basic view of how a steam reformer produces hydrogen.

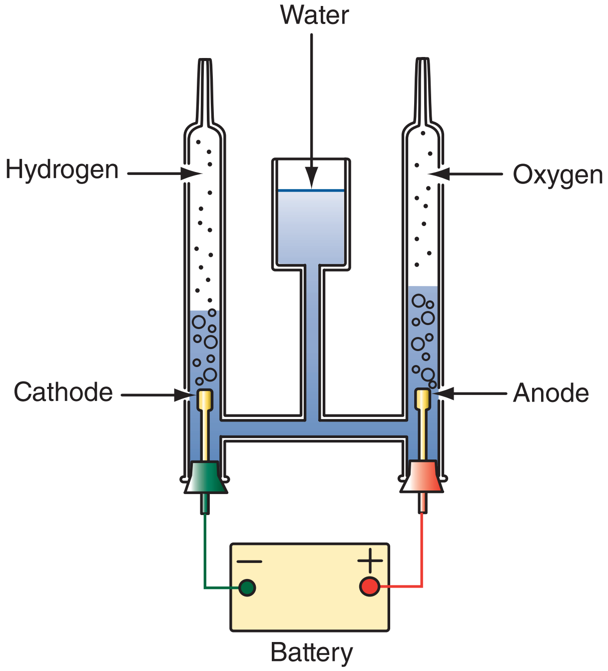


FIGURE 36–38 The process of electrolysis converts water into hydrogen and oxygen using electricity as the source of energy to cause the reaction.

Obviously, the more hydrogen that can be stored in the vehicle, the longer the car will be able to drive without refueling. Hydrogen can be stored as a liquid or as a compressed gas **(Figure 36–39)**. When stored as a liquid, hydrogen must be kept very cold. Keeping it that cold adds weight and complexity to the storage system. At cryogenic (icy cold) temperatures, more hydrogen can be stored in a given space. Cryogenic fuels were used in the rockets of NASA's space shuttles. However, liquid storage has some safety issues that are not present with compressed hydrogen storage.

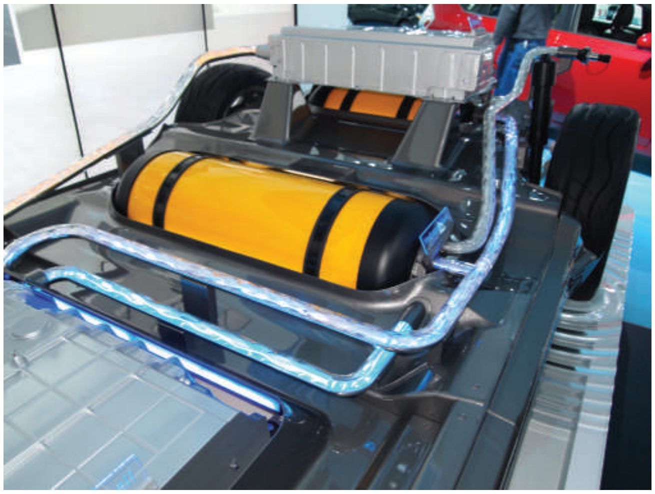


FIGURE 36–39 A hydrogen storage tank for an FCV.

The tanks required for compressed hydrogen need to be very strong, which translates to very heavy and expensive tanks. Most hydrogen tanks have an aluminum liner covered with carbon fiber and fiberglass. Also, higher pressures mean more hydrogen can be packed into a tank, but the tank must be made stronger to hold the higher pressures.

High-pressure tanks are very expensive. The typical fuel cell vehicle stores hydrogen at 5,000 psi (352 kg/cm) and has a driving range of about 150 miles (241 km). Doubling the pressure would nearly double the driving range. To double the pressure, stronger or more tanks are required, which adds to the cost of the vehicle.

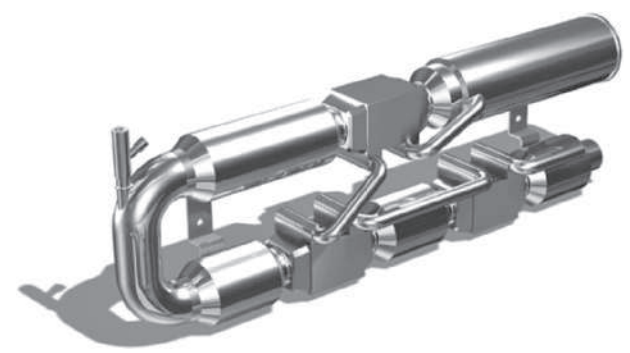
These considerations explain why storing enough hydrogen for an acceptable driving range is very difficult. Naturally, you can store more in a larger container but that container would consume more space and add considerable weight to the vehicle.

In-vehicle hydrogen storage is another area of much attention for researchers and engineers, and other storage technologies are being developed. Two of the technologies getting the most attention are systems based on metal hydrides and carbon nanotubes. The use of metal hydrides offers the possibility of storing three times more hydrogen in a given volume than when it is compressed. Carbon nanotubes are microscopic tubes of carbon that can store hydrogen in their pores. Because the surface of these tubes is quite irregular, the actual surface area is larger than the size of the tubes. The use of metal hybrids and carbon nanotubes may help solve the hydrogen storage problem for the future.

Reformers

The supply of hydrogen can be provided by a **reformer** that extracts hydrogen from another fuel, such as gasoline, methanol, or natural gas. Therefore a reformer can solve the hydrogen storage problem, since storing these fuels requires less space and is much simpler than storing pure hydrogen. The objections to using a reformer are plentiful. A reformer has undesirable emissions, such as carbon dioxide. Using reformers does not reduce our dependence on fossil fuels. Reformers **(Figure 36–40)** are expensive, slow, and require long run times before they can provide enough hydrogen to move a vehicle a few feet. Plus, the cost of the reformer adds to the already high cost of a fuel cell.

Reformers also make an FCEV more practical because the fuel supply is easily replenished. However, reformers have some emissions issues and consume valuable vehicle space. There is also an issue of the purity of the fuels that will be reformed. Many of these fuels have a substantial amount of sulfur. The sulfur can contaminate the catalysts used in the fuel cell and may not be totally filtered out of the hydrogen during the reforming process.



PowerCell Sweden AB.

FIGURE 36–40 An example of a reformer.

Fuel Cells

A fuel cell produces electricity through an electrochemical reaction that combines hydrogen and oxygen to form water. The basic principle of operation is the opposite of electrolysis. Electrolysis is the process of separating a water molecule into oxygen and hydrogen atoms by passing a current through an electrolyte placed between two electrodes **(Figure 36–41)**. In a fuel cell, catalysts are used to combine the fuel (hydrogen) with oxygen. The reaction releases electrons or electrical energy.

A single fuel cell produces very low voltage, normally less than 1 volt. To provide the amount of power needed to propel a vehicle, several hundred fuel cells are connected in series. This assembly is the **fuel cell stack (Figure 36–42)**, called this because the cells are layered or stacked next to each other.

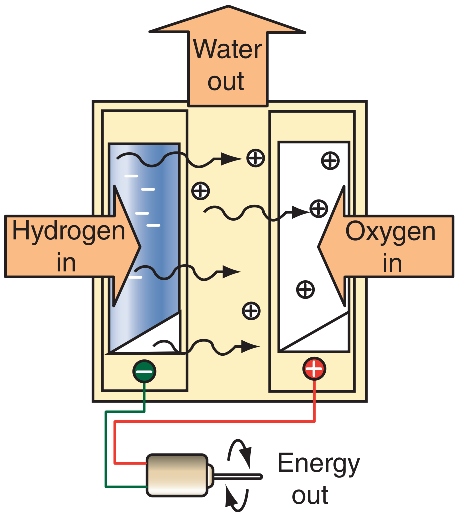
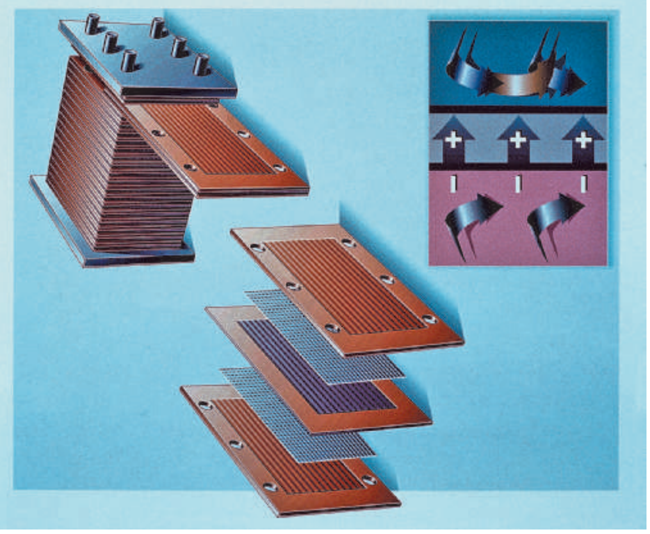


FIGURE 36–41 The basics of fuel cell operation.



Courtesy of Chrysler LLC.

FIGURE 36–42 A fuel cell stack.

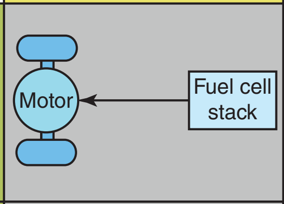
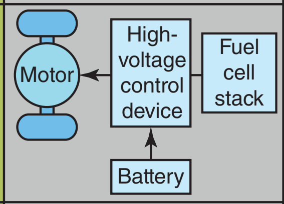
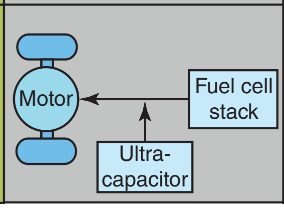
	Basic configuration	System features	Efficiency	Power performance
Fuel cell direct-supply system		Simple high-voltage system startup device required	Good efficiency No regenerative braking	Responsiveness depends on the output of the fuel cell stack
Battery-hybrid system		High-voltage distribution system required	Heat losses affect efficiency Regenerative braking	Output assist is possible
Capacitor-assisted system		High-voltage distribution system not required	Good efficiency Regenerative braking	Instantaneous high-output assist is possible

FIGURE 36–43 The different configurations of an FCEV.

FCEV Configurations

There are three basic configurations that describe the design of an FCEV powertrain **(Figure 36–43)**. When the powertrain has a direct-supply system, the energy from the fuel cell is delivered directly to the electric traction motor(s). With this configuration, the FCEV cannot have regenerative braking and propulsion power depends entirely on the output of the fuel cell.

In a battery hybrid powertrain system, the energy from the fuel cell is sent to the motor(s), the battery pack, or both. This configuration can use regenerative braking. The battery can also supplement the fuel cell's energy to improve performance. This system requires more electronic controls than the direct-supply system.

The third configuration uses ultra-capacitors rather than a battery. The ultra-capacitors are charged by the fuel cell and regenerative braking. Ultra-capacitors charge and discharge quickly, which allows the powertrain to respond quicker to changing conditions. Complex electronic systems are also required for this type of system.

Controls

To control the output of a fuel cell and therefore the speed of the vehicle, advanced electronics are necessary. Much of this technology is already used in hybrid vehicles but the uniqueness of the fuel cell demands additional new controls. FCEVs have high- and low-voltage systems and electronic controls are necessary to allow the fuel cell to power both. This means that all FCEVs need a DC-DC converter **(Figure 36–44)** to reduce the high-voltage from the fuel cell. These controls are in addition to the typical computer systems of other vehicle types. However, since a fuel cell generates DC voltage, an inverter is not needed unless the traction motors and the accessories require AC voltage.

Temperature Concerns

Most fuel cells take some time to start, especially when they are cold. In fact, freezing temperatures can kill a fuel cell. An exhaust system plugged with ice will also shut down a fuel cell. This is an area of much research and some manufacturers have had some success dealing with the problem. The basic thrust has been making sure all water is removed from the fuel cell after it has been shut down. This requires energy from a storage device. There is also research being done on mixing special coolants in the water. The fact that a fuel cell does not generate electricity until it has a temperature of 32 °F (0 °C) is an obstacle that needs to be overcome.

On the other side of the temperature scale, heat must be carefully controlled. Fuel cells become very hot while they operate and operate best within a particular temperature range. That range depends on the type of fuel cell. Some fuel cells operate best at a lower temperature than conventional engines

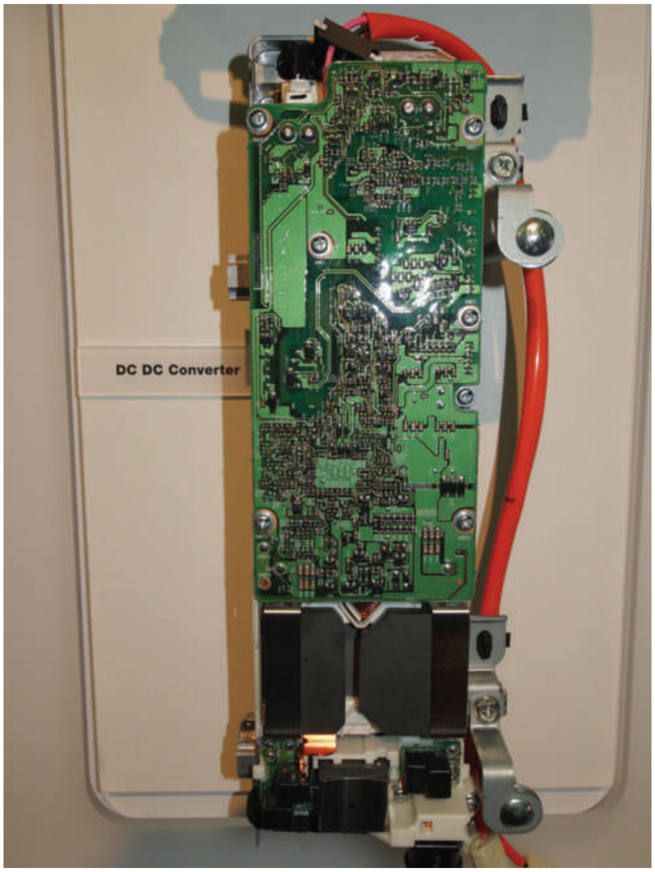


FIGURE 36–44 A DC-DC converter.

(Figure 36–45). This presents a major challenge as it is more difficult to get rid of low heat than it is high heat. This means the cooling system may need larger and/or more radiators. This means more space is needed in the vehicle just for the cooling system. This results in less useable space for passengers and luggage.

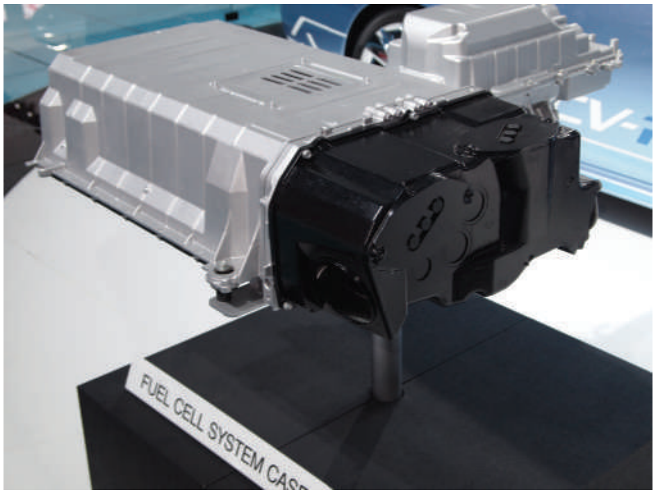


FIGURE 36–45 A fuel cell case with its cooling system.

When the space for the cooling system is added to the required space for the fuel cell stack and other components, very careful planning of that space is necessary. This becomes more of a challenge when one considers that the electronics and traction motors must also be kept cool. The cooling of these requires an additional cooling system because they operate at a different temperature range than the fuel stack. An additional cooling problem happens when the vehicle is equipped with a high-voltage battery pack and/or ultra-capacitors.

Another heat-related problem is generated by the air compressor that feeds outside air into the fuel cell. As air is compressed, its temperature increases. Because the fuel cell works best with a specific temperature range, the compressed air can heat up the cell beyond that range. To eliminate this, intercoolers must be added to the air-compressor system. These, again, occupy space. There is also the problem of filtering the incoming air. Ideally, the incoming air would be free of all dirt and other contaminants. A filtering system occupies space and has an impact on the overall layout and design of the vehicle.

Fuel Cell Types

The different types of fuels cells vary by size, weight, fuel, cost, and operating temperature. Regardless of design, all fuel cells have two electrodes coated with a catalyst. The catalyst, normally platinum, on the electrodes causes the chemical reaction in the fuel cell, but it does not materially take part in the reaction. One of the electrodes has a positive polarity, the anode, and the other is negative and is the cathode. The electrodes are separated from each other by an electrolyte and separators **(Figure 36–46)**.

The catalyst materials are not consumed during the operation of a fuel cell. A fuel cell consumes only hydrogen and oxygen. The oxygen is delivered to the cell by an air compressor that draws air in from outside the fuel cell. Hydrogen is fed into the fuel cell from a pressurized tank or from a reformer. The actual reactions that take place within a fuel cell depend on its design. What follows are descriptions of various fuel cells that may find their way into an automobile.

Proton Exchange Membrane Fuel Cell

The **proton exchange membrane (PEM) fuel cell (Figure 36–47)**, or derivatives of it, is a favored design for use in vehicles because it allows for adjustable outputs which are necessary for driving. The speed of the vehicle can be controlled by controlling the

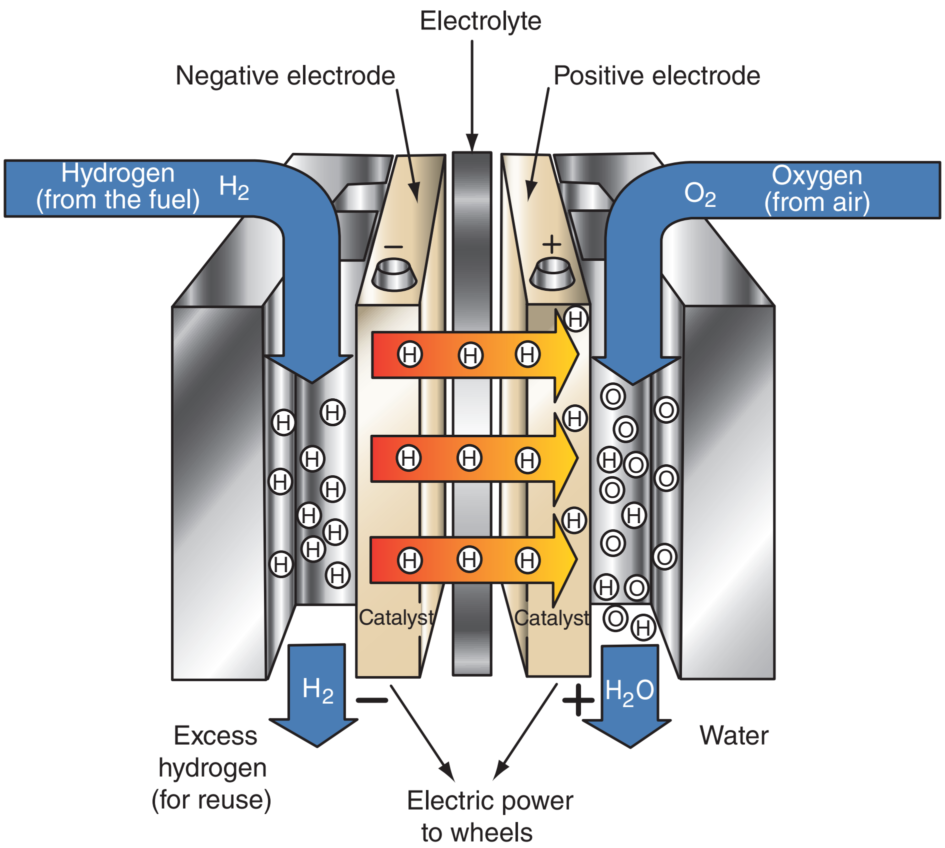


FIGURE 36–46 All fuel cells contain two electrodes—one positively and one negatively charged—and an electrolyte sandwiched between them.

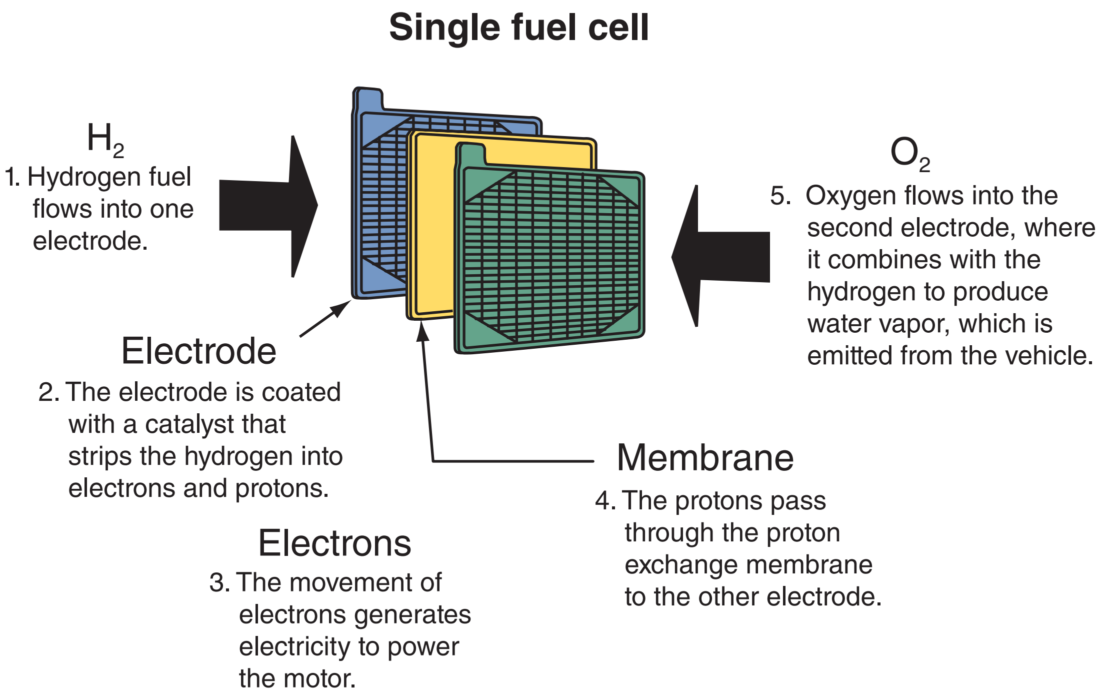


FIGURE 36–47 The basic operation of a fuel cell.

output of the fuel cell. Although it is quite compact, it is capable of providing high outputs. When compared to other fuel cell designs, it is most efficient at relatively low temperatures of 86 to 212 °F (30 to 100 °C). However, it is expensive to manufacture.

In a PEM, the electrolyte is a polymer membrane, called the proton or ion exchange membrane. Polymers can be very resistant to chemicals and can serve as an electrical insulator or separator. The polymer membrane in a fuel cell does both.

When hydrogen is delivered to the anode, the catalyst causes the hydrogen atoms to separate into electrons and protons. Oxygen enters the other side of the fuel cell and reacts to the catalyst on the cathode. This splits the oxygen molecules into oxygen ions. The protons (hydrogen ions) that were released from the hydrogen at the anode move toward the oxygen ions. Keep in mind, electrons always move to something more positive but cannot pass through the membrane. Therefore, their only path to the positive side of the fuel cell is through an external circuit. The movement of the electrons through that circuit results in direct current flow.

Since the membrane that separates the two electrodes will only allow protons to pass through, the hydrogen ions move to the cathode where they bond with oxygen ions to form water. Some of the water produced by the fuel cell is used to humidify the incoming hydrogen and oxygen. This is important because in order for the fuel cell to work properly, the ion exchange membrane must be kept moist. The remaining amount of water produced by the fuel cell is emitted as exhaust from the fuel cell. Some heat is also emitted by the fuel cell. The heat is either released to the outside air or used to heat the fuel cell. It can also be used to heat the passenger compartment.

One of the biggest disadvantages of the PEM cell is the need to keep the membrane moist. In cold temperatures, the water can freeze, making the fuel cell very difficult to get started. Also, carbon monoxide (CO) can weaken the platinum catalysts. Because outside air is delivered to one side of the cell, the presence of CO in that air will reduce the output of the cell. Much research and development is taking place to alleviate these obstacles.

Solid Oxide Fuel Cell

The **solid oxide fuel cell (SOFC)** may be the first design used in a mass-produced automobile. However, it will not be used to power a traction motor. Rather, it may be used to replace the belt-driven generator (alternator). Current alternators are not very efficient and their output is dependent on rotational speed. They also rely on engine power to operate, which means they contribute to an engine's fuel consumption. Removing the alternator and using an SOFC will increase the efficiency of the engine. The SOFC can also provide much higher power levels, which means more accessories can be electrically driven. This again will increase the efficiency of the engine. Using a SOFC will also allow accessories to operate when the engine is not running and without draining the battery.

These cells have a ceramic anode, ceramic cathode, and a solid electrolyte **(Figure 36–48)**. To be efficient, these cells must operate at very high temperatures from 1,290 to 1,830 °F (700 to 1,000 °C). Although these temperatures restrict the type of materials used in the cells to ceramics, they also eliminate the need for expensive catalysts. This means SOFCs have low production costs. These fuel cells can operate with a simple, single-stage,

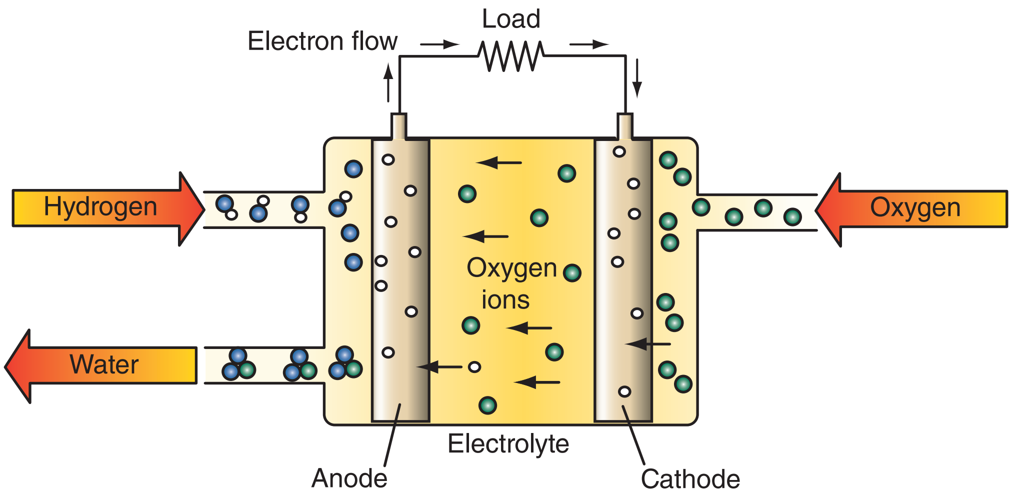


FIGURE 36–48 A solid oxide fuel cell (SOFC).

built-in reformer because of the high operating temperatures. Also, the high temperatures eliminate the chances of CO poisoning the electrodes. Efficiency estimates for this type of fuel cell vary from 40 to 45 percent, as compared to 20 to 30 percent for an internal combustion engine.

The high operating temperature is also a reason why these fuel cells may not be used to power a vehicle. When this high heat is generated, it must be released. Releasing a large quantity of high heat can cause many problems to other automotive systems.

Direct Methanol Fuel Cell

The **direct methanol fuel cell (DMFC)** is a type of PEM fuel cell. Liquid methanol, rather than hydrogen, is oxidized at the anode and oxygen is reduced at the cathode. Methanol is considered an ideal hydrogen carrier because it takes little energy to release its hydrogen. The methanol is delivered directly into the cell and therefore a reformer is not needed. So the cost of these cells is lower than the PEM. Liquid methanol is also easier to store than hydrogen and has a much higher energy density than compressed hydrogen.

These cells are simple and compact units that can provide a good amount of energy for a long period of time. They operate at about the same temperature as PEMs, but the cells are not as efficient as PEMs and their response time is slower than a PEM. Also, they have emissions that are not present with other fuel cells designs. As the hydrogen is removed from the methanol, carbon is released. The carbon and oxygen atoms combine to form CO_2 and the oxygen and hydrogen form water.

Alkaline Fuel Cell

The **alkaline fuel cell (AFC)** is the one used by NASA. It is expensive, but highly efficient. In a spacecraft, the water (its exhaust) is used as drinking water for the space travelers. This fuel cell will undoubtedly never be used in automobiles because of its cost. It is also very sensitive to carbon dioxide, which means it does best where all CO_2 can be removed from the incoming supply of air. This fuel cell operates in the same manner as a PEM.

Alkaline fuel cells use a water-based solution of potassium hydroxide (KOH) as the electrolyte. The electrodes are coated with a catalyst, although due to the operating temperature and the purity of the incoming gases, platinum (the typical metal used as a catalyst) is not required, increasing efficiency and reducing costs.

Hydrogen Fueling Infrastructure

Until there is a well-established distribution system for hydrogen, FCEVs will not be a dominant source of transportation. However, there are many companies trying to establish hydrogen fueling stations. In the United States there are more than 50 refueling stations available, and this is not enough to sustain the growth of fuel cell vehicles. These stations will look like normal gas pumps **(Figure 36–49)**, however the car's filler neck is very different **(Figure 36–50)** as is the fuel nozzle **(Figure 36–51)**.

FIGURE 36–49 A hydrogen fueling station.

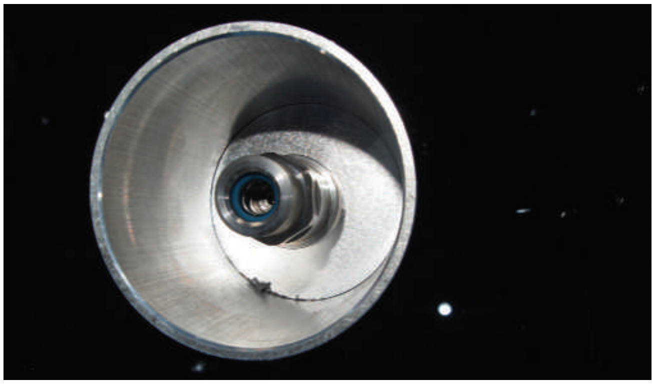


FIGURE 36–50 The fuel filler neck of a hydrogen FCV.

FIGURE 36–51 The fueling hose and nozzle for hydrogen.

FIGURE 36–52 A Toyota fuel cell concept car.

Current FCEVs

Fuel cell vehicles for everyday use are still years away; however, there are many fuel cell prototypes on the road all over the world. All of these are part of the ongoing research that is taking place. Every major manufacturer has built at least one type of FCEV and many have developed a new model nearly every year. The manufacturers are testing different technologies in real-world settings. It is difficult to predict exactly how a mass-produced FCEV will be equipped, but it is certain that some of the technology used in today's prototypes will be part of that final design.

Below are some examples of FCEVs on the road today in some parts of North America.

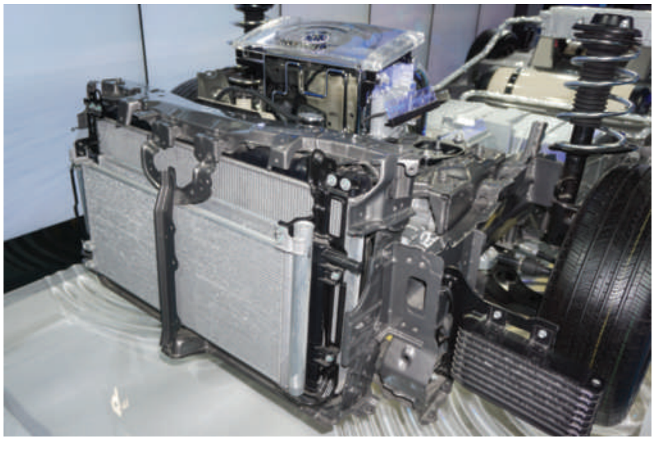


FIGURE 36–53 The fuel cell and its components fill the engine compartment of this FCEV.

Toyota

Much of what Toyota has learned with its hybrids is transferable to its fuel cell vehicles. In fact, many of the same components can be transferred as well. Toyota's first FCEV, the RAV4 FCEV, used a Toyota developed PEM fuel cell and was configured as a battery hybrid FCEV. There were two generations of the RAV4 FCEV; the first stored the hydrogen in metal hydrides, and the other had a methanol reformer and provided a range of 310 miles (500 km).

To take a look at how hybrid technology and components are used in a fuel cell vehicle, consider one of their latest FCEV, the Mirai **(Figure 36–52)**. The vehicle is a battery hybrid FCEV and is propelled by 109 hp (80 kW) electric motors. The compressed fuel is stored in four hydrogen fuel tanks at 10,000 psi (700 kg/cm). The battery and associated electronics are also similar to those found in the Prius. A power control unit is in the engine compartment and is a slightly modified version of that used in the Prius. The control unit monitors the current operating conditions and determines when to use the battery, fuel cell, or both to propel the vehicle and to charge the battery. This is the same strategy used in hybrid vehicles. However, in the FCEV the fuel cell and its output replace the engine **(Figure 36–53)**.

SHOP TALK

The name of this Toyota FCEV is a bit different and has no true English roots. The Japanese word "mirai" means future. And the car is definitely looking into the future.

Toyota Mirai

The Toyota Mirai is one of the first FCEVs to be sold commercially. Toyota initially sold the vehicle through just eight dealerships in California. The Mirai has a sticker price of $57,500 or it can be leased for $349 per month for three years. Operating within the EPA drive cycle, the Mirai has a total range of 312 miles (502 km) with a full supply of hydrogen. The Mirai has a combined fuel mileage rating of 66-MPG-e (3.6 L/100 km-e). With those ratings the Mirai is the most fuel efficient hydrogen fuel cell vehicle rated by the EPA, and the one with the longest range.

The Mirai uses a fuel cell system developed by Toyota. The Mirai has a power control unit and 152 hp (113 kW) electric traction motor in the front of the car. The area under the front seat houses the fuel cell stack and a hydrogen storage tank. In the rear is the other hydrogen tank and a 245 volts (1.6 kWh) NiMH battery pack. Toyota's most recent hybrid components are used extensively in the powertrain, including the electric motor, power control, and battery **(Figure 36–54)**.

The Toyota FC Stack has a maximum output of 152 hp (114 kW) and has the world-leading power output density. This is the result having fine mesh flow channels inside the FC. The channels form a three-dimensional lattice structure that enhances the movement of oxygen, which in turn allows each FC cell to produce the same amount of electricity. Each FC stack is made up of 370 cells; each of these is only 0.05 inch (1.34 mm) thick and weighs 0.22 lbs (102 g). The FC boost converter is a compact 79.3 cubic inch (13 liter), high-efficiency, high-capacity converter that can boost the voltage generated from the FC 650 volts.

The FC is fed by two 10,000 psi (70 MPa) high-pressure hydrogen tanks placed under the body, one under the rear seat and the other in the trunk **(Figure 36–55)**. These tanks have a three-layer structure made of carbon fiber-reinforced plastic. This construction gives the tanks strength, durability, and good hydrogen permeation prevention. The system has hydrogen sensors that can detect gas leakage and turn off tanks' valves. As a convenience the car's navigation system has the locations of area hydrogen filling stations programed in it. Through its CHAdeMO power-out connection, the car can provide 60 kWh of electricity to a home during power outages. There is a button on the dash labeled H_2O **(Figure 36–56)** that opens a small door at the rear of the car. Water vapor that is a by-product of the FC is dumped out, this is critical in cold climates as the water may turn into ice and block the exhausts of the FC.

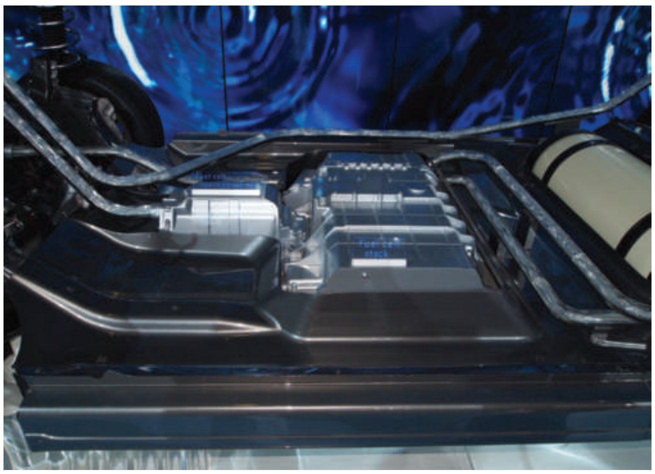


FIGURE 36–54 A fuel cell stack in a Toyota concept FCV.

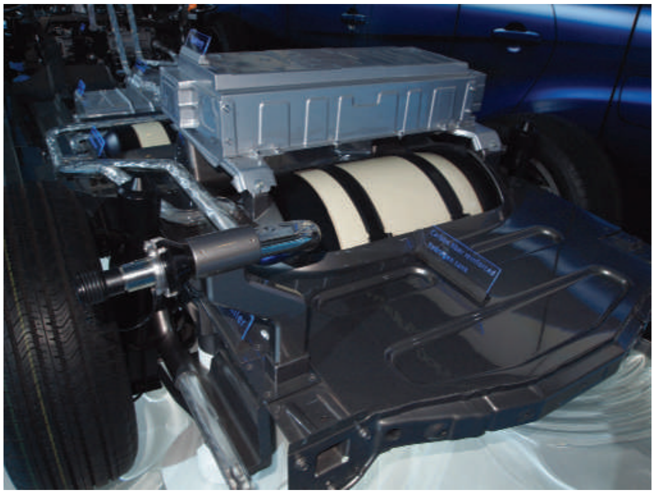


FIGURE 36–55 The hydrogen storage tank.

At low speeds the FCEV operates like an all-electric vehicle using the energy stored in its battery, which is charged through regenerative braking. At higher speeds, only the FC powers the vehicle. When extra power is required, the FC and the battery work together to supply additional power.

FIGURE 36–56 The button to release water vapor byproduct of the fuel cell.

Honda

Honda has also been busy with fuel cell vehicle research. Unlike Toyota, the hybrid system used by Honda does not easily adapt to an FCEV. However, many of the controls and features do transfer rather nicely. Plus, Honda also has much experience with battery electric vehicles. This vehicle, called the Clarity FVC **(Figure 36–57)**, is not for sale but can be leased for three years at a cost of $369 per month. To help offset the cost, Honda gives buyers a $15,000 fuel card with a 3 year lease.

Honda uses its latest design of fuel cell, one that is compact but powerful, and can operate in very low temperatures. This new fuel cell is a PEM fuel cell. The FC is designed to control exhaust water flow, because this is important for fuel cell efficiency and start-up times. Oxygen and hydrogen flow from the top to the bottom of the stack. The most important feature of the FC is that it is designed to allow gravity to get rid of the unwanted water in the FC to prevent ice formation during cold operation. The FC is capable of starting in temperatures as low as –22 °F (–30 °C).

The fuel cell of the Clarity is under the hood and the voltage-control unit sits on top of the FC. The control unit boosts and regulates the power produced by the FC. An air compressor increases airflow into the stack, which also increase power output. The AC synchronous electric motor is rated at 174 hp and is connected directly to a transmission.

A 1.7 kWh Li-ion battery pack is mounted below the front seats and acts as a buffer for the fuel cell and provides extra power during heavy loads. The Clarity is always powered by the battery and moved by the electric motor, never directly by the FC. The battery can store the electricity generated by the FC and the regenerative braking.

Two aluminum-lined and composite-reinforced "fuel" tanks, each of a different size, store hydrogen at 10,000 psi (70 MPa). To fill the tanks, the fuel nozzle is locked over the fuel filler neck. Shortly the fuel will begin to flow. At 10,000 psi, the tanks hold 5.5 kilograms of hydrogen, which is roughly equal to 5.5 gallons of gasoline.

FIGURE 36–57 A concept model of Honda's Clarity FCEV.

The Clarity's instrument display has a dot that changes color and size as hydrogen consumption increases. A separate display shows the battery power level and another shows motor output.

Hyundai

The **Hyundai ix35 FCEV** or **Tucson FCEV** is a hydrogen fuel cell electric vehicle developed by Hyundai. The first ix35 FCEV was delivered in June 2014 in Tustin (California) with a lease price of $499/month, a $2,999 down payment with unlimited free fueling for a 3-year period and it was the first mass-produced fuel cell compact SUV. Hyundai is leasing the Tucson Fuel Cell in selected parts of California.

The Tucson Fuel Cell uses a PEM fuel cell to generate 100 kWh of electricity. The Tucson ix35 FCEV has a powerful FC rated at 100 kW (134 horsepower), and a range of about 369 miles (594 km). Range has improved since the last Hyundai FCVEV because ix35 FCEV has a large space to hold the hydrogen tanks, it has higher tank pressures, and there have been many advancements made to the FC.

The tanks contain compressed hydrogen at 10,000 psi (70 MPa) and hold 5.64 kg of hydrogen. This means they store enough fuel for a 369 miles (594 km) drive. A 134 hp electric motor drives the front wheels, which is fed power by a 4 kW Li-ion battery.

Prototype FCEVs

The development of practical FCEVs will involve the cooperation of different auto manufacturers. Several joint ventures have already been announced. Daimler, Ford, and Nissan are working together to make a common propulsion system that can be used in a variety of vehicles. Their target date is 2017. They are also working on improving the infrastructure for hydrogen. Several joint ventures to improve the infrastructure for hydrogen have been formed. For example, Daimler has joined with a gas distributor (Linde) to establish hydrogen refuelling stations throughout Europe. Currently there a few joint efforts that provide hydrogen fuelling stations located in California. Another joint venture has also been established. This one is with BMW and Toyota. They are working together to design a platform for a midsize sports vehicle by 2020.

There are many FCEV prototypes and concept vehicles on the road all over the world. All of these

are part of the ongoing research that is taking place. Every major manufacturer has built at least one type of FCEV and many have developed a new model nearly every year. These vehicles are testing different technologies in real-world settings.

The below section looks at some of FCEVs in the works.

Audi

Audi has been developing several electric vehicles in the past few years, most of these have the suffix of e-tron after the model name. The A7 h-tron which is a hybrid in the sense that it has some plug-in e-tron components taken from the A3 Sportback e-tron. In addition, the added 300 cell FC allow the A7 h-tron to operate for a time as a pure electric vehicle for considerable driving range.

The instrument panel has a power meter that displays the current power flow. The outer section of the meter shows the level in the hydrogen tank and the level of battery charge. There is also an EV button that allows the car to operate on battery power only.

Daimler

Daimler started developing fuel cell vehicles in 1994 and has produced well over 100 vehicles for testing purposes. These vehicles include cars, buses, and vans. Their vehicles are on the roads in the United States, Europe, China, Australia, Japan, and Singapore. At each location, feasibility studies are being done while the vehicles are being used in varying driving and climate conditions.

Through continuous research, Daimler has been able to extend driving range, minimize the space required for the fuel cell components, and improve cold weather starting and operation. To minimize the space requirement, engineers have fit the entire fuel cell drive system in the floor. Doing this allowed them to convert a small car, the Mercedes-Benz A-Class, and small SUVs into an FCEV and still have room for passengers and luggage **(Figure 36–58)**.

One prototype is a Mercedes B-Class F-Cell that has a 136 hp (100 kW) electric motor. This vehicle uses battery power to start the vehicle and assist the fuel cell in delivering power to the electric motors during acceleration. The battery pack is recharged by the fuel cell and with regenerative braking. The hydrogen is stored at 10,000 psi and has a driving range of about 280 miles.

Soon Daimler will release the Mercedes-Benz GLC Plug-in Fuel-Cell Vehicle. This vehicle will use a 9-kWh battery pack located in the rear of the car.

FIGURE 36–58 Mercedes-Benz A-Class F-Cell passenger cars, like the one seen here, are being operated by customers in Singapore, Japan, Germany, and the United States.

The Li-ion battery has about a range of 30 all electric miles range. The fuel cell will add another 300 miles of range. Also, the battery can be used to provide some power when the driver is seeking a hydrogen refueling station. The battery is in the rear and the fuel cell is under the hood.

General Motors Corporation

With several experimental FCEVs, GM has worked to minimize the required space for hydrogen storage and to increase driving range. In 2002, it introduced the "skateboard" concept **(Figure 36–59)**. In this design, all of the fuel cell related components are packed into a carbon fiber structure that also serve as the vehicle's chassis. This propelled chassis was designed with the intent of placing any body configuration on it. The first of these vehicles was the AUTOnomy and the Hy-wire. They featured many futuristic concepts, including total drive-by-wire systems.

A recent GM concept fuel cell vehicle is the Sequel. The Sequel uses the technologies that worked well in the AUTOnomy and the Hy-wire. This battery hybrid FCEV uses a Li-Ion battery to provide electrical energy to the three electric motors during acceleration and to capture energy during braking. A transverse-mounted, three-phase AC motor drives the front wheels, and two three-phase AC wheel hub motors drive the rear wheels. There is a separate inverter for each motor. The electrical system includes three separate systems with three different voltages. A high-voltage system provides energy for the traction motors; the 42-volt system supplies energy for the brakes, steering, air conditioning, and other by-wire systems; and the 12-volt system is used for the conventional accessories and lights.

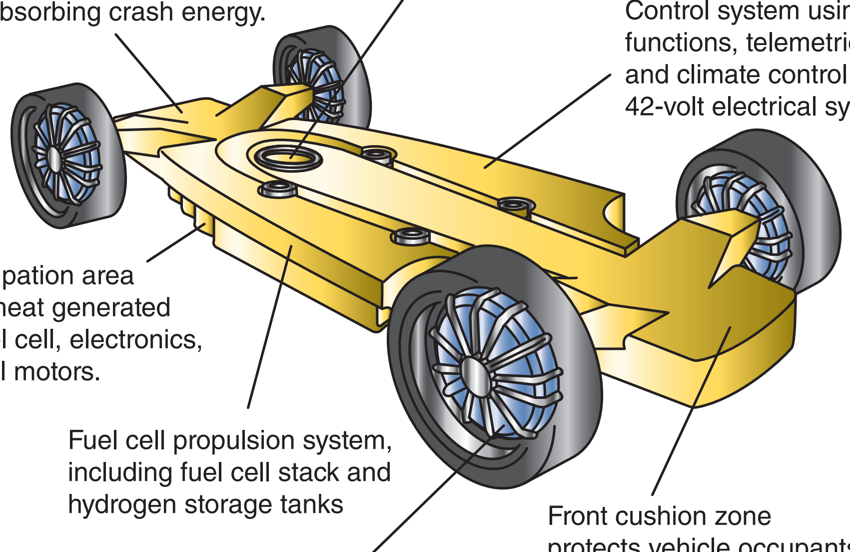


FIGURE 36–59 The basic layout of General Motors's skateboard chassis.

The fuel cell stack, hydrogen and air processing subsystems, high-voltage distribution system, and hydrogen storage tanks are housed in the skateboard. The storage tanks are designed to hold compressed hydrogen at 10,000 psi (703 kg/cm).

Recently GM unveiled a fuel-cell-powered version of its Chevrolet Volt. In this concept car, the generator was replaced by a fuel cell. To accommodate the hydrogen storage tanks, the battery pack was made half of its original size. It also uses a more advanced fuel-cell design and the vehicle is lighter. The lithium-ion battery pack can be recharged by plugging it in, by the fuel cell, or through regenerative braking. When the car is first started, it is powered by the fuel cell. When more power is needed, the battery pack provides additional energy to the traction motor.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2012	**Make:** Nissan	**Model:** Leaf	**Mileage:** 41,058	**RO:** 16603
Concern:	Customer states driving range decreased significantly in last few weeks.			
The technician checks for illuminated malfunction warning lights and for service bulletins. Finding none, he performs a visual inspection of the vehicle. After checking the tires and the cargo area and finding no problems, he then raises the vehicle to look underneath. Not seeing any damage to the vehicle, he spins each tire, checking the brake drag. The brakes feel normal and he notices that the tire appear very new. He inspects the tires more closely and finds they are not the low rolling resistance tires normally used on this vehicle.				
Cause:	Inspected vehicle and found replacement tires that do not meet OE tire specs.			
Correction:	Inspection of the vehicle found the new tires do not have the same ratings as the OE tires, creating increased rolling resistance. Suggested customer replace with LRR tires to regain lost range.			

KEY TERMS

Alkaline fuel cell (AFC)
Conductive charging
Direct methanol fuel cell (DMFC)
Electrolysis
Fuel cell electric vehicle (FCEVs)
Fuel cell stack
Hyundai ix35 FCEV
Inductive charging
Proton exchange membrane (PEM) fuel cell
Reformer
Solid oxide fuel cell (SOFC)
Steam reforming
Tucson FCEV

SUMMARY

- Battery electric vehicles (BEVs) use electrical energy stored in batteries to power the traction motors and have zero emissions.
- Fuel cell electric vehicles (FCEVs) are also electrically-powered zero-emission vehicles but they rely on hydrogen as the fuel.
- The basic systems in a BEV are a high-voltage battery pack, battery management system, the motor(s) and supporting system, 12-volt system, converter and/or inverter, and the driver's displays and controls.
- One kilowatt (kW) is the international unit to measure power (not only electrical); 1 kW is 1,000 watts and equals 1.34 horsepower.
- The amount of energy available from a battery or other electrical source is expressed in kilowatt hours (kWh); this states what can be accomplished by 1 kilowatt acting for 1 hour.
- Most production BEVs use AC motors and FCEVs and many conversion EVs use DC motors.
- In most EVs, there is no transmission because a motor is capable of providing enough torque throughout its speed range to move the vehicle without torque multiplication.
- Inductive charging transfers electricity from a charger to the vehicle using magnetic principles. There is no metal-to-metal contact between the charge paddle and the charge port of the vehicle.
- Conductive charging takes place by making a connection between the charging connector and the charge port.
- Conductive charging is normally accomplished with a fuel nozzle looking connector called the ODU.
- SAE's J1772 standard covers the basic physical, electrical, communication protocol, and performance requirements for an EV's conductive charge system and coupler.
- During diagnosis and repair of a BEV always keep in mind that the vehicle has very high voltage. Always adhere to the safety guidelines given by the manufacturer.
- Fuel cell vehicles use hydrogen as their fuel or energy source.
- Hydrogen is full of energy. Due to its atomic structure and abundance it may be the fuel of the future.
- The main powertrain components in a typical fuel cell vehicle include a fuel cell stack, high-pressure hydrogen supply or reformer with a fuel tank, air supply system, humidification system, fuel cell cooling system, storage battery or ultra-capacitor, traction motor and transmission, and control module and related inputs and outputs.
- A fuel cell produces electricity through a process that works in the opposite way as electrolysis in which hydrogen and oxygen are combined to form water.

REVIEW QUESTIONS

Short Answer

1. Why are carbon dioxide emissions a concern?
2. List five things a driver of a BEV can do to extend the driving range of the vehicle.
3. What makes up the propulsion system in a BEV?
4. What basic factors affect the required time to recharge the battery pack in a BEV?
5. There are two basic ways a BEV is connected to an external source of electricity for charging: conductive and inductive. What is the difference between the two?
6. Why is water control so important to the effectiveness of a PEM fuel cell?
7. Explain what the ratings of kilowatts and kilowatt-hours mean.

True or False

1. *True or False?* All fuel cell vehicles have regenerative braking and 12-volt auxiliary systems.
2. *True or False?* A PEM fuel cell needs to operate at very high temperatures.

Multiple Choice

1. Which of the statements about hydrogen is true?
   a. A hydrogen atom is one proton and two electrons.
   b. Hydrogen is one of the heaviest elements known and is full of energy.
   c. Fossil fuels are combinations of carbon and hydrogen.
   d. Hydrogen is produced in a fuel cell when water is broken down into its basic elements.
2. Which of the following CANNOT be used as a source for the production of hydrogen?
   a. Gasoline
   b. Methanol
   c. Carbon dioxide
   d. Natural gas
3. Which of the following statements about fuel cells is NOT true?
   a. A single fuel cell produces very low voltage, normally less than one volt.
   b. A fuel cell produces electricity through an electrochemical reaction that combines hydrogen and oxygen to form water.
   c. A fuel cell is composed of two electrodes coated with a catalyst and separated from each other by an electrolyte and from the case by separators.
   d. In a fuel cell, catalysts are used to ignite the hydrogen; this causes a release of electrons or electrical energy.
4. What is the basic fuel for a fuel cell?
   a. Hydrogen
   b. Methanol
   c. Electricity
   d. Gasoline
5. The component that changes the molecular structure of hydrocarbons into hydrogen-rich gas is called a ___.
   a. pressure container
   b. fuel cell
   c. fuel injector
   d. reformer
6. Which of the following statements about hydrogen is *not* true?
   a. Hydrogen displaces air, so any release in an enclosed space could cause asphyxiation.
   b. Hydrogen must be stored as a compressed gas.
   c. Hydrogen is nontoxic.
   d. Hydrogen is highly flammable and there is risk for an explosion.

ASE-STYLE REVIEW QUESTIONS

1. Technician A says power is the ability to do work. Technician B says energy is the rate at which work is done. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
2. While discussing inductive charging: Technician A says most current BEVs use this system because it is safe. Technician B says this method requires that a weatherproof paddle be inserted into the vehicle's charge port. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
3. Technician A says some BEVs use liquid to heat the passenger compartment. Technician B says some BEVs use an electric resistance heater with a fan to heat the passenger compartment. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B

4. While discussing charger connections: Technician A says nearly all BEVs currently sold in North America have an AVCON connector. Technician B says the connector currently used for DC fast charging on the Nissan Leaf and Mitsubishi i vehicles is based on the CHAdeMO standard. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Technician A says that a fuel cell produces electricity through an electrochemical reaction that combines hydrogen and oxygen to form water. Technician B says that in a fuel cell, catalysts are used to ignite the hydrogen, causing a release of electrons or electrical energy. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. While diagnosing a decreased driving concern on a BEV: Technician A begins by checking the tire pressure and tire type. Technician B inspects under-vehicle covers and shields. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. While discussing controllers in BEVs: Technician A says the controller may reverse the current flow to the motor when reverse gear is selected. Technician B says modern controllers adjust motor speed through pulse width modulation. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. Technician A says that all FCEVs have regenerative braking. Technician B says that all FCEVs have an auxiliary 12-volt battery. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
9. Technician A says that gasoline can be used as a source of hydrogen for a fuel cell. Technician B says that carbon dioxide can be used as a source of hydrogen for a fuel cell. Who is correct?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
10. While discussing hydrogen: Technician A says that a hydrogen atom has one proton and two electrons. Technician B says that hydrogen is produced in a fuel cell when water is broken down into its basic elements. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B

SECTION 5

MANUAL TRANSMISSIONS
AND TRANSAXLES

CHAPTER

37 CLUTCHES

The clutch assembly is located between the transmission and engine where it provides a mechanical coupling between the engine's flywheel and the transmission's input shaft. **Figure 37–1** shows the components needed to do this: the flywheel, clutch disc, pressure plate assembly, clutch release bearing (or throwout bearing), and the clutch fork.

The driver operates the clutch through a linkage that extends from the passenger compartment to the **bell housing** (also called the

OBJECTIVES

- Describe the various clutch components and their functions.
- Name and explain the advantages of the different types of pressure plate assemblies.
- Name the different types of clutch linkages.
- Explain how to perform basic clutch maintenance.
- Name the most common problems that occur with clutches.
- Explain the basics of servicing a clutch assembly.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2010	**Make:** Toyota	**Model:** FJ Cruiser	**Mileage:** 151,889	**RO:** 15844
Concern:	Customer states that there is noise coming from the clutch area when the pedal is depressed. The noise stops when the pedal is released.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

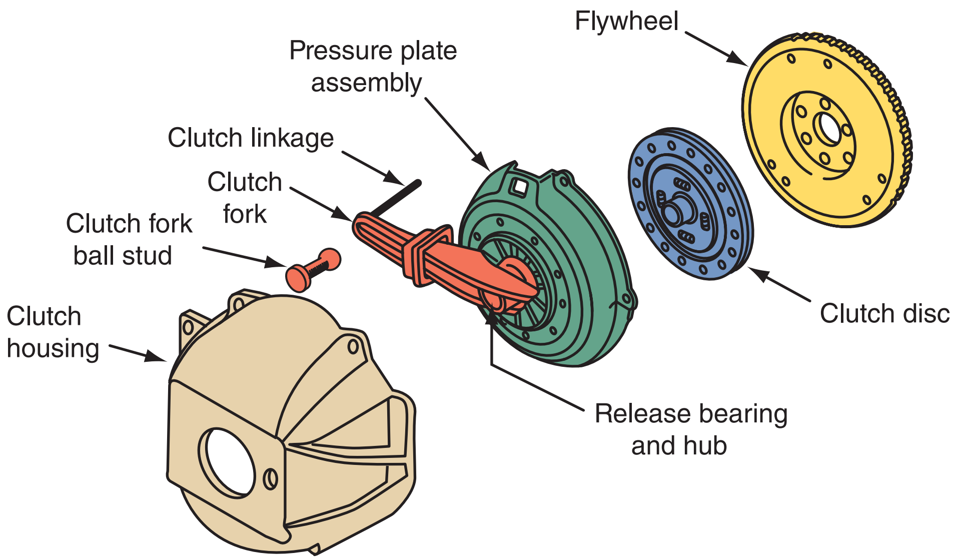


FIGURE 37–1 Major parts of a clutch assembly.

clutch housing) between the engine and the transmission.

All manual transmissions require a clutch to engage or disengage the transmission. If the vehicle had no clutch and the engine was always connected to the transmission, the engine would stop every time the vehicle was brought to a stop. The clutch allows the engine to idle while the vehicle is stopped. It also allows for easy shifting between gears. (Of course, all of this applies to manual transaxles as well.)

Operation

The basic principle of clutch operation is shown in **Figure 37–2**. The pressure plate and flywheel are the drive or input members of the assembly. The **clutch disc** (plate), also called the **friction disc**, is the driven or output member and is connected to the transmission's input shaft. As long as the clutch is disengaged (clutch pedal depressed), the drive members turn independently of the driven member, and the engine is disconnected from the transmission. However, when the clutch is engaged (clutch pedal released), the pressure plate moves toward the flywheel and the clutch disc is squeezed

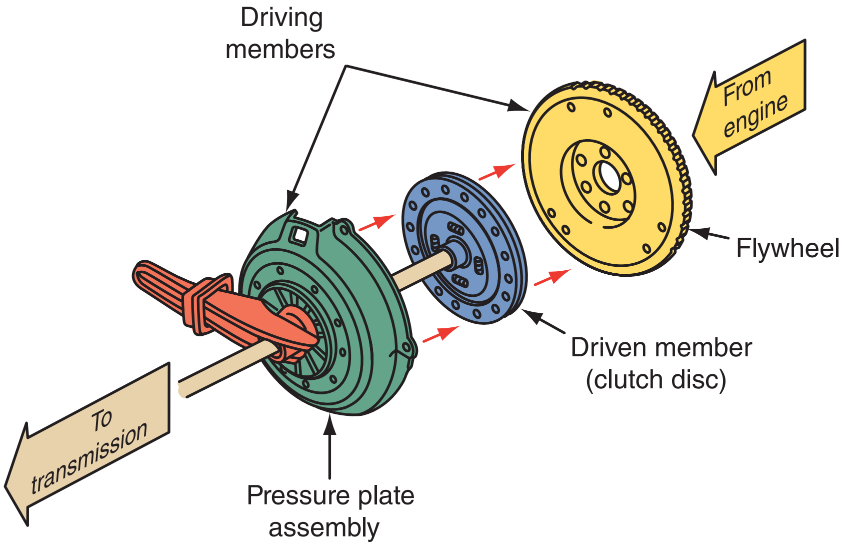


FIGURE 37–2 When the clutch is engaged, the driven member is squeezed between the two driving members. The transmission is connected to the driven member.

between the two revolving drive members and forced to turn at the same speed.

Warning! Use the appropriate cleaning liquid and equipment before and during disassembling a clutch assembly. Some clutch discs were made with asbestos. Inhalation of asbestos can cause serious illnesses. Assume that all clutch discs have asbestos and follow the procedures for containing it.

Torque Transfer

When the clutch is firmly clamped between the flywheel and pressure plate, engine torque moves into the transmission. A clutch assembly is designed to prevent any loss of torque when it is engaged, but it needs to allow some slippage as the disc begins to be squeezed between the pressure plate and the flywheel. This slippage prevents jarring that can result from the sudden transfer of power to the wheels.

Flywheel

The flywheel, an important part of the engine, is also the main driving member of the clutch **(Figure 37–3)**. It is normally made of nodular or gray cast iron, which has a high graphite content to lubricate the engagement of the clutch. Welded to or pressed onto the outside diameter of the flywheel is the starter ring gear. The large diameter of the flywheel allows for an excellent gear ratio of the starter drive to ring gear, which provides for ample engine rotation during starting. The rear surface of the flywheel is a friction surface machined very flat to ensure smooth clutch engagement. The flywheel also provides some absorption of torsional vibration of the crankshaft. It further provides the inertia to rotate the crankshaft through the four strokes.

The flywheel has two sets of bolt holes drilled into it. The inner set is used to fasten the flywheel to the crankshaft, and the outer set provides a mounting plate for the pressure plate assembly. A bore in the center of the flywheel and crankshaft holds the **pilot bushing** or bearing, which supports the front end of the transmission input shaft and maintains alignment with the engine's crankshaft. Often a ball or roller needle bearing is used instead of a pilot bushing. Some transaxles have a short, self-centering input shaft that does not require a pilot bushing or bearing.

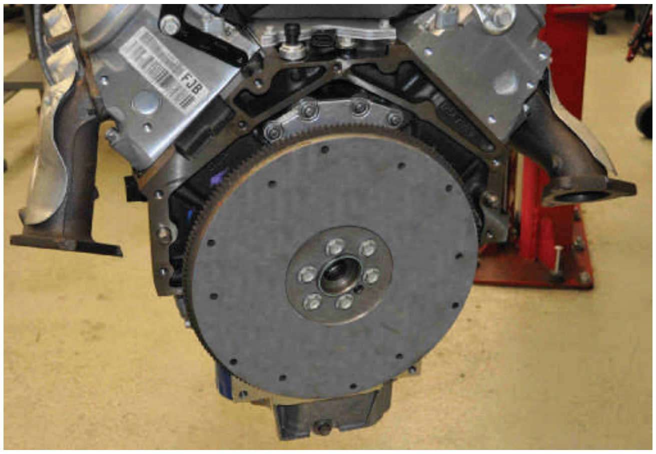


FIGURE 37–3 A typical flywheel mounted to the rear of an engine's crankshaft.

Dual-Mass Flywheel A few cars and light trucks use a **dual-mass flywheel** (DMF) and their use will likely increase as manufacturers continue to downsize their engines. These flywheels are used to reduce engine vibrations transmitted through the transmission, provide for smoother shifting, and reduce gear noise. Dual-mass flywheels can reduce the oscillations of the crankshaft before they move through the transmission **(Figure 37–4)** by acting as a torsional damper.

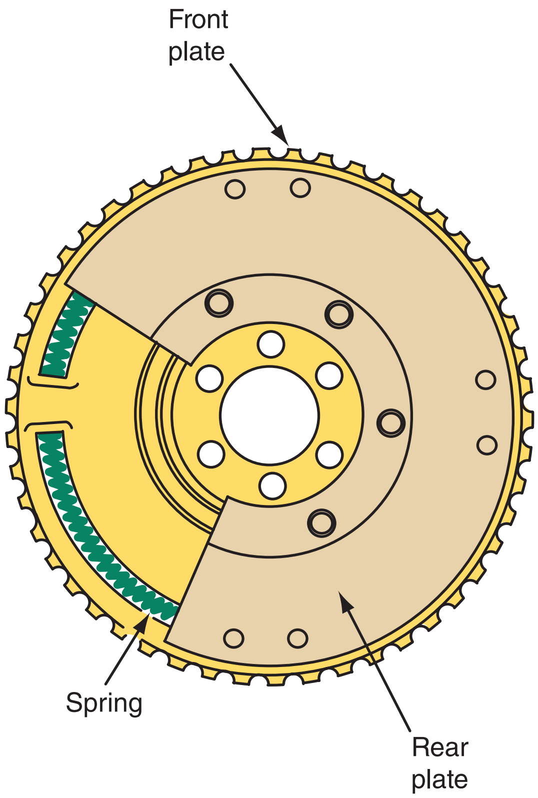


FIGURE 37–4 A dual-mass flywheel.

The flywheel consists of two rotating plates connected by a spring and damper system. The forward most portion of the flywheel is bolted to the end of the crankshaft and smooths out the crankshaft's oscillations. The pressure plate of the clutch is bolted to the rearward portion of the flywheel. Engine torque moves from the front plate through the damper and spring assembly to the rear plate before it enters the transmission. A bearing in the center allows for the two sections to rotate separately from each other. Depending on the vehicle, the flywheel may contain additional dampening elements which tune the flywheel to the engine application.

Some have a torque-limiting feature that prevents damage to the transmission during peak torque loads. The rotation of the two flywheel plates can differ by as much as 360 degrees. This allows the forward plate to absorb torque spikes and not pass them along through the transmission.

Clutch Disc

The clutch disc **(Figure 37–5)** is splined to the transmission's input shaft and receives the driving motion from the flywheel and pressure plate assembly and transmits that motion to the transmission input shaft. The parts of a clutch disc are shown in **Figure 37–6**.

The hub of the clutch plate has internal splines that fit over the external splines on the transmission's input shaft. As the clutch disc is engaged and disengaged, it slides back and forth on the splines. The clutch disc is designed to absorb such things as crankshaft vibration, abrupt clutch engagement, and driveline shock. The disc has a damper to reduce

FIGURE 37–5 A clutch disc.

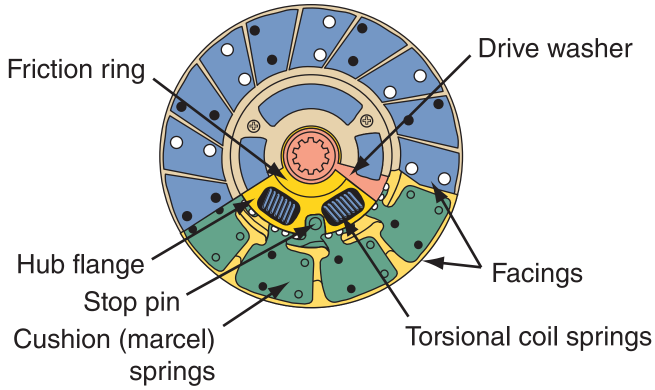


FIGURE 37–6 The major parts of a clutch disc.

the torsional vibrations caused by engine's power pulses. The damper is actually the disc hub and related springs. These torsional coil springs allow the disc to rotate slightly in relation to the pressure plate while they absorb the torque forces. The number and tension of these springs is determined by engine torque and vehicle weight. Stop pins limit this torsional movement to approximately inch.

Clutch Facings The facing of a disc is the frictional material that covers the steel clutch disc. The facing must be able to withstand the heat generated by the friction between the disc and the pressure plate. When the facing becomes over heated, clutch slippage can result followed by more heat. Overheated clutch discs do not have a long service life.

There are two types of facings. Molded friction facings can withstand greater pressure plate loading force without damage. Woven friction facings are used when additional cushioning action is needed for clutch engagement. In the past, the facing material was predominantly asbestos. Now, because of the hazards associated with asbestos, other materials such as paper-base and ceramics are being used instead. Particles of cotton, brass, rope, and wire are added to prolong the life of the clutch disc and provide torsional strength.

The amount of torque that can be transferred through the clutch disc mainly depends on how tightly the disc is squeezed and the facing's coefficient of friction. Basically, the coefficient of friction describes the amount of friction there is between two surfaces. The overall efficiency of a clutch assembly depends on its coefficient of friction. If a clutch's coefficient of friction is lower than desired, the clutch will slip. If the coefficient is higher than desired, the clutch will experience grabbing.

Grooves are cut across the face of the friction facings. This promotes clean disengagement of the driven disc from the flywheel and pressure plate; it

also promotes better cooling. The facings are riveted to wave springs, also called cushioning springs, which cause the contact pressure on the facings to rise gradually as the springs flatten out when the clutch is engaged. These springs reduce chatter when the clutch is engaged and also reduce the chance of the clutch disc sticking to the flywheel and pressure plate surfaces when the clutch is disengaged. The wave springs and friction facings are fastened to the steel disc.

Retaining Plate

The retaining plate of a clutch disc connects the disc's hub to the disc's facing. When the clutch is engaged, the facing and hub are squeezed together, in the same way as the disc is squeezed against the flywheel. Between the facing and the hub are wave springs, commonly called the marcel. These springs are compressed when the clutch is engaged and help to disengage the clutch when the pedal is depressed. The purpose of the marcel is to make engagement and disengagement as smooth as possible.

Pilot Bushing/Bearing

A pilot bushing or bearing **(Figure 37–7)** is sometimes used to support the outer end of the transmission's input shaft. This pilot is normally pressed into a bore at the center of the outer end of the engine's crankshaft. The transmission end of the input shaft is supported by a large bearing in the transmission case. Because the input shaft extends unsupported from the transmission, a pilot bushing is used to keep it in position. By supporting the shaft, the pilot bushing keeps the clutch disc centered in the pressure plate.

The pilot bushing can be made of sintered bronze saturated in oil during manufacture. Pilot bearings are normally needle bearings, but can be roller bearings or sealed bearing assemblies. Because the

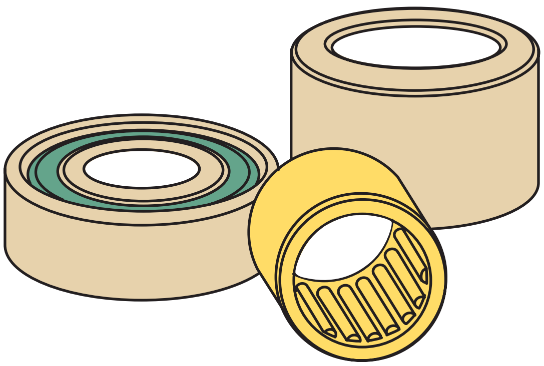


FIGURE 37–7 Different designs of pilot bushings and bearings used in today's clutch assemblies.

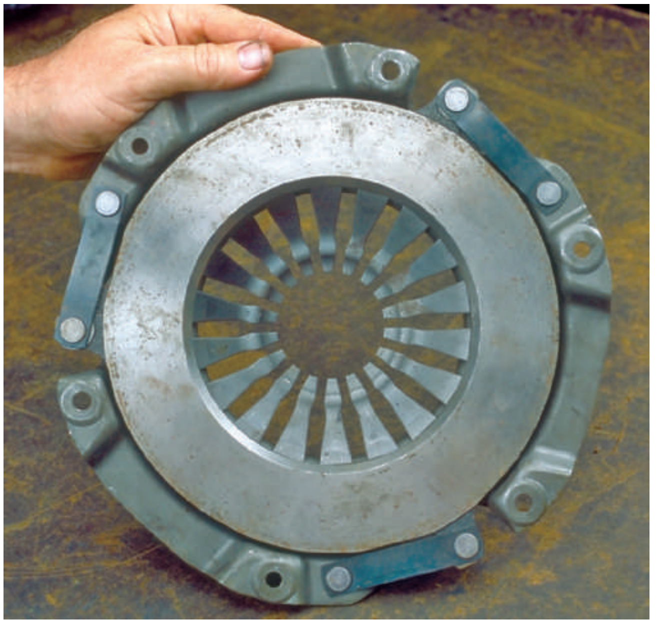


FIGURE 37–8 A diaphragm spring clutch pressure plate.

length of the input shaft is short or because the input shaft is supported internally by more than one bearing, there is no need for a pilot bearing or bushing with many transaxles.

Pressure Plate Assembly

A pressure plate assembly is comprised on a pressure ring (plate), cover, pressure springs, and release levers. The purpose of the assembly **(Figure 37–8)** is twofold. First, it must squeeze the clutch disc onto the flywheel with sufficient force to transmit engine torque efficiently. Second, it must move away from the clutch disc so the clutch disc can stop rotating when the clutch is disengaged, even though the flywheel and pressure plate continue to rotate.

The pressure ring is a flat, heavy iron ring that moves against the outside diameter of the clutch disc to squeeze it against the flywheel. The cover of a pressure plate assembly is normally a stamped-steel housing that serves as the mounting points for the pressure plate, pressure springs, and release levers. The cover bolts to the flywheel. Basically, there are two types of pressure plate assemblies: those with coil springs and those with a **diaphragm** spring.

Coil Spring Pressure Plate Assembly A coil spring pressure plate assembly **(Figure 37–9)** uses coil springs and release levers to move the pressure plate back and forth. The springs exert pressure to hold the pressure plate tightly against the clutch disc

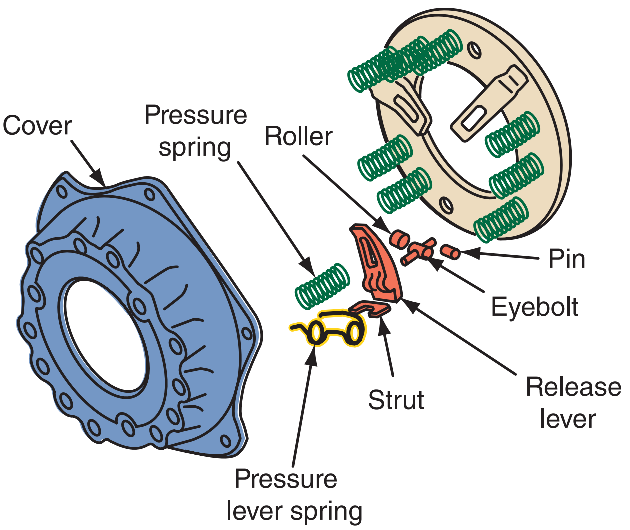


FIGURE 37–9 Parts of a coil spring pressure plate.

and flywheel. This forces the clutch disc against the flywheel. The release levers release the holding force of the springs. There are usually three of them. Each one has two pivot points. One of these pivot points attaches the lever to a pedestal cast into the pressure plate and the other to a release lever yoke/keybolt bolted to the cover. The levers pivot on the pedestals and release lever yokes to move the pressure plate through its engagement and disengagement operations.

To disengage the clutch, the release bearing pushes the inner ends of the release levers forward toward the flywheel. The release levers are class one levers, which means the fulcrum is between the effort and the load. Each end of the lever moves in the opposite direction. When force pushes one end of the lever down, the other end moves up. In a coil spring pressure plate, the release lever yokes act as fulcrums for the levers, and the outer ends of the release levers move backward, pulling the pressure plate away from the clutch disc. This compresses the springs and releases the clamping of the clutch disc between the pressure plate and flywheel.

When the clutch is engaged, the release bearing moves away from the pressure plate. This allows the pressure plate springs to push the pressure plate and clutch disc against the flywheel, allowing power transfer from the engine to the transmission.

Some of the advantages and disadvantages of a coil spring pressure plate include the following:

- Clamping pressure is increased or decreased by changing the number of springs and their tension.
- They require more pedal effort than diaphragm pressure plates.
- As the clutch disc wears, the coil springs expand and their clamping force is reduced.
- Because of these disadvantages, passenger cars and light trucks are now almost exclusively equipped with diaphragm spring clutches because of the disadvantages of coil spring pressure plates.

Diaphragm Spring Pressure Plate Assembly A diaphragm spring pressure plate assembly relies on a cone-shaped diaphragm spring between the pressure plate and the pressure plate cover to move the pressure plate back and forth. The diaphragm spring (sometimes called a Belleville spring) is a single, thin sheet of metal that works in the same manner as the bottom of an oil can. The metal yields when pressure is applied to it. When the pressure is removed, the metal springs back to its original shape. The center portion of the diaphragm spring is slit into numerous fingers that act as release levers **(Figure 37–10)**.

During clutch disengagement, these fingers are moved forward by the release bearing. The diaphragm spring pivots over the fulcrum ring (also called the pivot ring), and its outer rim moves away from the flywheel. The retracting springs pull the pressure plate away from the driven disc and disengage the clutch.

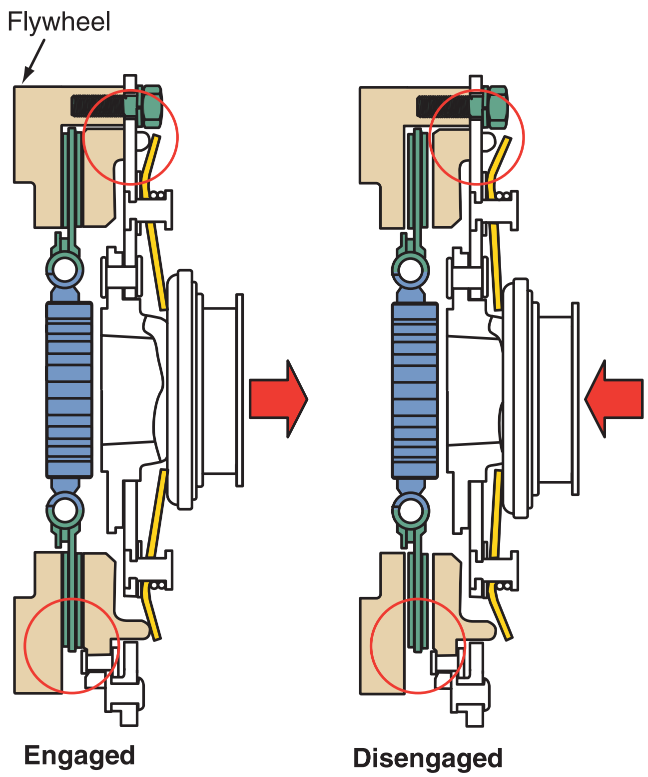


FIGURE 37–10 The action of a diaphragm spring-type pressure plate assembly.

When the clutch is engaged, the release bearing and the fingers of the diaphragm spring move toward the transmission. As the diaphragm pivots over the pivot ring, its outer rim forces the pressure plate against the clutch disc so the clutch is engaged to the flywheel.

Diaphragm spring pressure plate assemblies have the following advantages over other types of assemblies:

- Compactness
- Less weight
- Fewer moving parts to wear out
- Little pedal effort is required from the operator.
- They provide a balanced force around the pressure plate so rotational unbalance is reduced.
- Clutch disc slippage is less likely to occur. Mileage builds because the force holding the clutch disc to the flywheel does not change throughout its service life.

Clutch Release Bearing

The **clutch release bearing**, also called a **throwout bearing**, is usually a sealed, prelubricated ball bearing **(Figure 37–11)**. Its function is to smoothly and quietly move the pressure plate release levers or diaphragm spring through the engagement and disengagement process.

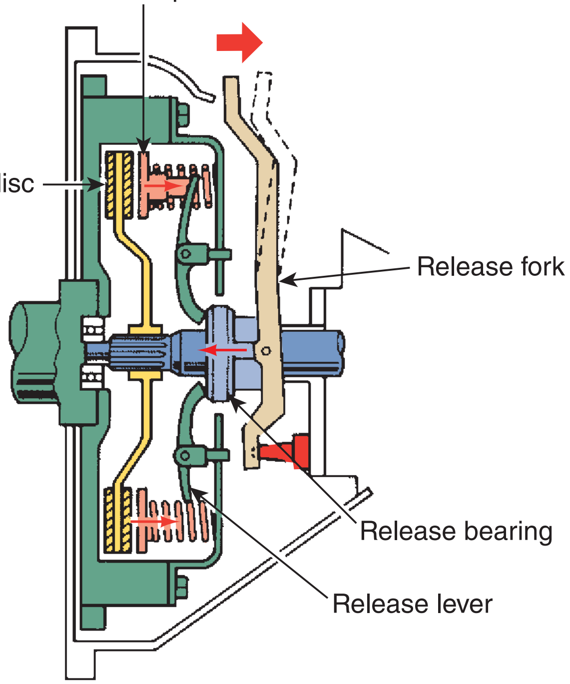


FIGURE 37–11 The action of the release fork and bearing on the pressure plate when the clutch pedal is depressed.

The release bearing is mounted on a hub, which fits over a hollow shaft at the front of the transmission housing. This hollow shaft fits over the clutch (input) shaft **(Figure 37–12)** and is part of the transmission's front bearing retainer.

To disengage the clutch, the release bearing is moved on its shaft by the **clutch fork**. As the release bearing contacts the release levers or diaphragm spring of the pressure plate assembly, it begins to rotate with the rotating pressure plate assembly. As the release bearing continues forward, the clutch disc is disengaged from the pressure plate and flywheel.

To engage the clutch, the release bearing slides to the rear of the shaft. The pressure plate moves forward and traps the clutch disc against the flywheel to transmit engine torque to the transmission input shaft. Once the clutch is fully engaged, the release bearing is normally stationary.

Rotating Release Bearing Self-adjusting clutch linkages, used on many vehicles, apply just enough tension to the clutch control cable to keep a constant light pressure against the release bearing. As a result, the release bearing is kept in contact with the release levers or diaphragm spring of the rotating pressure plate assembly. The release bearing rotates with the pressure plate.

Clutch Fork

The clutch fork is a forked lever that pivots on a support shaft or ball stud located in an opening in the bell housing. The forked end slides over the hub of the release bearing and the small end protrudes from the bell housing and connects to the clutch linkage and clutch pedal. The clutch fork moves the release bearing and hub back and forth during engagement and disengagement.

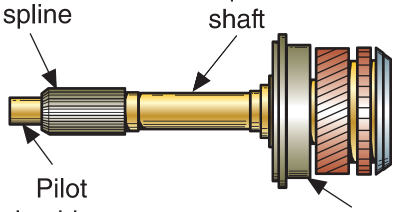


FIGURE 37–12 A clutch (input) shaft.

Clutch Linkage

The clutch linkage is a series of parts that connects the clutch pedal to the clutch fork. It is through the clutch linkage that the operator controls the engagement and disengagement of the clutch assembly smoothly and with little effort.

On some vehicles when the clutch is engaged, the clutch linkage pulls the release bearing a small amount away from the release levers in the pressure plate. The slight amount the release bearing is moved away from the pressure plate defines the free play of the clutch pedal. If the vehicle has a self-adjusting mechanical linkage or hydraulic linkage, there is always slight contact between the release bearing and the pressure plate.

Shaft and Lever Linkage Found on older vehicles, the shaft and lever clutch linkage has many parts and pivot points, and transfers the movement of the clutch pedal to the release bearing via shafts, levers, and bell cranks. On some vehicles, the pivot points were equipped with grease fittings; others had low-friction plastic grommets and bushings at their pivot points.

A typical shaft and lever clutch control assembly includes a release lever and rod, an equalizer or cross shaft, a pedal-to-equalizer rod, an assist or over-center spring, and the pedal assembly. Depressing the pedal moves the equalizer, which, in turn, moves the release rod. When the pedal is released, the assist spring returns the linkage to its normal position and removes the pressure on the release rod. This action causes the release bearing to move away from the pressure plate.

Cable Linkage A cable linkage can perform the same controlling action as the shaft and lever linkage but with fewer parts. The clutch cable system does not take up much room. It also has the advantage of flexible installation so it can be routed around the power brake and steering units. These advantages help to make it the most commonly used clutch linkage.

The clutch cable **(Figure 37–13)** is made of braided wire. The upper end is connected to the top of the clutch pedal arm, and the lower end is fastened to the clutch fork. It is designed with a flexible outer housing that is fastened at the fire wall and the clutch housing.

When the clutch pedal is pushed to the disengaged position, it pivots on the pedal shaft and pulls the inner cable through the outer housing. This action moves the clutch fork to disengage the clutch. The pressure plate springs and springs on the clutch

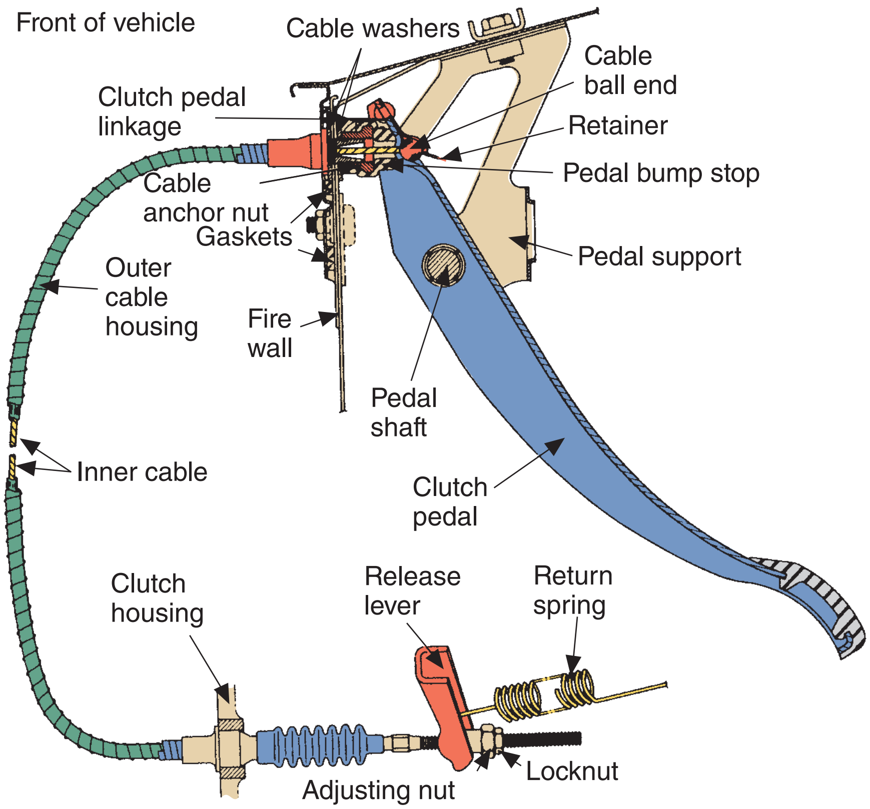


FIGURE 37–13 A typical clutch cable system.

pedal provide the force to move the cable back when the clutch pedal is released.

Self-Adjusting Clutch Self-adjusting clutch mechanisms monitor clutch pedal play and automatically adjust it when necessary.

Usually the self-adjusting clutch mechanism is a ratcheting mechanism located at the top of the clutch pedal behind the dash panel **(Figure 37–14)**. The ratchet is designed with a pawl and toothed segment, and a pawl tension spring is used to keep the pawl in contact with the toothed segment. The pawl allows the toothed segment to move in only one direction in relation to the pawl.

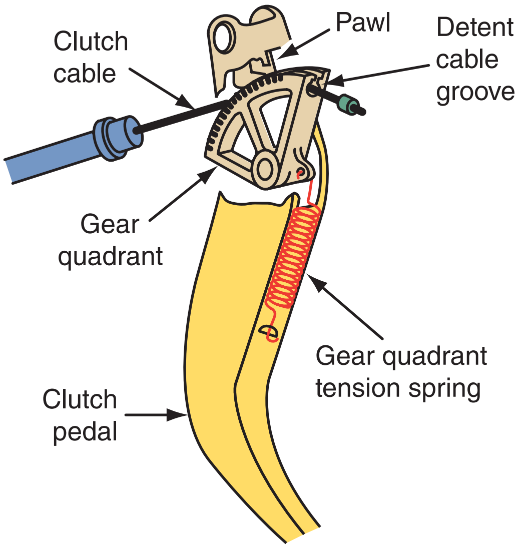


FIGURE 37–14 A typical clutch cable self-adjusting mechanism.

The clutch cable is guided around and fastened to the toothed segment, which is free to rotate in one direction (backwards) independently of the clutch pedal. The tension spring pulls the toothed segment backwards.

When the clutch cable develops slack due to stretching and clutch disc wear, the cable is adjusted automatically when the clutch is released. The tension spring pulls the toothed segment backwards and allows the pawl to ride over to the next tooth. This effectively shortens the cable. Actually, the cable is not really shortened; but the slack has been reeled in by the repositioning of the toothed segment. This self-adjusting action takes place automatically during the clutch's operational life.

Hydraulic-Operated Clutch Linkage Frequently, the clutch assembly is controlled by a hydraulic system **(Figure 37–15)**. In the hydraulic clutch linkage system, hydraulic (liquid) pressure transmits motion from one sealed cylinder to another through a hydraulic line. Like the cable linkage assembly, the hydraulic linkage is compact and flexible. These linkages allow engineers to place the release fork anywhere that gives them more flexibility in body design. In addition, the hydraulic pressure developed by the master cylinder decreases required pedal effort and provides a precise method of controlling clutch operation. Brake fluid is commonly used as the hydraulic fluid in hydraulic clutch systems. Some vehicles share the brake fluid reservoir with the clutch master cylinder reservoir as well.

A clutch slave cylinder can be mounted on the outside, or in the inside of the transmission. When

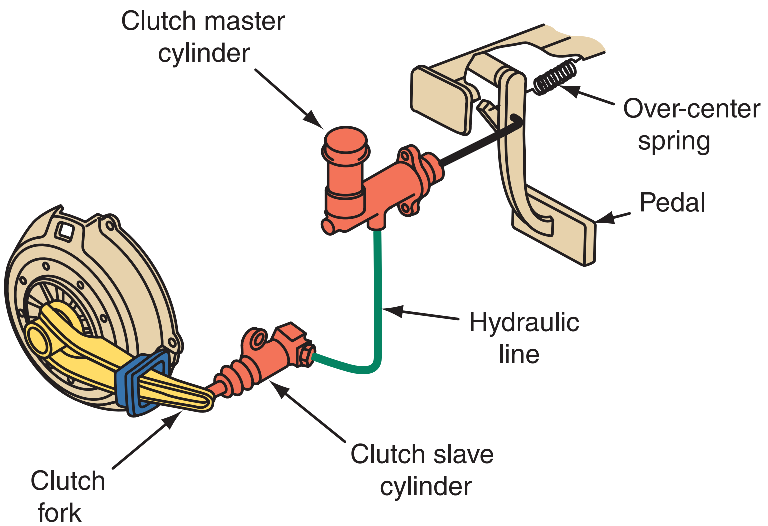


FIGURE 37–15 A typical hydraulic clutch linkage arrangement.

mounted at the outside of the transmission, the cylinder has a rod or lever that moves back and forth in response to the movement of the clutch pedal. The lever is in contact with the release fork, which controls the action of the pressure plate. A hydraulic clutch master cylinder's pushrod moves the piston and primary cup to create hydraulic pressure. A snapring restricts the travel of the piston. The secondary cup at the snapring end of the piston stops hydraulic fluid from dripping into the passenger compartment. The piston return spring holds the primary cup and piston in the fully released position. Hydraulic fluid is stored in the reservoir on top of the master cylinder housing.

The slave cylinder may have a bleeder valve to bleed air from the hydraulic system for efficient clutch linkage operation. The cylinder body is threaded for a tube and fitting at the fluid entry port. Rubber seal rings are used to seal the hydraulic pressure between the piston and the slave cylinder walls. The piston retaining ring is used to restrict piston travel to a certain distance. Piston travel is transmitted by a pushrod to the clutch fork. The pushrod boot keeps contaminants out of the slave cylinder.

When the clutch pedal is depressed, the movement of the piston and primary cup develops hydraulic pressure that is displaced from the master cylinder, through a tube, into the slave cylinder. The slave cylinder piston movement is transmitted to the clutch fork, which disengages the clutch.

When the clutch pedal is released, the primary cup and piston are forced back to the disengaged position by the master cylinder piston return spring. External springs move the slave cylinder pushrod and piston back to the engaged position. Fluid pressure returns through the hydraulic tubing to the master cylinder assembly. There is no residual pressure in the system when the clutch assembly is in the engaged position.

Concentric Slave Cylinders A concentric (internal) slave cylinder is found on some cars and light trucks. These units are actually a combination of the slave cylinder and the clutch release bearing **(Figure 37–16)**. These slave cylinders may be made of plastic, aluminum, or cast iron. They also are part of a hydraulic clutch system and are controlled by pressurized mineral oil or brake fluid.

By having the slave cylinder directly behind the release bearing, the movement of the release bearing is linear. In other clutch linkage designs, the release bearing moves through an arc as it engages and disengages the clutch.

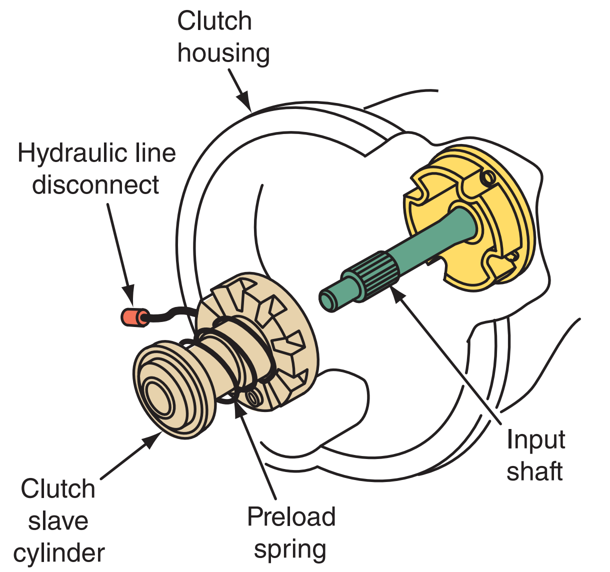


FIGURE 37–16 A concentric internal clutch slave cylinder.

An internal slave cylinder is a doughnut-shaped unit that mounts to the front of the transmission, and the transmission's input shaft passes through it. The slave cylinder is either bolted to the transmission's front bearing cover or is held by a pressed pin **(Figure 37–17)**.

A concentric slave cylinder reduces the weight of clutch linkage assembly and extends the assembly's service life because it has fewer parts. However, in most cases, the transmission must be removed to properly diagnose it.

Clutch Pedal Switch Nearly all vehicles have a clutch pedal switch. This switch is used to let the

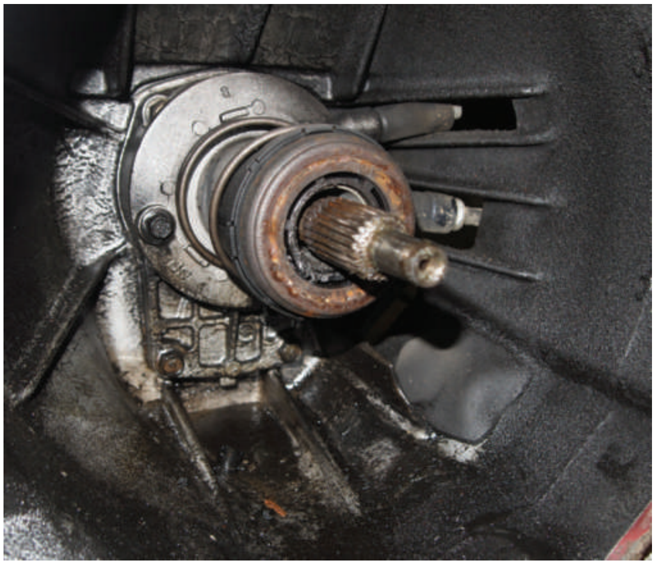


FIGURE 37–17 A concentric slave cylinder bolted to the transmission's front bearing cover.

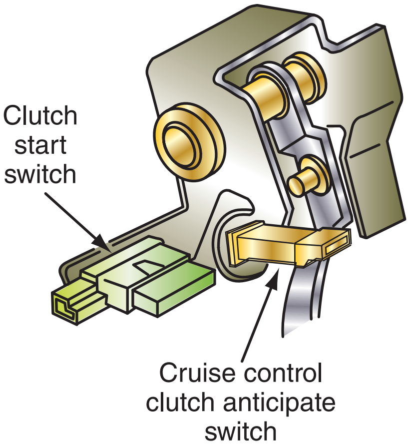


FIGURE 37–18 Various clutch switches are used to control engine starting and cruise control operation.

PCM know the clutch pedal is depressed to allow the engine to start and to cancel cruise control operation **(Figure 37–18)**. The switch is a normally open switch that closes when the clutch pedal is fully depressed. If the switch is adjustable, it is important to make sure the adjustment is correct after any linkage adjustment has been made.

Clutch Service Safety Precautions

When servicing the clutch, exercise the following precautions:

- Always wear eye protection when working underneath a vehicle.
- Remove asbestos dust only with a special, approved vacuum collection system or an approved liquid cleaning system.
- Never use compressed air or a brush to clean off asbestos dust.
- Follow all federal, state, and local laws when disposing of collected asbestos dust or liquid containing asbestos dust.
- Never work under a vehicle that is not raised on a hoist or supported by safety or jack stands.
- Use jack stands and special jacks to support the engine and transmission.
- Have a helper assist in removing the transmission.
- Be sure the work area is properly ventilated, or attach a ventilating hose to the vehicle's exhaust system when an engine is to be run indoors.
- Do not allow anyone to stand in front of or behind the automobile while the engine is running.
- Set the emergency brake securely and place the gearshift in neutral when running the engine of a stationary vehicle.
- Avoid touching hot engine and exhaust system parts. Whenever possible, let the vehicle cool down before beginning to work on it.

Clutch Maintenance

Clutches may require checking and adjustment of linkage at regular intervals. Vehicles with external clutch linkage require periodic lubrication. These maintenance procedures are explained in this section.

Clutch Fluid Level

The fluid for a hydraulic clutch system is checked by looking at the fluid's level in the master cylinder's reservoir. Most reservoirs have a mark to indicate the proper level. If there are no marks, check the service information. Normally, the desired level is ¼- to ½-inch (6 to 9 mm) from the top.

Clutch Linkage Adjustment

Except for systems with self-adjusting linkages, the release bearing should not touch the pressure plate release levers when the clutch is engaged (pedal up). Clearance between these parts prevents premature clutch plate, pressure plate, and release bearing wear. As the clutch disc wears and becomes thinner, this clearance is reduced.

This clearance can be adjusted to provide the clutch linkage with a specified amount of play, or **free travel**. Free travel is the distance a clutch pedal moves when depressed before the release bearing contacts the clutch release lever or diaphragm spring of the pressure plate. Insufficient free travel can prevent the clutch from completely engaging by keeping pressure against the release bearing. Excessive play may not allow the clutch to completely disengage.

To check pedal play, use a tape measure or ruler. Place the tape measure or ruler beside the clutch

USING SERVICE INFORMATION

The service information should include adjustment procedures and instructions for clutch removal, inspection, installation, and troubleshooting. It may also offer information to aid in clutch release bearing analysis.

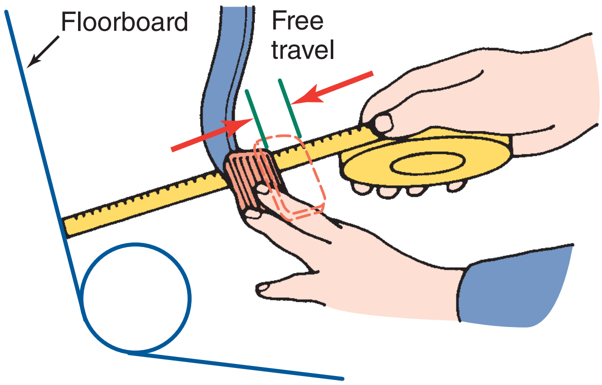


FIGURE 37–19 Checking clutch pedal play.

pedal and the end against the floor of the vehicle and note the reading **(Figure 37–19)**. Then depress the clutch pedal just enough to take up the pedal play and note the reading again. The difference between the two readings is the amount of pedal play.

To adjust clutch pedal play, refer to the manufacturer's service information for the correct procedure and adjustment points. Often pedal play can be increased or decreased by turning a threaded fastener located either under the dash at the clutch pedal or where the linkage attaches to the clutch fork.

Clean the linkage with a shop towel and solvent, if necessary, before checking it and replacing any damaged or missing parts or cables. Check hydraulic-operated linkage systems for leaks at the clutch master cylinder, hydraulic hose, and slave cylinder.

External Clutch Linkage Lubrication

External clutch linkage should be lubricated at regular intervals, such as during a chassis lubrication. Refer to the vehicle's service information to determine the proper lubricant. Many clutch linkages use the same chassis grease used for suspension parts and U-joints. Lubricate all the sliding surfaces and pivot points in the clutch linkage **(Figure 37–20)**. The linkage should move freely after lubrication.

On vehicles with hydraulic clutch linkage, check the clutch master cylinder reservoir fluid level. It should be approximately ¼ inch (6.35 mm) from the top of the reservoir. If it must be refilled, use approved brake fluid. Also, because the clutch master cylinder does not consume fluid, check for leaks in the master cylinder, connecting flexible line, and slave cylinder, if the fluid is low. On some vehicles, the brake fluid reservoir is shared with the hydraulic clutch.

SHOP TALK Normally, clutch condition will dictate the amount of clutch pedal free play. However, there should always be free play with hydraulic clutch systems.

Clutch Problem Diagnosis

Check and attempt to adjust the clutch pedal play before attempting to diagnose any clutch problems. If the friction lining of the clutch is worn too thin **(Figure 37–21)**, the clutch cannot be adjusted successfully. The most common clutch problems are described here.

Slippage

Clutch slippage is a condition in which the engine overspeeds without generating any increase in torque to the driving wheels. It occurs when the clutch disc is not gripped firmly between the flywheel and the pressure plate. Instead, the clutch disc slips between these driving members. Slippage can occur during initial acceleration or subsequent shifts.

One way to check for slippage is by driving the vehicle. Normal acceleration from a stop and several gear changes indicate whether the clutch is slipping.

Slippage also can be checked in the shop. Check the service information for the correct procedures. A general procedure for checking clutch slippage follows. Be sure to follow the safety precautions stated earlier.

With the parking brake on, disengage the clutch. Shift the transmission into third gear, and increase the engine speed to about 2,000 rpm. Slowly release the clutch pedal until the clutch engages. The engine should stall immediately.

If it does not stall within a few seconds, the clutch is slipping. Safely raise the vehicle and check the clutch linkage for binding and broken or bent parts. If no linkage problems are found, the transmission and the clutch assembly must be removed so the clutch parts can be examined.

Clutch slippage can be caused by an oil-soaked or worn disc facing, warped pressure plate, weak or broken diaphragm spring, or the release bearing

SHOP TALK Severe or prolonged clutch slippage causes grooving or heat damage to the pressure plate and/or flywheel.

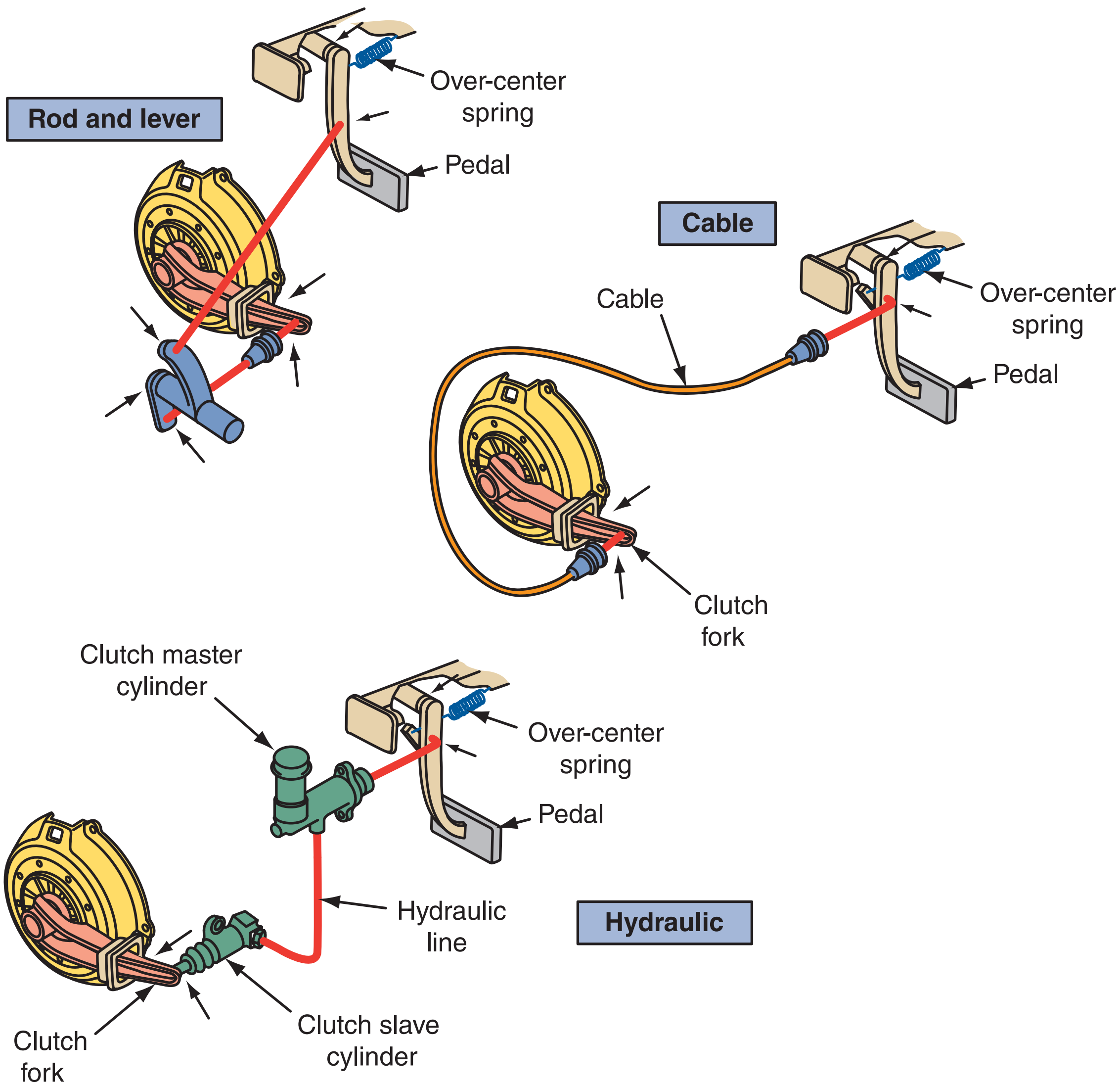


FIGURE 37–20 Clutch linkage lubrication points.

contacting and applying pressure to the release levers. The latter may be corrected by adjusting the pedal's free travel.

Drag and Binding

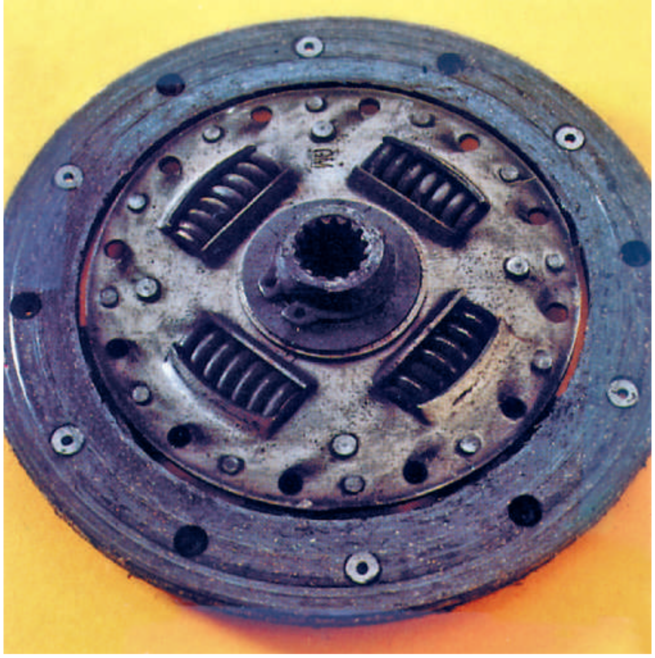
If the clutch disc is not completely released when the clutch pedal is fully depressed, clutch drag occurs. Clutch drag causes gear clash, especially when shifting into reverse. It can also cause hard starting and vehicle movement during starting because the engine attempts to turn the transmission input shaft.

To check for clutch drag, start the engine, depress the clutch pedal completely, and shift the transmission into first gear. Do not release the clutch. Then shift the transmission into neutral and wait 5 seconds before attempting to shift smoothly into reverse.

It should take no more than 5 seconds for the clutch disc, input shaft, and transmission gears to come to a complete stop after disengagement. This period, called the clutch spindown time, is normal and should not be mistaken for clutch drag.

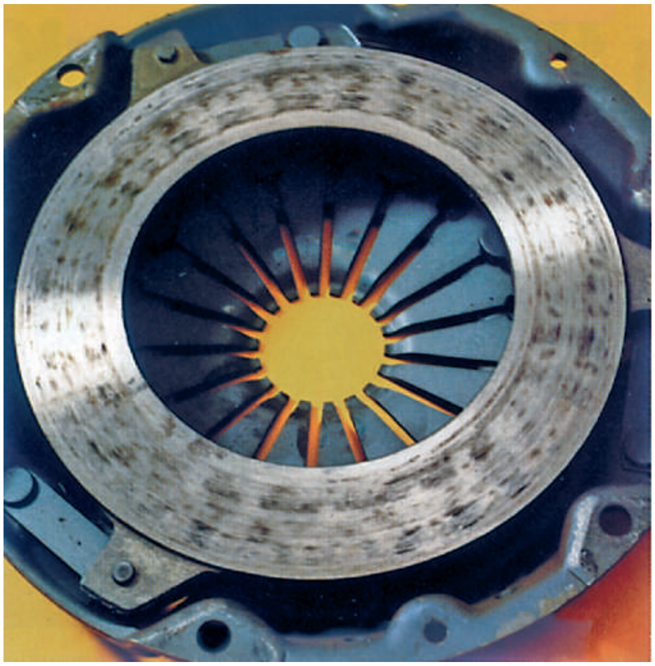
If the shift into reverse causes gear clash, raise the vehicle safely and check the clutch linkage for binding, broken, or bent parts. If no problems are found in the linkage, the transmission and clutch assembly must be removed so that the clutch parts can be examined.

Clutch drag can occur as a result of a warped disc or pressure plate, a loose disc facing, a defective release lever, or incorrect clutch pedal adjustment that results in excessive pedal play. A binding or seized pilot bushing or bearing can also cause clutch drag. A cracked or broken fire wall around the clutch master cylinder or cable guide can also cause



Courtesy of LuK Automotive Systems.

FIGURE 37–21 A severely worn clutch disc.



Courtesy of LuK Automotive Systems.

FIGURE 37–22 The marks on the surface of this pressure plate are caused by clutch chatter.

the clutch to bind or drag. Because the cable or master cylinder is mounted to the fire wall, they will be able to move by the force exerted on the clutch linkage.

Binding can result when the splines in the clutch disc hub or on the transmission input shaft are damaged or when there are problems with the release levers.

Chatter

A shaking or shuddering that is felt in the vehicle as the clutch is engaged is known as clutch **chatter (Figure 37–22)**. It usually occurs when the pressure plate first contacts the clutch disc and stops when the clutch is fully engaged.

To check for clutch chatter, start the engine, depress the clutch completely, and shift the transmission into first gear. Increase engine speed to about 1,500 rpm, then slowly release the clutch pedal and check for chatter as the pedal begins to engage. Do not release the pedal completely, or the vehicle might jump and cause serious injury. As soon as the clutch is partially engaged, depress the clutch pedal immediately and reduce engine speed to prevent damage to the clutch parts.

Usually clutch chatter is caused by liquid leaking onto the clutch and contaminating its friction surfaces. This results in a mirrorlike shine on the pressure plate or a glazed clutch facing. Oil and clutch hydraulic fluid leaks can occur at the engine rear main bearing seal transmission input shaft seal, clutch slave cylinder, and hydraulic line. Other causes of clutch chatter include broken engine or transmission mounts, loose bell housing bolts, and damaged clutch linkage.

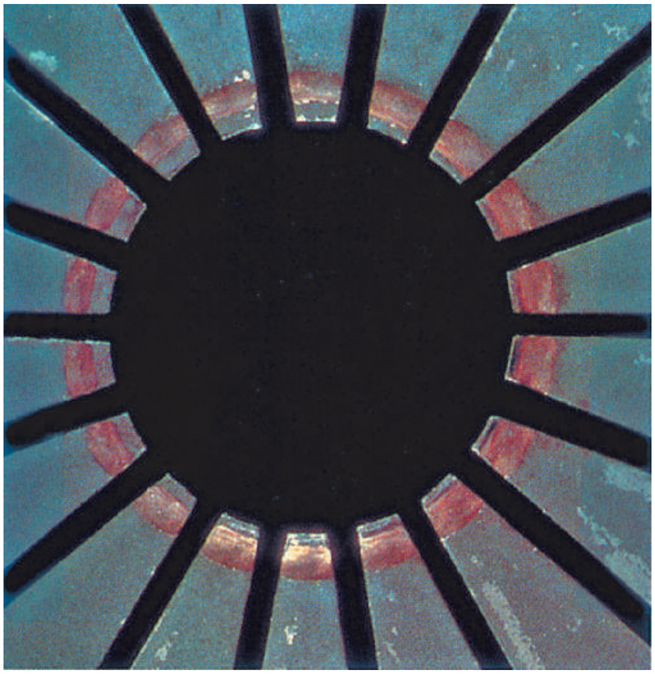
During disassembly, check for a warped pressure plate or flywheel, hot spots on the flywheel, a burned or glazed disc facing, and worn input shaft splines. If the chattering is caused by an oil-soaked clutch disc and no other parts are damaged, then the disc alone needs to be replaced. However, the cause of the oil leak must also be found and corrected.

Clutch chatter can also be caused by broken or weak torsional coil springs in the clutch disc and by the failure to resurface the flywheel when a new clutch disc and/or pressure plate is installed. It is highly recommended that the flywheel be resurfaced every time a new clutch disc or pressure plate is installed.

Pedal Pulsation

Pedal pulsation is a rapid up-and-down movement of the clutch pedal as the clutch disengages or engages. This pedal movement usually is minor, but it can be felt through the clutch pedal. It is not accompanied by any noise. Pulsation begins when the release bearing makes contact with the release levers.

To check for pedal pulsation, start the engine, depress the clutch pedal slowly until the clutch just begins to disengage, and then stop briefly. Resume



Courtesy of LuK Automotive Systems.

FIGURE 37–23 The shiny areas on this pressure plate shows that the release bearing is not evenly contacting the pressure plate.

depressing the clutch pedal slowly until the pedal is depressed to a full stop.

On many vehicles, minor pulsation is considered normal. If pulsation is excessive, the clutch must be removed and disassembled for inspection.

Pedal pulsations can result from the misalignment of parts. Check for a misaligned bell housing or a bent flywheel. Inspect the clutch disc and pressure plate for warpage. Broken, bent, or warped release levers also create misalignment **(Figure 37–23)**.

Vibration

Clutch vibrations, unlike pedal pulsations, can be felt throughout the vehicle, and they occur at any clutch pedal position. These vibrations usually occur at normal engine operating speeds (more than 1,500 rpm).

CUSTOMER CARE

If you repair a vehicle with clutch slippage, tactfully inform the customer about the different poor driving habits that can cause this problem. These habits include riding the clutch pedal and holding the vehicle on an incline by using the clutch as a brake.

There are several possible sources of vibration that should be checked before disassembling the clutch to inspect it. Check the engine mounts and the crankshaft damper pulley. Look for any indication that engine parts are rubbing against the body or frame.

Accessories can also be a source of vibration. To check them, remove the drive belts one at a time. Set the transmission in neutral, and securely set the emergency brake. Start the engine and check for vibrations. Do not run the engine for more than 1 minute with the belts removed.

If the source of vibration is not discovered through these checks, the clutch parts should be examined. Be sure to check for loose flywheel bolts, excessive flywheel runout, and pressure plate cover balance problems.

Noises

Many clutch noises come from bushings and bearings. Pilot bushing noises are squealing, howling, or trumpeting sounds that are most noticeable in cold weather. These bushing noises usually occur when the pedal is being depressed and the transmission is in neutral. Release bearing noise is a whirring, grating, or grinding sound that occurs when the clutch pedal is depressed and stops when the pedal is fully released. It is most noticeable when the transmission is in neutral, but it also can be heard when the transmission is in gear.

Hydraulic-Operated Clutch Diagnosis

Diagnostics of a hydraulic clutch system should begin with an inspection of the fluid. Check the fluid and reservoir for dirt and contamination. Foreign matter in the fluid will destroy the seals and wear grooves in the master and slave cylinders' bores.

A soft clutch pedal, excessive pedal travel, or a clutch that fails to release when the pedal is depressed can be caused by low fluid in the reservoir. To correct this problem, refill the reservoir to the correct level then bleed the system. This problem can also be caused by a faulty or damaged primary or secondary seal in the master cylinder. A leaking secondary seal will be evident by external leaks, whereas a primary seal leak will be internal. To correct either of these problems, replace the master cylinder, then refill and bleed the system.

If the seals inside a slave cylinder are bad, fluid will leak out and air will leak in causing a soft and spongy pedal. A leaking slave cylinder should be replaced and the system refilled with fluid and then bled.

If there is an extremely hard pedal, check the pedal mechanism and release fork for binding. If there is evidence of binding, repair and lubricate the assembly to ensure free movement. A hard pedal can also be caused by a blocked compensation port in the master cylinder. The port may be blocked by improper pushrod adjustments or because the piston is binding in the master cylinder bore. If the piston is binding, the master cylinder should be replaced or rebuilt and the hydraulic system flushed, refilled, and bled. This problem may be also caused by swollen cup seals or contamination in the master or slave cylinders. If this is the problem, the master or slave cylinder should be replaced and the system flushed, refilled, and bled. Restricted hydraulic lines can also cause a hard pedal.

Restricted lines can also prevent the clutch from being totally engaged. The residual pressure will keep the release bearing in contact with the pressure plate. This problem will also cause wear on the pressure plate fingers and the release bearing. Restricted lines should be replaced and the system flushed to remove all debris.

If the clutch does not fully engage when the pedal is released, check the pedal and release assemblies for binding or improper adjustment. A swollen primary cup in the master cylinder can also cause this problem. Swollen cups are caused by fluid contamination. This is typically the result of ATF being added to the fluid reservoir instead of DOT-3 brake fluid, which is the most commonly used fluid in a hydraulic-operated clutch system. If this is the case, the master and slave cylinders should be replaced and the system flushed.

Clutch Service

A prerequisite for removing and replacing the clutch in a vehicle is removing the driveline or drive shafts and transmission or transaxle.

Removing the Clutch

After raising the vehicle on a hoist, clean excessive dirt, grease, or debris from around the clutch and transmission. Then disconnect and remove the clutch linkage. Cable systems need to be disconnected at the transmission.

On rear-wheel drive vehicles, remove the driveline and transmission because the engine is somewhat supported by the transmission mounts. It may be necessary to support the engine with a tall jack stand. In some cases, the bell housing is removed with the transmission. In other cases, it is removed after the transmission is removed.

On front-wheel drive vehicles with transaxles, any parts that interfere with transaxle removal must be removed first. These parts might include drive axles, parts of the engine, brake and suspension system, or body parts. Check the service information for specific instructions.

The clutch assembly is accessible after the bell housing has been removed. Use an approved vacuum collection system or an approved liquid cleaning system to remove asbestos dust and dirt from the clutch assembly.

Photo Sequence 313 outlines the typical procedure for replacing a clutch disc and pressure plate. Always refer to the manufacturer's recommendations for bolt torque specifications prior to reinstalling the assembly. Compare the new parts with the old to make sure they are the correct replacements. This includes checking the splines of the disc with the input shaft.

While working on a clutch assembly, follow these guidelines:

- Check the bell housing, flywheel, and pressure plate for signs of oil leakage. Identify and repair the cause before installing new parts.
- Make sure that the mating surfaces of the engine block and bell housing are clean. The smallest amount of dirt can cause misalignment, which can cause premature wear of transmission shafts and bearings.
- Check the engine-to-bell housing dowels and dowel bores. Replace or repair any damaged parts.
- Check the mounting surfaces of the bell housing for damage and runout.
- Use a clutch alignment tool during disassembly and reassembly **(Figure 37–24)**. The tool will keep the disc centered on the pressure plate.
- Loosen and tighten the pressure plate bolts according to the prescribed sequence.

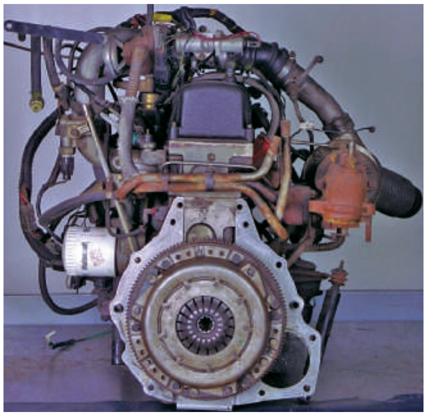
When installing a flywheel, make sure the bolts are tightened to specifications and in the prescribed sequence (normally a star pattern).

When measuring the lining thickness of a bonded clutch disc, measure the total thickness of the facing or lining. To measure the wear of a riveted lining, measure the material above the rivet heads.

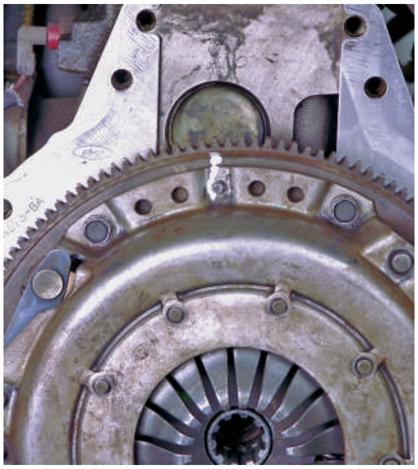
- Keep grease off the frictional surfaces of the clutch disc, flywheel, and pressure plate.
- Check the pressure plate surface for warpage by laying a straightedge across the surface and inserting a feeler gauge between the surface and the straightedge. Compare the measurement against the specifications given in the service information.

PHOTO SEQUENCE 31

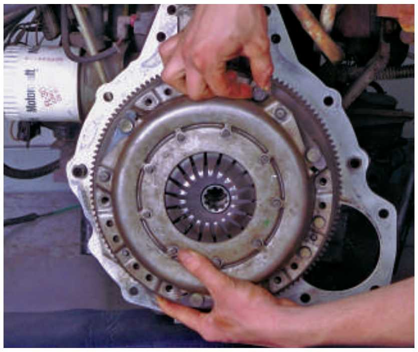
Installing and Aligning a Clutch Disc



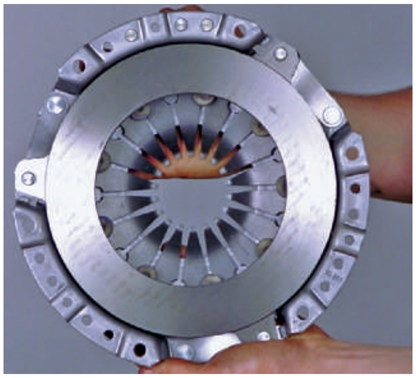
P31-1 The removal and replacement of a clutch assembly can be completed while the engine is in or out of the car. The clutch assembly is mounted to the flywheel that is mounted to the rear of the crankshaft.



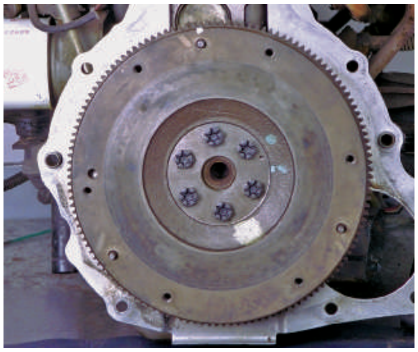
P31-2 Before disassembling the clutch, make sure alignment marks are present on the pressure plate and flywheel.



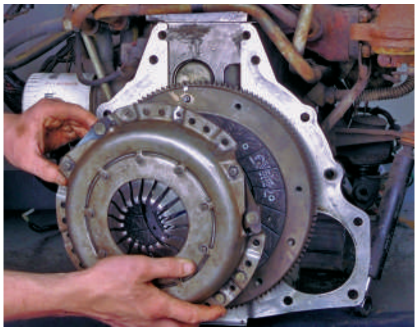
P31-3 The attaching bolts should be loosened before removing any of the bolts. With the bolts loosened, support the assembly with one hand while using the other to remove the bolts. The clutch disc will be free to fall as the pressure plate is separated from the flywheel. Keep it intact with the pressure plate.



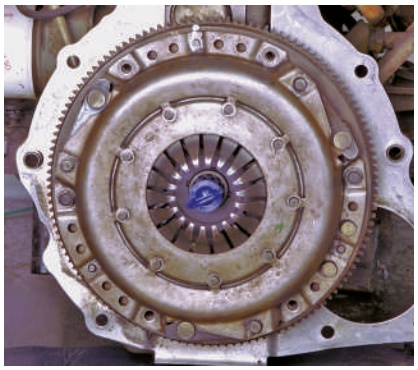
P31-4 The surface of the pressure plate should be inspected for signs of burning, grooving, warpage, and cracks. Any faults normally indicate that the plate should be replaced.



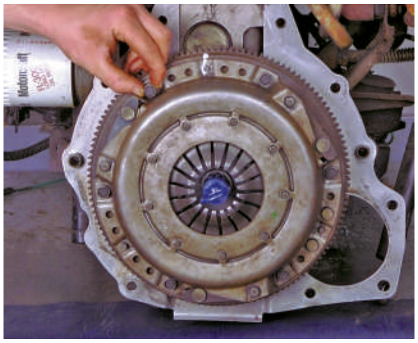
P31-5 The surface of the flywheel should also be carefully inspected. Normally the flywheel surface can be resurfaced to remove any defects. Also check the runout of the flywheel. The pilot bushing or bearing should also be inspected.



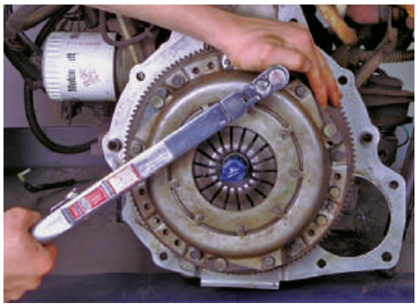
P31-6 The new clutch disc is placed into the pressure plate as the pressure plate is moved into its proper location. Make sure the disc is facing the correct direction. Most are marked to indicate which side should be seated against the flywheel surface.



P31-7 Install the pressure plate according to the alignment marks made during disassembly. Then install the clutch alignment tool through the hub of the disc and the pilot bearing to center the disc on the flywheel.



P31-8 Install the attaching bolts, but do not tighten.



P31-9 With the disc aligned, tighten the attaching bolts according to the procedures outlined in the service information and check the release finger/lever height after tightening the bolts. In most cases, the flywheel will need to be held in order to tighten the bolts.

FIGURE 37–24 An assortment of clutch alignment tools.

- Check the release levers of the pressure plate for uneven wear or damage.
- Check the release bearing by turning it with your fingers and making sure it rotates freely.
- Check the pilot bushing or bearing for wear. Replace it if necessary.
- Lightly lubricate the input shaft and bearing retainer **(Figure 37–25)**.
- Lubricate the clutch fork pivot points, the inside of the release bearing hub, and the linkages.
- After the clutch assembly has been reinstalled, check the clutch pedal free travel.

Flywheel Inspection The flywheel should have a smooth and flat surface. Check the flywheel for signs of glazing, overheating, or excessive wear. Discoloration of the surface may indicate glazing or overheating of the flywheel. If the surface of the flywheel appears to have slight grooves or shows signs of uneven wear, it should be resurfaced or replaced. If it has any evidence of cracks, it must be replaced. If the flywheel's surface appears to be fine, it does not need resurfacing or replacement. Check the teeth on the flywheel's ring gear; if there is damage, the ring gear or flywheel should be replaced.

Careful attention should be paid to make sure there are no signs of warpage or hard spots. Warpage occurs with overheating and can cause clutch chatter and vibrations. The flatness of the flywheel can be checked with a straightedge and a feeler

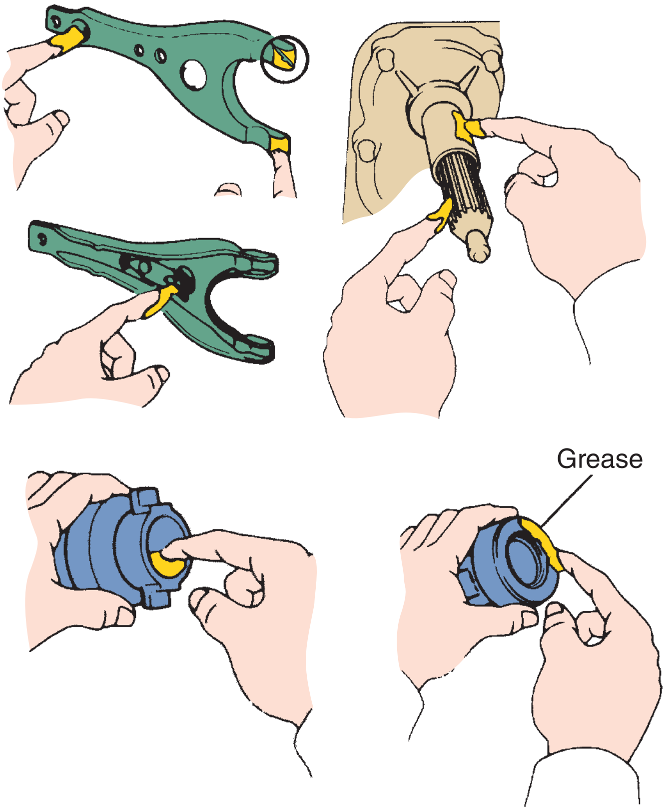


FIGURE 37–25 All contact points of the clutch release system should be lightly lubricated. Avoid applying too much grease.

gauge set. Typically, if the warpage is greater than 0.002 inch per inch of the flywheel's diameter, the flywheel should be resurfaced or replaced. The overall runout of the flywheel should also be checked **(Figure 37–26)**.

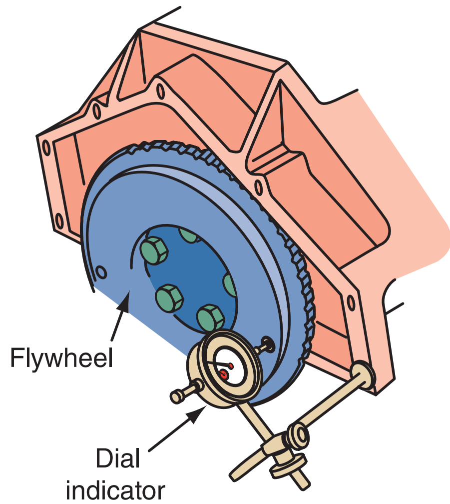


FIGURE 37–26 Measure the runout of the flywheel with a dial indicator.

Hard spots are evident as raised areas on the surface that take on a blueish tint. Hard spots can cause clutch chattering. At times, the hard spots can be removed by resurfacing the flywheel; other times, flywheel replacement is the only cure.

Dual-Mass Flywheel Inspection

During the service life of a DMF, the internal springs will weaken and the bearings will wear. This can allow vibration and noise to increase. Two measurements are common: free play in the internal spring and play in the bearing between the two masses. Special testing tools may be required to accurately check the flywheel. Typically, the ring gear is secured and an angle gauge is used to measure the movement of the internal mass. The measurement movement is compared to a specification. Bearing wear is checked using a dial indicator to measure forward and backward play in the bearing.

As a rule, dual-mass flywheels are not serviced in the field, meaning they are not repaired or resurfaced if the friction surface is scored or warped. In addition, many manufacturers specify replacing the DMF as part of clutch replacement.

Flywheel Service Resurfacing is done by grinding or cutting. Grinding normally relies on a dedicated grinder and is done with wet process silicone carbide stone, or dry process with cubic boron nitride stones. Cutting the flywheel is not generally preferred because it can remove too much metal and can miss hard spots. Cutting is typically done on a brake lathe machine.

SHOP TALK

If the vehicle is a hybrid, make sure you disconnect the high-voltage system before beginning any work. Also, if the electric motor is sandwiched between the engine and transmission (Figure 37–27), make sure you follow all procedures. The permanent magnet used in the motor is very strong and requires special tools to remove and install it.

FIGURE 37–27 The electric motor for a hybrid vehicle with a clutch assembly attached to it.

Linkage Service

Often clutch problems can be solved by repairing the clutch linkage assembly and/or parts associated with it.

Hydraulic-Operated Clutch Linkage Service

The proper fluid level in the reservoir is usually marked on the reservoir. The reservoir is normally mounted to the top of the master cylinder or is part of the brake master cylinder assembly. The hydraulic system does not consume fluid; therefore, if the fluid is low, check for leaks at the master and slave cylinders and the connecting hydraulic lines. Verify the correct fluid to use and fill the reservoir only to the fill line to allow the fluid to rise as the clutch disc wears. Overfilling the system will cause slip and premature failure. Air can enter the system through the compensation and bleed ports if the fluid level in the reservoir is too low. The system must be bled to remove the trapped air.

Master cylinder problems are typically external or internal fluid leaks that require that the unit be replaced or rebuilt. Rebuild kits are available for most master cylinders. If a cast-iron master cylinder is rebuilt, the cylinder bore should be honed to remove any imperfections in the bore and new seals used. The bores of aluminum master cylinders should never be honed.

Internal and external leaks are also typical problems for slave cylinders. Seldom are these cylinders rebuilt; rather, they are replaced. Replacing a slave cylinder is rather straightforward on most vehicles. Simply disconnect the hydraulic lines and unbolt the unit. If it appears that the piston of a slave cylinder is seized in its bore, check the movement of the release fork and lever at the clutch before replacing the slave cylinder. Leaks may also result from damaged or corroded hydraulic lines. These lines should be replaced, if damaged, with the same type of tube as was originally installed.

Replacing a Concentric Slave Cylinder When a concentric slave cylinder goes bad, fluid leakage and a soft or spongy pedal normally results. Since the slave cylinder is inside the transmission housing, the procedure for replacing it is different than those for replacing an external slave.

Bleeding the System Whenever the hydraulic system is opened, the entire system should be bled. **Bleeding** may also be necessary if the system has run low on fluid and air is trapped in the lines or cylinders. Bleeding can be accomplished through the use of a power bleeder (the same device used to bleed a brake system), a vacuum

PROCEDURE

Replacing a Concentric Slave Cylinder

STEP 1 Carefully clean the hydraulic tube coupling and disconnect it with the appropriate quick disconnect tool.

STEP 2 Remove the transmission.

STEP 3 Remove the concentric slave cylinder mounting bolts and remove the cylinder from the transmission.

STEP 4 Clean the transmission's input shaft.

STEP 5 Inspect the shaft for damage and excessive wear.

STEP 6 Install the new slave cylinder. Make sure it is installed flat against its mounting surface inside the transmission.

STEP 7 Tighten the slave cylinder's mounting bolts to specifications.

STEP 8 Reinstall the transmission.

STEP 9 Bleed the hydraulic system.

PROCEDURE

Bleeding the Hydraulic System

STEP 1 Check the entire hydraulic circuit to make sure there are no leaks.

STEP 2 Check the clutch linkage for wear and repair any defects before continuing.

STEP 3 Make sure all mounting points for the master and slave cylinders are solid and do not flex under the pressure of depressing the pedal.

STEP 4 Fill the master cylinder with the approved fluid **(Figure 37–28)**.

STEP 5 Attach one end of a hose to the end of the bleeder screw and the other end into a catch can **(Figure 37–29)**. Loosen the bleed screw at the slave cylinder approximately one-half turn.

STEP 6 Fully depress the clutch pedal, and then move the pedal through three quick and short strokes. Allow the fluid and air to exit the system and then immediately close the bleeder screw.

STEP 7 Release the pedal rapidly.

STEP 8 Recheck the fluid level in the master cylinder.

STEP 9 Repeat Steps 3 and 4 until no air is evident in the fluid leaving the bleeder screw.

STEP 10 Close the bleeder screw immediately after the last downward movement of the pedal **(Figure 37–30)**.

FIGURE 37-28 Fill the fluid reservoir with the correct fluid.

FIGURE 37-29 Attach a hose between the bleeder screw and a container before beginning to bleed the system.

bleeder, or the use of a coworker. On most cars, it is impossible to pressurize the system and bleed the hydraulic lines at the same time; therefore, it is important that you have the proper equipment or

FIGURE 37-30 Make sure the bleeder screw is tight after the system has been bled.

someone to assist you. The typical procedure for bleeding the system follows:

Gravity Bleeding Often the hydraulic system can be bled by allowing gravity to push the fluid through the system and move any trapped air with it. The process for doing this is rather simple. Begin by opening the bleeder screw on the slave cylinder—make sure there is a container below the bleeder to catch the dispelled fluid. Watch the flow of the fluid. When a constant flow of fluid without air bubbles is seen, tighten the bleeder and check the action of the pedal. This process may need to be repeated a few times. Make sure the reservoir is topped off between each procedure.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2010	**Make:** Toyota	**Model:** FJ Cruiser	**Mileage:** 151,889	**RO:** 15844
Concern:	Customer states that there is noise coming from the clutch area when the pedal is depressed. The noise stops when the pedal is released.			
After confirming the complaint, the technician suspects the clutch release bearing is at fault and requests teardown time to confirm the cause.				
Cause:	Clutch release bearing failure.			
Correction:	Due to age and mileage, replaced clutch assembly. Clutch working properly and without noise.			

KEY TERMS

Bell housing
Bleeding
Chatter
Clutch disc
Clutch fork
Clutch release bearing
Diaphragm
Dual-mass flywheel
Free travel
Friction disc
Pilot bushing
Throwout bearing

SUMMARY

- The clutch, located between the transmission and the engine, provides a mechanical coupling between the engine flywheel and the transmission's input shaft. All manual transmissions and transaxles require a clutch.
- The flywheel, an important part of the engine, is also the main driving member of the clutch.
- Dual-mass flywheels may require special testing tools to determine their condition.
- The clutch disc receives the driving motion from the flywheel and pressure plate assembly and transmits that motion to the transmission input shaft.
- The twofold purpose of the pressure plate assembly is to squeeze the clutch disc onto the flywheel and move away from the clutch disc so the disc can stop rotating. There are basically two types of pressure plate assemblies: those with coil springs and those with a diaphragm spring.
- The clutch release bearing, also called a throwout bearing, smoothly and quietly moves the pressure plate release levers or diaphragm spring through the engagement and disengagement processes.
- The clutch fork moves the release bearing and hub back and forth. It is controlled by the clutch pedal and linkage.
- Clutch linkage can be mechanical or hydraulic.
- The self-adjusting clutch is a clutch cable linkage that monitors clutch pedal play and automatically adjusts it when necessary.
- It is important that certain precautions are exercised when servicing the clutch. Clutch maintenance includes linkage adjustment and external clutch linkage lubrication.
- Slippage occurs when the clutch disc is not gripped firmly between the flywheel and the pressure plate. It can be caused by an oil-soaked or worn disc facing, warped pressure plate, weak diaphragm spring, or the release bearing contacting and applying pressure to the release levers.
- Clutch drag occurs if the clutch disc is not completely released when the clutch pedal is fully depressed. It can occur as a result of a warped disc or pressure plate, a loose disc facing, a defective release lever, or incorrect clutch pedal adjustment that results in excessive pedal play.
- Chatter is a shuddering felt in the vehicle when the pressure plate first contacts the clutch disc and it stops when the clutch is fully engaged. Usually chatter is caused when liquid contaminates the friction surfaces.
- Pedal pulsation is a rapid up-and-down movement of the clutch pedal as the clutch disengages or engages. It results from a misalignment of parts.
- Clutch vibrations can be felt throughout the vehicle, and they occur at any clutch pedal position. Sources of clutch vibrations include loose flywheel bolts, excessive flywheel runout, and pressure plate cover balance problems.

REVIEW QUESTIONS

Short Answer

1. What is another name for the diaphragm spring?
2. What is used to measure clutch pedal play?
3. The pressure plate moves away from the flywheel when the clutch pedal is ___.
4. Name three types of clutch linkages.

True or False

1. *True or False?* If the fluid reservoir for a hydraulic clutch is low, the entire system should be checked for fluid leaks.
2. *True or False?* Both the clutch and the brake system may share the same master cylinder.

Multiple Choice

1. The clutch, or friction, disc is connected to the ___.
   a. engine crankshaft
   b. transmission input shaft
   c. transmission output shaft
   d. transmission countershaft
2. Torsional coil springs in the clutch disc ___.
   a. cushion the driven disc engagement rear to front
   b. are the mechanical force holding the pressure plate against the driven disc and flywheel
   c. absorb the torque forces
   d. are located between the friction rings
3. Which of the following is probably *not* the cause of a vibrating clutch?
   a. Excessive crankshaft end play
   b. Out-of-balance pressure plate assembly
   c. Excessive flywheel runout
   d. Loose flywheel bolts

4. When the clutch pedal is released on a hydraulic clutch linkage, the ___.
   a. master cylinder piston is returned by spring tension
   b. master cylinder piston is returned by hydraulic pressure
   c. slave cylinder is returned by hydraulic pressure
   d. slave cylinder piston does not move
5. When the clutch is disengaged, the power flow stops at the ___.
   a. transmission input shaft
   b. driven disc hub
   c. pressure plate and flywheel
   d. torsion springs
6. Insufficient clutch pedal clearance results in ___.
   a. gear clashing while shifting transmission
   b. a noisy front transmission bearing
   c. premature release bearing failure
   d. premature pilot bearing failure
7. Before making a clutch adjustment, it is necessary to ___.
   a. measure clutch pedal free travel
   b. lubricate the clutch linkage
   c. check the hydraulic fluid level
   d. place the transmission in reverse
8. The surface of the pressure plate contacts the ___.
   a. transmission main shaft
   b. throwout bearing
   c. clutch disc
   d. flywheel
9. Which of the following would *not* cause clutch binding?
   a. A warped clutch disc
   b. Improper pedal adjustment
   c. An oil-soaked clutch disc
   d. A cracked fire wall

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that clutch slippage is most noticeable in higher gears. Technician B says that clutch slippage is not noticeable in lower gears. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. While discussing ways to determine if a pilot bushing is faulty: Technician A says that if it operated quietly, it does not need to be replaced. Technician B says that a careful inspection of the transmission's input shaft can determine the condition of the pilot bushing. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. While discussing the different types of pressure plates: Technician A says that coil spring types are commonly used because they have strong springs. Technician B says that Belleville-type pressure plates are not commonly used because they require excessive space in the bell housing. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. While discussing the purpose of a clutch pressure plate: Technician A says that the pressure plate assembly squeezes the clutch disc onto the flywheel. Technician B says that the pressure plate moves away from the clutch disc so that the disc can stop rotating. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. Technician A says that an oil-soaked clutch disc can cause clutch chatter. Technician B says that clutch chatter can be caused by loose bell housing bolts. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

6. While discussing different abnormal clutch noises: Technician A says that pilot bushing noises are most noticeable in cold weather and usually occur when the pedal is being depressed and the transmission is in neutral. Technician B says that release bearing noise is most noticeable when the transmission is in neutral and occurs when the clutch pedal is depressed and stops when the pedal is fully released. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. Technician A says that incorrect clutch adjustment can cause premature clutch disc wear. Technician B says that incorrect clutch adjustment can cause premature clutch release bearing wear. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. While discussing the cause of a pulsating clutch pedal: Technician A says that this can be caused by a low fluid level in the hydraulic system. Technician B says that this can be caused by a warped flywheel. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. Technician A says that if the hydraulic clutch reservoir is overfilled, the clutch may prematurely wear. Technician B says that if the fluid level is too low, the clutch may not disengage. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. Technician A says that all manual transmission vehicles have at least one pilot bearing or bushing for the input shaft. Technician B says that the pressure plate always rotates with the input shaft when the engine is running. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER

38

MANUAL TRANSMISSIONS AND TRANSAXLES

OBJECTIVES

- Explain the design characteristics of the gears used in manual transmissions and transaxles.
- Explain the fundamentals of torque multiplication and overdrive.
- Describe the purpose, design, and operation of synchronizer assemblies.
- Describe the purpose, design, and operation of internal and remote gearshift linkages.
- Explain the operation and power flows produced in typical manual transmissions and transaxles.

The transmission or transaxle **(Figure 38–1)** is a vital link in the powertrain of any modern vehicle. The purpose of the transmission or transaxle is to use gears of various sizes to give the engine a mechanical advantage over the driving wheels. During normal operating conditions, power from the engine is transferred through the engaged clutch to the input shaft of the transmission or transaxle. Gears in the transmission or transaxle housing alter the torque and speed of this power input before passing it on to other components in the drivetrain. Without the mechanical advantage the gearing provides, an engine can generate only limited torque at low speeds. Without sufficient torque, moving a vehicle from a standing start would be impossible.

In any engine, the crankshaft always rotates in the same direction. If the engine transmitted its

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE		REPAIR ORDER		
Year: 1995	**Make:** Ford	**Model:** Mustang	**Mileage:** 115,941	**RO:** 15865
Concern:	Customer states the transmission won't go into gear easily and it makes noise when shifting gears.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

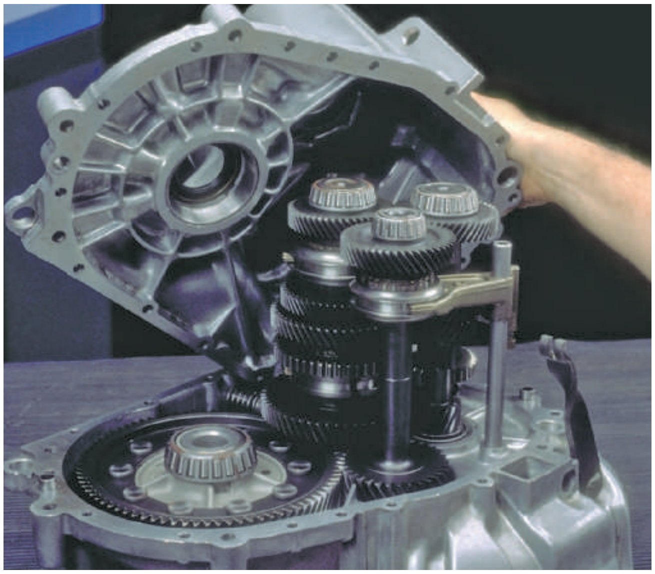


FIGURE 38–1 A late-model transaxle.

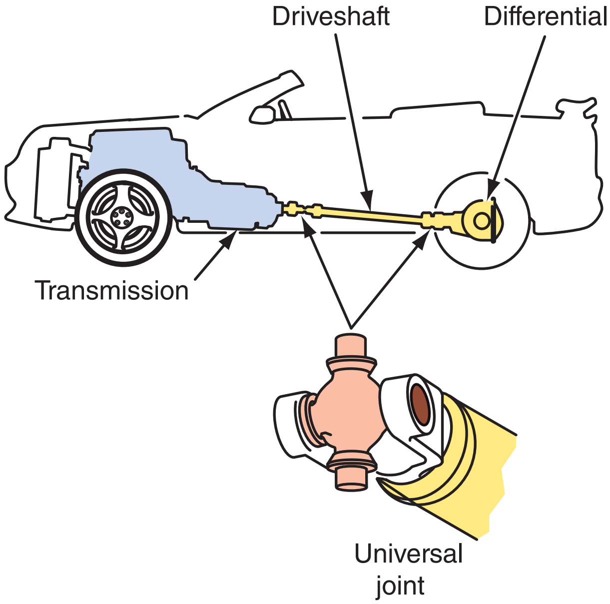


FIGURE 38–2 A transmission mounted to the rear of the engine can be connected to the drive axle by a driveshaft with universal joints.

power directly to the drive axles, the wheels could be driven only in one direction. Instead, the transmission or transaxle provides the gearing needed to reverse direction so the vehicle can be driven backward. There is also a neutral position that stops power from reaching the drive wheels.

Transmission Versus Transaxle

The type of drive system used determines whether a conventional transmission or a transaxle is used. Vehicles propelled by the rear wheels normally use a transmission. Transmission gearing is located within an aluminum or iron casting called the transmission case assembly. The transmission case assembly is attached to the rear of the engine **(Figure 38–2)**, which is normally located in the front of the vehicle. A drive shaft links the output shaft of the transmission with the final drive gears and drive axles located in a separate housing at the rear of the vehicle. A differential splits the driveline power and redirects it to the two rear drive axles, which then pass it on to the wheels.

Cars with a mid- or rear-mounted engine send power to the rear wheels through a transaxle. Also, some front engine RWD vehicles have a shaft that connects the engine to a transaxle assembly at the rear axle.

Front-wheel drive (FWD) vehicles are propelled by the front wheels. For this reason, they must use a drive design different from that of a RWD vehicle. The transaxle is the special power transfer unit commonly used on FWD vehicles. A transaxle combines the transmission gearing, differential, and drive axle connections into a single case housing located in front of the vehicle **(Figure 38–3)**. This design offers many advantages. One major advantage is the good traction on slippery roads due to the weight of the drivetrain components being directly over the driving axles of the vehicle. It is also more compact and lighter than the transmission of a RWD vehicle. Transverse engine and transaxle configurations also allow for lower hood lines, thereby improving the vehicle's aerodynamics.

Four-wheel drive vehicles typically use a transmission and transfer case. The transfer case mounts on the side or back of the transmission. A chain or gear drive inside the transfer case receives power from the transmission and transfers it to two separate drive shafts. One drive shaft connects to a differential on the front drive axle. The other drive shaft connects to a differential on the rear drive axle.

Most manual transmissions and transaxles are constant mesh, fully synchronized units. Constant mesh means that whether or not the gear is locked to the output shaft, it is in mesh with its counter gear. All gears rotate in the transmission, except for reverse gear, as long as the clutch is engaged. Fully synchronized means the unit uses a mechanism of rings and clutches to bring rotating shafts and gears to the same speed before shifts occur. This promotes

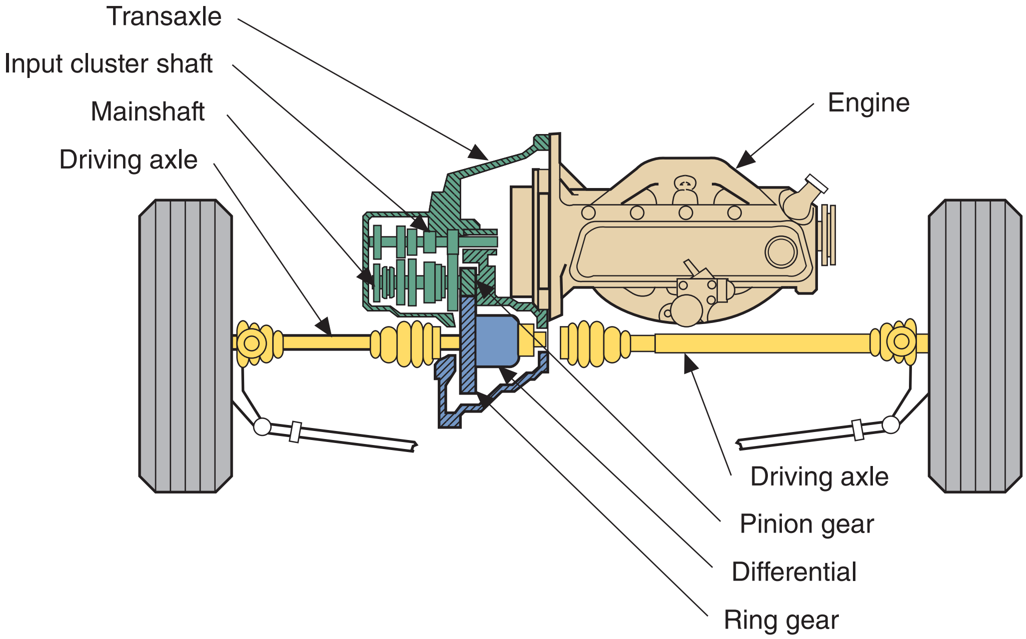


FIGURE 38–3 The location of typical front-wheel-drive powertrain components.

smooth shifting. In a vehicle equipped with a four-speed manual shift transmission or transaxle, all four forward gears are synchronized. Reverse gearing may or may not be synchronized, depending on the type of transmission/transaxle.

Transmission Designs

All automotive transmissions/transaxles are equipped with a varied number of forward speed gears, from three to seven **(Figure 38–4)**, a neutral gear, and one reverse speed. Transmissions are often divided into groupings based on the number of forward speed gears they have.

Six-speed transmissions and transaxles are now the most commonly used units. Normally the last one or two gears are overdrive gears. Overdrive reduces engine speed at a given vehicle speed, which increases top speed, improves fuel economy, and lowers engine noise. Most late-model six-speed transmissions and transaxles provide two overdrive gears. The addition of the two overdrive gears allows the manufacturers to use lower final drive gears for acceleration. The fifth and sixth gears reduce the overall gear ratio and allow for slower engine speeds during highway operation.

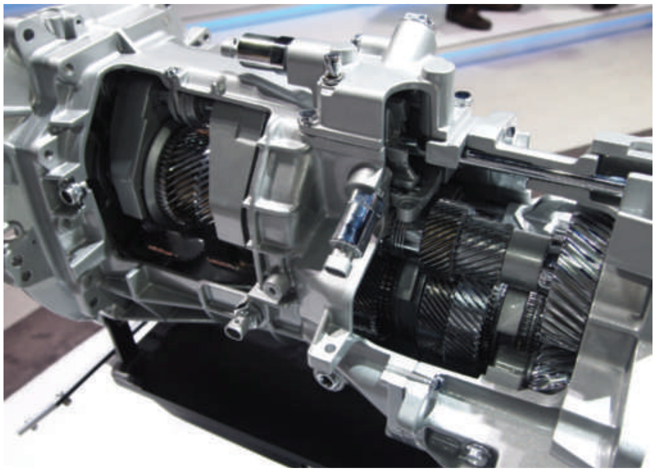


FIGURE 38–4 A seven-speed transmission from a current Corvette.

Gears

The purpose of the gears in a manual transmission or transaxle is to transmit rotating motion. Gears are normally mounted on a shaft, and they transmit rotating motion from one parallel shaft to another **(Figure 38–5)**.

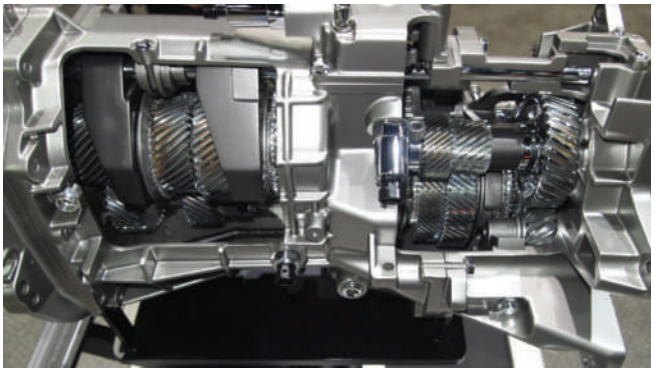


FIGURE 38–5 The gears in a transmission transmit the rotating power from the engine.

Gears and shafts can interact in one of three ways: the shaft can drive the gear; the gear can drive the shaft; or the gear can be free to turn on the shaft. In this last case, the gear acts as an idler gear.

Sets of gears can be used to multiply torque and decrease speed, increase speed and decrease torque, or transfer torque and leave speed unchanged.

Gear Design

Gear pitch is a very important factor in gear design and operation. Gear pitch refers to the number of teeth per given unit of pitch diameter. A simple way of determining gear pitch is to divide the number of teeth by the pitch diameter of the gear. For example, if a gear has thirty-six teeth and a 6-inch pitch diameter, it has a gear pitch of six **(Figure 38–6)**. The important fact to remember is that gears must have the same pitch to operate together. A five-pitch gear meshes only with another five-pitch gear, a six-pitch only with a six-pitch, and so on.

Spur Gears The **spur gear** is the simplest gear design used in manual transmissions and transaxles. As shown in **Figure 38–7**, spur gear teeth are cut straight across the edge parallel to the gear's shaft. During operation, meshed spur gears have only one tooth in full contact at a time.

Its straight tooth design is the spur gear's main advantage. It minimizes the chances of popping out of gear, an important consideration during acceleration/deceleration and reverse operation. For this reason, spur gears are often used for the reverse gear.

The spur gear's major drawback is the clicking noise that occurs as teeth contact one another. At higher speeds, this clicking becomes a constant whine. Quieter gears, such as the helical design, are often used to eliminate this gear whine problem.

Helical Gears A **helical gear** has teeth that are cut at an angle or are spiral to the gear's axis of rotation **(Figure 38–8)**. This configuration allows two or more teeth to mesh at the same time, which distributes tooth load and produces a very strong gear. Helical gears also run more quietly than spur gears because they create a wiping action as they engage and disengage the teeth on another gear. One disadvantage is that helical teeth on a gear cause the gear to move fore or aft (axial thrust) on a shaft, depending on the direction of the angle of the gear teeth. This axial thrust must be absorbed by thrust washers and other transmission gears, shafts, or the transmission case.

Helical gears can be either righthanded or lefthanded, depending on the direction the spiral

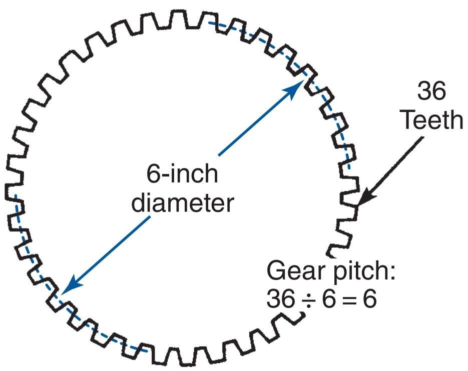


FIGURE 38–6 Determining gear pitch.

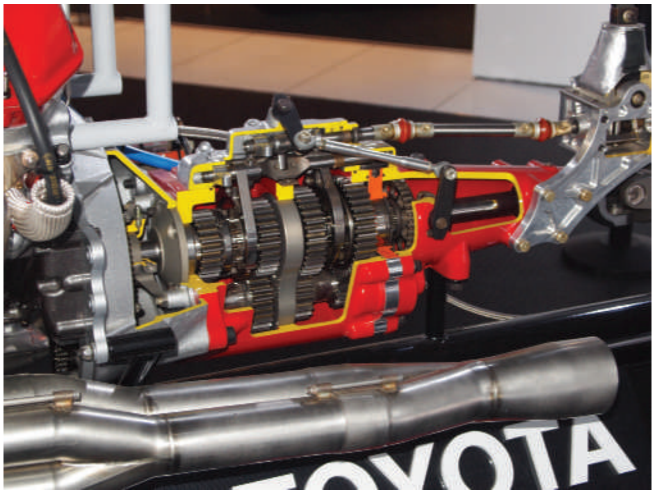


FIGURE 38–7 Spur gears have teeth cut straight across the gear edge parallel to the shaft.

SHOP TALK

When a small gear is meshed with a much larger gear, the input gear is often called a pinion or pinion gear, regardless of its tooth design.

FIGURE 38–8 Helical gears have teeth cut at an angle to the gear's axis of rotation.

appears to go when the gear is viewed face-on. When mounted on parallel shafts, one helical gear must be righthanded and the other lefthanded. Two gears with the same direction spiral do not mesh in a parallel mounted arrangement.

Spur and helical gears that have teeth cut around their outside diameter edge are called **external gears**. When two external gears are meshed together, one rotates in the opposite direction as the other **(Figure 38–9)**. If an external gear is meshed with an internal gear (one that has teeth around its inside diameter), both rotate in the same direction.

Idler Gears

An **idler gear** is a gear that is placed between a drive gear and a driven gear. Its purpose is to transfer motion from the drive gear to the driven gear without changing the direction of rotation. It can do this because all three gears have external teeth **(Figure 38–10)**.

Idler gears are used in reverse gear trains to change the directional rotation of the output shaft. In all forward gears, the input shaft and the output shaft turn in the same direction. In reverse, the output shaft turns in the opposite direction as the input shaft. This allows the vehicle drive wheels to turn backward.

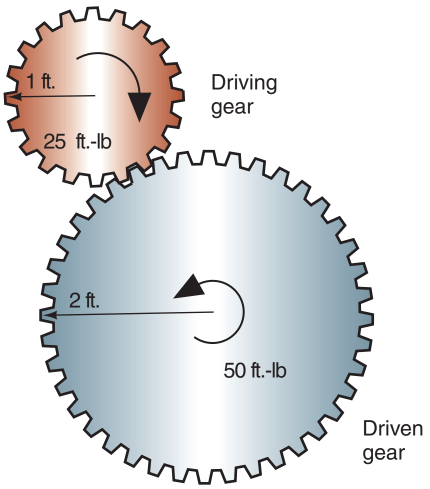


FIGURE 38–9 Externally meshed gears rotate in opposite directions.

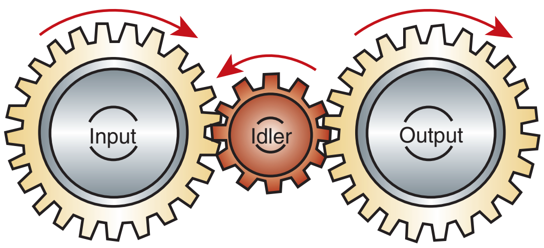


FIGURE 38–10 An idler gear is used to transfer motion without changing rotational direction.

Basic Gear Theory

GO TO Chapter 3 for a detailed explanation on how gears multiply torque.

As gears with different numbers of teeth mesh, each rotates at a different speed and torque. A manual transmission is an assembly of gears and shafts that transmit power from the engine to the drive axle. By moving the shift lever, various gear and speed ratios can be selected. The gears in a transmission are selected to give the driver a choice of both speed and torque. Lower gears allow for lower vehicle speeds but more torque **(Figure 38–11A)**. Higher gears provide less torque but higher vehicle speeds **(Figure 38–11B)**. There is often much confusion about the terms *high* and *low gear ratios.* A gear ratio of 4:1 is lower than a ratio of 2:1. Although numerically the 4 is higher than the 2, the 4:1 gear ratio

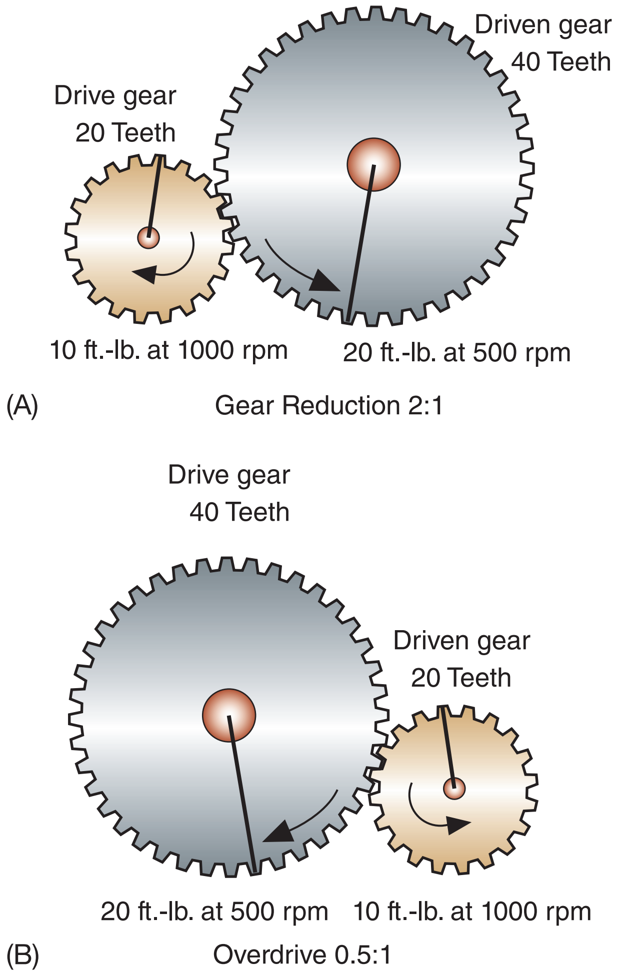


FIGURE 38–11 (A) Lower gears allow for lower vehicle speeds but more torque. (B) Higher gears decrease engine speed but reduce torque.

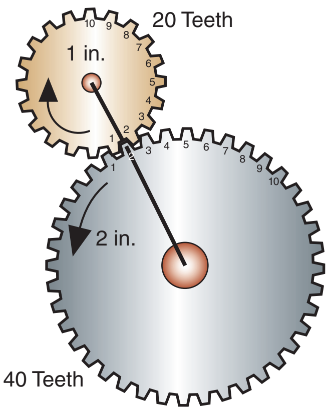


FIGURE 38-12 Even numbered gear ratios would allow the same teeth to always contact each other.

allows for lower speeds and hence is termed a low gear ratio.

Although used here as example, it is unlikely you will find transmission gear ratios that are round numbers such as 2:1. This is because even numbered ratios allow one set of driving gear teeth to only contact a particular set of teeth on the driven gear **(Figure 38–12)**. Transmissions use prime gear sets, such as 3.73:1, which means that each tooth on the driving gear will eventually contact every tooth on the driven gear. This is preferable to even out wear on the teeth.

Different gear ratios are necessary because an engine develops relatively little power at low engine speeds. The engine must be turning at a fairly high speed before it can deliver enough power to get the car moving. Through selection of the proper gear ratio, torque applied to the drive wheels can be multiplied.

Transmission Gearsets

Power is moved through the transmission via four gears (two sets of two gears) for each selected gear range. Speed and torque are altered in steps. To explain how this works, let us assign numbers to each of the gears **(Figure 38–13)**. The small gear on the input shaft has twenty teeth. The gear it meshes with has forty. This provides a gear ratio of 2:1. The output of this gearset moves along the shaft of the forty-tooth gear and rotates other gears. The gear involved with first gear has fifteen teeth. This gear rotates with the same speed and with the same torque as the forty-tooth gear. However, the fifteen-tooth gear is meshed with a larger gear with thirty-five teeth. The gear ratio of the fifteen-tooth and the thirty-five-tooth gearset is 2.33:1. However, the ratio of the entire gearset (both sets of two gears) is 4.67:1.

To calculate this gear ratio, divide the driven (output) gear of the first set by the drive (input) gear of the first set. Do the same for the second set of gears, and then multiply the answer from the first by the second. The result is equal to the gear ratio of the entire gearset. The mathematical formula follows:

$$\frac{\text{driven (A)}}{\text{drive (A)}} \times \frac{\text{driven (B)}}{\text{drive (B)}} = \frac{40}{20} \times \frac{35}{15} = 4.67{:}1$$

Most of today's transmissions have at least one overdrive gear. Overdrive gears have ratios of less than 1:1. These ratios are achieved by using a small driving gear meshed with a smaller driven gear. Output speed is increased and torque is reduced. The purpose of overdrive is to promote fuel economy and reduce operating noise while maintaining highway cruising speed.

The driveline's gear ratios are further increased by the gear ratio of the ring and pinion gears in the drive axle assembly. Typical axle ratios are between 2.5 and 4.5:1. The final (overall) drive gear ratio is calculated by multiplying the transmission gear ratio by the

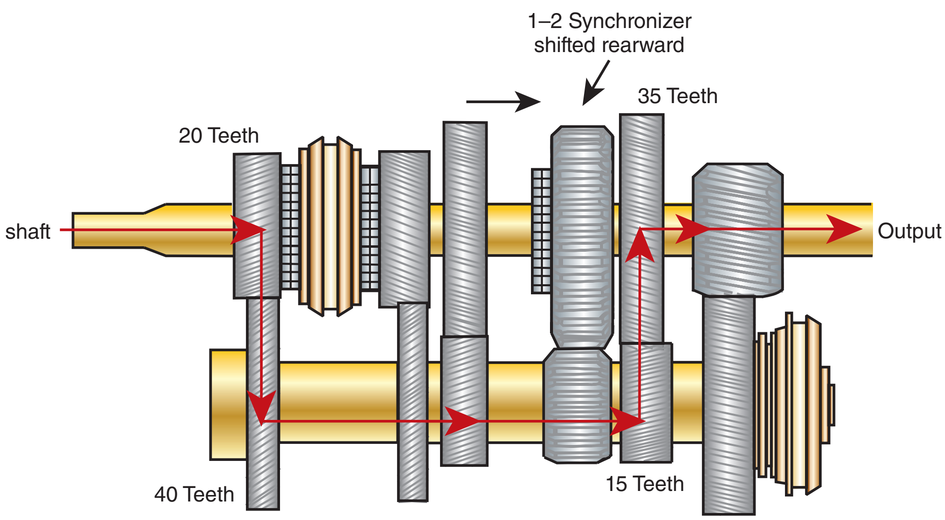


FIGURE 38-13 Overall gear ratio for first gear is determined by both sets of gears in mesh.

final drive ratio. If a transmission is in first gear with a ratio of 3.63:1 and has a final drive ratio of 3.52:1, the overall gear ratio is 12.78:1. If fourth gear has a ratio of 1:1, using the same final drive ratio, the overall gear ratio is 3.52:1. The overall gear ratio is calculated by multiplying the ratio of the first set of gears by the ratio of the second (3.63 times 3.52 equals 12.78).

Reverse Gear Ratios

Reverse gear ratios involve two driving (driver) gears and two driven gears:

- The input gear is driver #1.
- The idler gear is driven #1.
- The idler gear is also driver #2.
- The output gear is driven #2.

If the input gear has twenty teeth, the idler gear has twenty-eight teeth and the output gear has forty-eight teeth. However, since a single idler gear is used, the teeth of it are not used in the calculation of gear ratio. The idler gear merely transfers motion from one gear to another. The calculations for determining reverse gear ratio with a single idler gear follow.

$$\text{Reverse gear ratio} = \frac{\text{driven \#2}}{\text{driver \#1}} = \frac{48}{20} = 2.40$$

If the gearset uses two idler gears (one with twenty-eight teeth and the other with forty teeth), the gear ratio involves three driving gears and three driven gears:

- The input gear is driver #1.
- The #1 idler gear is driven #1.
- The #1 idler gear is also driver #2.
- The #2 idler gear is driven #2.
- The #2 idler gear is also driver #3.
- The output gear is driven #3.

The ratio of this gearset would be calculated as follows:

$$\text{Reverse gear ratio} = \frac{\text{driven \#1} \times \text{driven \#2} \times \text{driven \#3}}{\text{driver \#1} \times \text{driver \#2} \times \text{driver \#3}} = \frac{28 \times 40 \times 48}{20 \times 28 \times 40} = \frac{53{,}760}{22{,}400} = 2.40$$

As can be seen, idler gears do not affect the gear ratio.

Transmission/Transaxle Design

The internal components of a transmission or transaxle consist of a parallel set of metal shafts on which meshing gearsets of different ratios are mounted **(Figure 38–14)**. By moving the shift lever, gear ratios

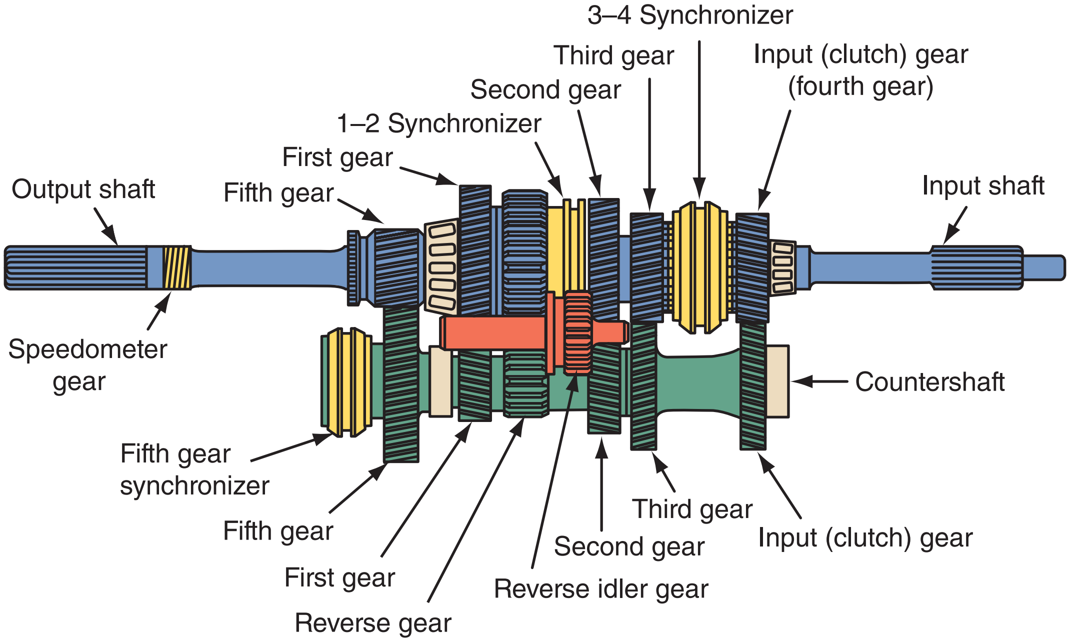


FIGURE 38–14 The arrangement of the gears and shafts in a typical five-speed transmission.

can be selected to generate different amounts of output torque and speed.

The gears are mounted or fixed to the shafts in a number of ways. They can be internally splined or keyed to a shaft. Gears can also be manufactured as an integral or "clustered" part of the shaft. Gears that must be able to freewheel around the shaft during certain speed ranges are mounted to the shaft using bushings or bearings.

The shafts and gears are contained in a transmission or transaxle case or housing. The components of this housing include the main case body, side or top cover plates, extension housings, and bearing retainers **(Figure 38–15)**. The metal components are bolted together with gaskets providing a leak-proof seal at all joints. The case is filled with transmission fluid to provide constant lubrication and cooling for the spinning gears and shafts.

Transmission Features

Although they operate in a similar fashion, the layout, components, and terminology used in transmissions and transaxles are not exactly the same.

Transmissions normally have three basic shafts: the mainshaft, input shaft, and **countershaft (Figure 38–16)**. The speed gears ride on the mainshaft. The mainshaft is also called the output shaft. The input shaft is inline with the mainshaft but is not directly connected to it. This shaft and its clutch gear rotates with the clutch assembly and drives the countergear assembly. The countergears, in turn, cause the speed gears to rotate. The countershaft assembly is often referred to as the cluster gear.

The countershaft is actually several gears machined out of a single piece of steel or iron. The countershaft may also be called the countergear or **cluster gear**. The countergear mounts on roller bearings on the countershaft. The countershaft is pinned in place and does not turn. Thrust washers control the amount of end play of the unit in the transmission case.

The main gears on the main shaft or output shaft transfer rotation from the countergears to the output shaft. The main gears are also called speed gears. They are mounted on the output shaft using roller bearings. Speed gears freewheel around the output shaft until they are locked to it by the engagement of their shift **synchronizer** unit.

Power flows from the transmission **input shaft** to the clutch gear. The clutch gear meshes with the large countergear of the countergear cluster. This cluster gear is now rotating. Since the cluster gear is meshed with the speed gears on the mainshaft, the speed gears are also turning.

There can be no power output until one of the speed gears is locked to the mainshaft. This is done by activating a shift fork, which moves its synchronizer to engage the selected speed gear to the mainshaft. Power travels along the countergear until it reaches this selected speed gear. It then passes through this gear back to the mainshaft and out of the transmission to the driveline.

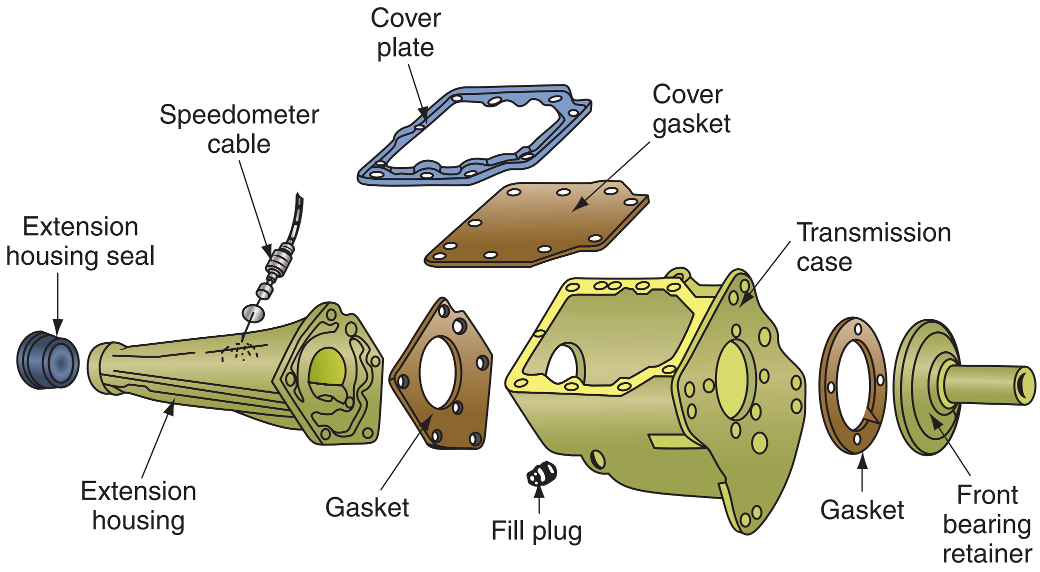


FIGURE 38–15 Typical manual transmission case components.

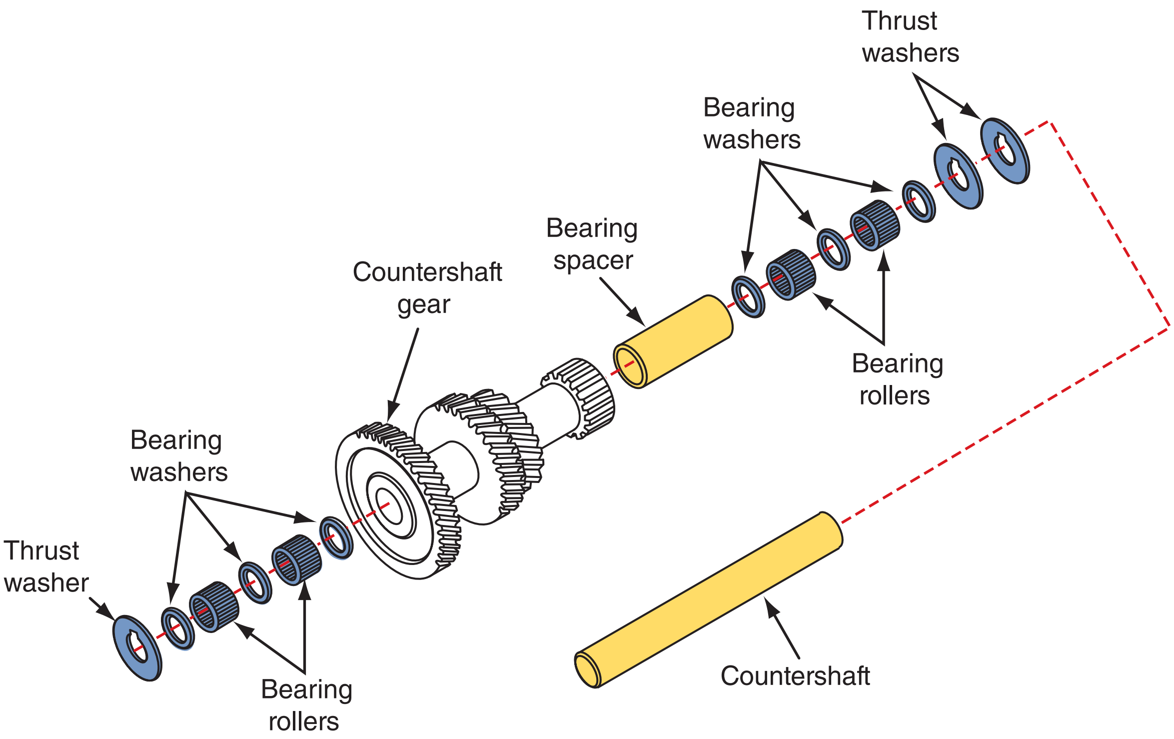


FIGURE 38–16 A typical countershaft assembly.

Transaxle Features

Transaxles use many of the design and operating principles found in transmissions. But because the transaxle also contains the differential gearing and drive axle connections, there are major differences in some areas of operation.

A transaxle typically has two separate shafts—an input shaft and an output shaft. The input shaft is the driving shaft. It is normally located above and parallel to the output shaft. Because the input shaft in most transversely mounted transaxles are supported by bearings in the housing, these units do not need a pilot bearing or bushing to support the portion of the input shaft that extends into the clutch assembly. This type of shaft is called a self-centering shaft. The output shaft is the driven shaft. The transaxle's main (speed) gears freewheel around the output shaft unless they are locked to the shaft by their synchronizer assembly. The main speed gears are in constant mesh with the input shaft drive gears. The drive gears turn whenever the input shaft turns.

The names used to describe transaxle shafts vary between manufacturers. The service information for some vehicles may refer to the input shaft as the mainshaft and the output as the driven pinion or drive shaft. Others call the input shaft and its gears the input gear cluster and refer to the output shaft as the mainshaft. For clarity, this text uses the terms input gear cluster for the input shaft and its drive gears, and pinion shaft for the output shaft.

A pinion gear is machined onto the end of the transaxle's pinion shaft. This pinion gear is in constant mesh with the differential ring gear located in the lower portion of the transaxle housing. Because the pinion gear is part of the pinion shaft, it must rotate whenever the pinion shaft turns. With the pinion rotating, engine torque flows through the ring gear and differential gearing to the drive shafts and driving wheels.

Some transaxles have a third shaft designed to offset the power flow on the output shaft. Power is transferred from the output shaft to the third shaft using helical gears and by placing the third shaft in parallel with the output and input shafts. Other transaxles with a third shaft use an offset input shaft that receives the engine's power and transmits it to a mainshaft, which serves as an input shaft. The third shaft is only added to transaxles when an extremely compact transaxle is required **(Figure 38–17)**.

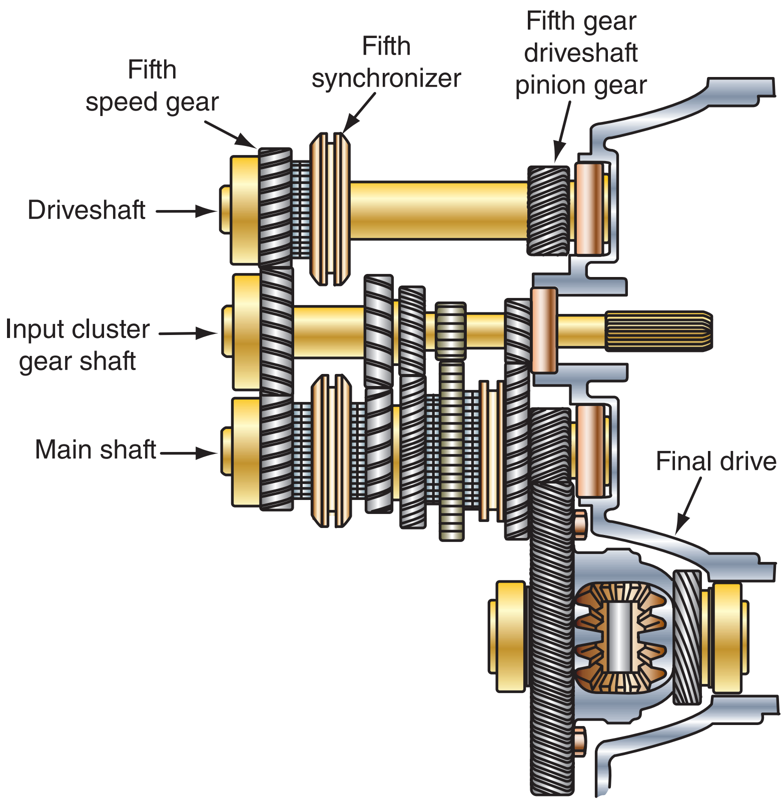


FIGURE 38–17 A transaxle with three gear shafts.

Synchronizers

The synchronizer performs a number of jobs vital to transmission/transaxle operation. Its main job is to bring components that are rotating at different speeds to a single synchronized speed. The second major job of the synchronizer is to lock these components together. The end result of these two functions is a clash-free shift. In some transmissions, a synchronizer can have another important job.

In modern transmissions and transaxles, all forward gears are synchronized. One synchronizer is placed between the first and second gears on the pinion shaft. Another is placed between the third and fourth gears on the mainshaft. If the transmission has a fifth gear, it is also equipped with a synchronizer. Reverse gear is not normally fitted with a synchronizer. A synchronizer requires gear rotation to do its job and reverse is selected with the vehicle at a stop.

Synchronizer Design

There are five primary components tied into synchronized shifting. The synchronizer sleeve has internal splines that slide over the external teeth of the synchronizer hub. The hub is fastened to the mainshaft. Spring-loaded keys (also referred to as dogs, struts, or insert plates) are positioned in the hub. Synchronizer or blocker rings have external splines and can move within the synchronizer sleeve. The outside of the synchronizer ring often has a cone-shaped surface to serve as a cone clutch. The other side of the cone clutch is machined to the side of a speed gear, which also has dog clutch teeth to allow the sleeve to fit over the speed gear. In the transmission, there is a speed gear on both sides of the sleeve.

Figure 38–18 illustrates the most commonly used synchronizer—a block or cone synchronizer. The synchronizer sleeve surrounds the synchronizer

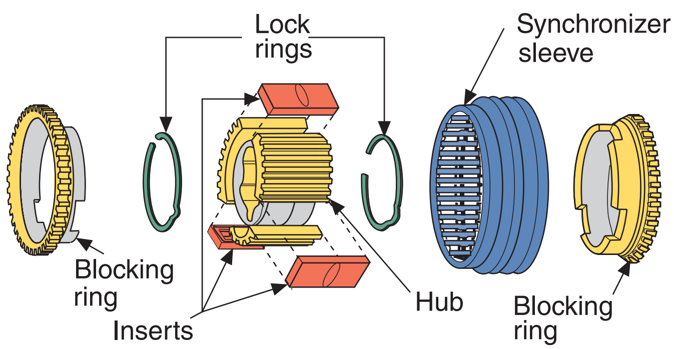


FIGURE 38–18 An exploded view of a blocking ring-type synchronizer assembly.

assembly and meshes with the external splines of the clutch hub. The clutch hub is splined to the transmission pinion shaft and is held in position by a snapring. A few transmissions use pin-type synchronizers.

The synchronizer sleeve has a small internal groove and a large external groove in which the shift fork rests. Three slots are equally spaced around the outside of the clutch hub. Inserts fit into these slots and are able to slide freely back and forth. These inserts, sometimes referred to as shifter plates or keys, are designed with a ridge in their outer surface. Insert springs hold the ridge in contact with the synchronizer sleeve internal groove.

The synchronizer sleeve is precisely machined to slide onto the clutch hub smoothly. The sleeve and hub sometimes have alignment marks to ensure proper indexing of their splines when assembling to maintain smooth operation.

Brass, bronze, or powdered iron synchronizing blocking rings are positioned at the front and rear of each synchronizer assembly. Some synchronizer assemblies use additional frictional material on the blocking rings to reduce slippage. Each blocking ring has three notches equally spaced to correspond with the three insert keys of the hub. Around the outside of each blocking ring is a set of beveled clutching teeth, called dog teeth, which is used for alignment during the shift sequence. The inside of the blocking ring is shaped like a cone. This coned surface is lined with many sharp grooves.

The cone of the blocking ring makes up only one-half of the total cone clutch. The second or matching half of the cone clutch is part of the speed gear to be synchronized. As shown in **Figure 38–19**, the shoulder of the speed gear is cone shaped to match the blocking ring. The shoulder also contains a ring of beveled clutching teeth designed to align with the clutching teeth on the blocking ring.

Operation

When the transmission is in neutral or reverse, the first/second and third/fourth synchronizers are in their neutral position and are not rotating with the pinion shaft. Gears on the mainshaft are meshed with their countershaft partners and are freewheeling around the pinion shaft at various speeds.

To shift the transmission into first gear, the clutch is disengaged and the gearshift lever is placed in first gear position. This forces the shift fork on the synchronizer sleeve toward the first speed gear on the pinion shaft. As the sleeve moves, the inserts also move because the insert ridges lock the inserts to the internal groove of the sleeve.

The movement of the inserts forces the blocking ring's coned friction surface against the coned surface of the first speed gear shoulder. When the blocking ring and gear shoulder come into contact, the grooves on the blocking ring cone cut through the lubricant film on the first speed gear shoulder and a metal-to-metal contact is made. The contact generates substantial friction and heat. This is one reason bronze or brass blocking rings are used. A nonferrous metal such as bronze or brass minimizes wear on the hardened steel gear shoulder. This frictional coupling is not strong enough to transmit loads for long periods. As the components reach the same speed, the synchronizer sleeve can now slide over the external clutching teeth on the blocking ring and then over the clutching teeth on the first speed gear shoulder. This completes the engagement **(Figure 38–20)**. Power flow is now from the first speed gear, to the synchronizer sleeve, to the synchronizer clutch hub, to the main output shaft, and out to the driveline.

To disengage the first speed gear from the pinion shaft and shift into second speed gear, the clutch must be disengaged as the shift fork is moved to pull

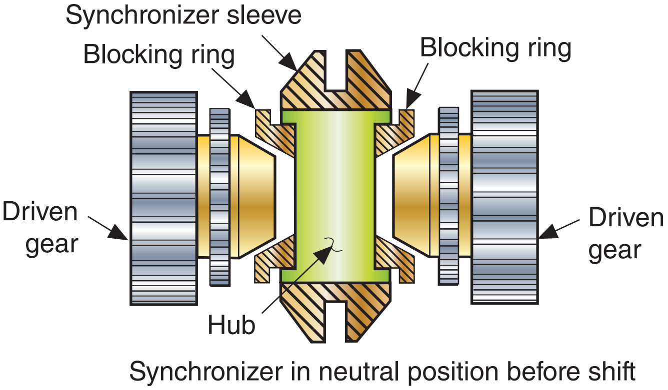


FIGURE 38–19 Gear shoulder and blocker ring mating surfaces.

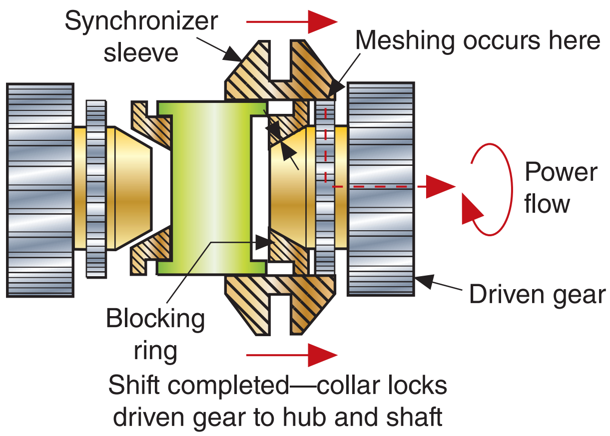


FIGURE 38–20 Gear shoulder and blocker ring mating surfaces when a gear is engaged.

the synchronizer sleeve and disengage it from the first gear. As the transmission is shifted into second gear, the inserts again lock into the internal groove of the sleeve. As the sleeve moves forward, the forward blocking ring is forced by the inserts against the coned friction surface on the second speed gear shoulder. Once again, the grooves on the blocking ring cut through the lubricant on the gear shoulder to generate a frictional coupling that synchronizes the speed gear and shaft speeds. The shift fork can then continue to move the sleeve forward until it slides over the blocking ring and speed gear shoulder clutching teeth, locking them together. Power flow is now from the second speed gear, to the synchronizer sleeve, to the clutch hub, and out through the pinion shaft.

Advanced Synchronizer Designs Many manufacturers are using multiple cone-type synchronizers in their transmissions. These transmissions are fitted with single-cone, double-cone, or triple-cone synchronizers. For example, first and second gears may have triple-cone synchronization, third and fourth may have double-cone, and fifth and sixth may have single-cone.

Double-cone synchronizers **(Figure 38–21)** have friction material on both sides of the synchronizer rings. The extra friction surfaces results in decreased shift effort and greater synchronizer durability. Triple-cone synchronizers provide a third surface of friction material.

With multiple-cone synchronizers, the size of the transmission can be reduced. The multiple-cone synchronizers offer a high synchronizer capacity in a smaller package. To obtain the same results in shifting, a single-cone synchronizer would need to have a larger diameter, which would increase the overall size and weight of the transmission.

Gearshift Mechanisms

Figure 38–22 illustrates a typical transmission shift linkage for a five-speed transmission. As you can see, there are three separate shift rails and forks. Each shift rail/shift fork is used to control the movement of a synchronizer, and each synchronizer is capable of engaging and locking two speed gears to the mainshaft. The shift rails transfer motion from the driver-controlled gearshift lever to the shift forks. The **shift forks (Figure 38–23)** are semicircular castings connected to the shift rails with split pins. The shift fork rests in the groove in the synchronizer sleeve and surrounds about one-half of the sleeve circumference.

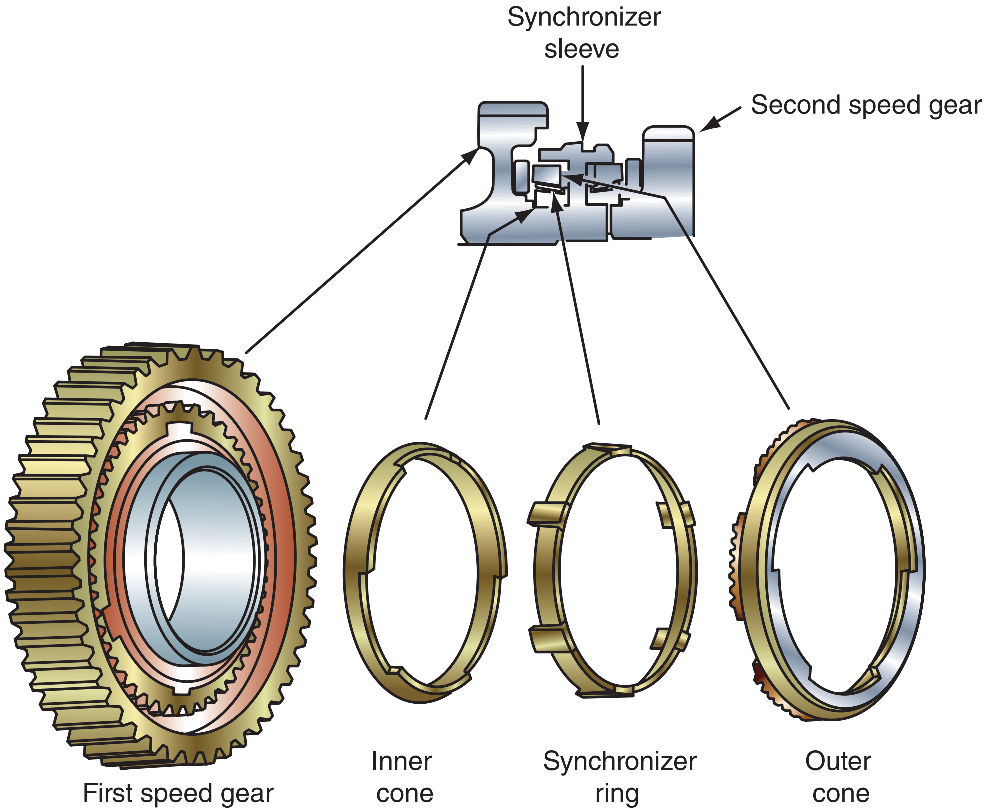


FIGURE 38–21 A two-cone synchronizer.

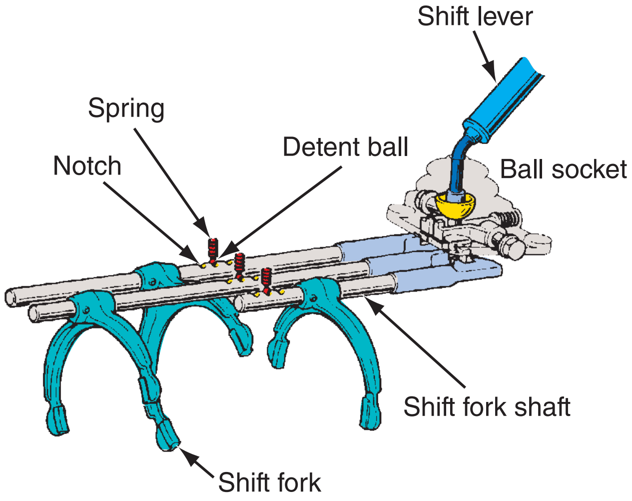


FIGURE 38–22 In a five-speed transmission, three separate shift rail/shift fork/synchronizer combinations control first/second, third/fourth, and fifth/reverse shifting.

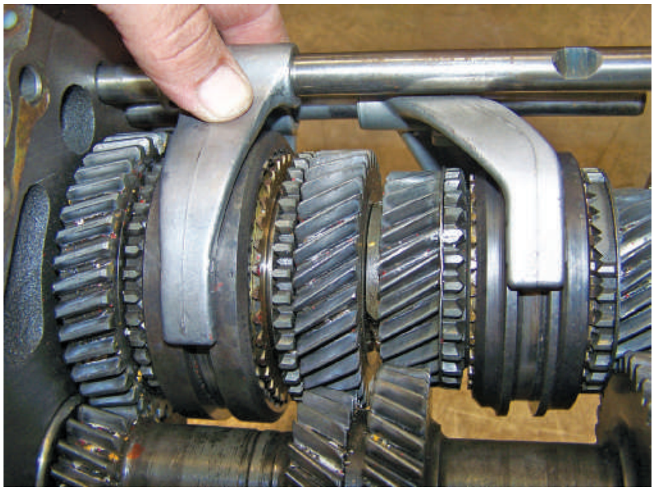


FIGURE 38–23 The shift forks, riding on shift rails, fit into the grooves of the synchronizer sleeve.

The gearshift lever is connected to the shift forks by means of a gearshift linkage. Linkage designs vary between manufacturers but can generally be classified as being direct or remote.

Gearshift Linkages

There are two basic designs of gearshift linkages: internal and external. Internal linkages are located at the side or top of the transmission. The control end of the shifter is mounted inside the transmission, as are all of the shift controls. Movement of the shifter moves a **shift rail** and shift fork toward the desired gear. This moves the synchronizer sleeve to lock the selected speed gear to the shaft. This type of linkage is often called a direct linkage, because the shifter is in direct contact with the internal gear shifting mechanisms.

Shift rails are machined with interlock and detent notches. The interlock notches prevent the selection of more than one gear during shifting. When a shift rail is moved by the shifter, interlock pins hold the other shift rails in their neutral position **(Figure 38–24)**. The detent notches and matching spring loaded pins or balls give the driver feedback as to when the shift collar is adequately moved.

As the shift rail moves, a detent ball moves out of its detent notch and drops into the notch for the selected gear. At the same time, an interlock pin moves out of its interlock notch and into the other shift rails.

External linkages function in much the same way, except that rods, external to the transmission, are connected to levers that move the internal shift rails of the transmission **(Figure 38–25)**. Some transaxles are shifted by rods **(Figure 38–26)** or by cable **(Figure 38–27)**.

Transmission Power Flow

The following sections describe the path of power through a typical five-speed transmission.

Neutral

When the gear selector is placed in the neutral position, the input shaft rotates at engine speed. The shaft's clutch gear is in mesh with the countergear, which rotates on the countershaft. The countergears are in mesh with the speed gears. Because none of the speed gears are locked to the mainshaft, the gears spin freely and no torque is applied to the mainshaft.

All gear changes pass through the neutral gear position. When changing gears, one speed gear is disengaged, resulting in neutral, before the chosen gear is engaged. This is important to remember when diagnosing hard-to-shift problems.

First Gear

First gear power flow is illustrated in **(Figure 38–28)**. Power or torque flows through the input shaft and clutch gear to the countergear. The countergear rotates. The first gear on the cluster drives the first speed gear on the mainshaft. When the driver selects first gear, the first/second synchronizer moves to the rear to engage the first speed gear and lock it to the mainshaft. The first speed gear drives the main (output) shaft, which transfers power to the driveline.

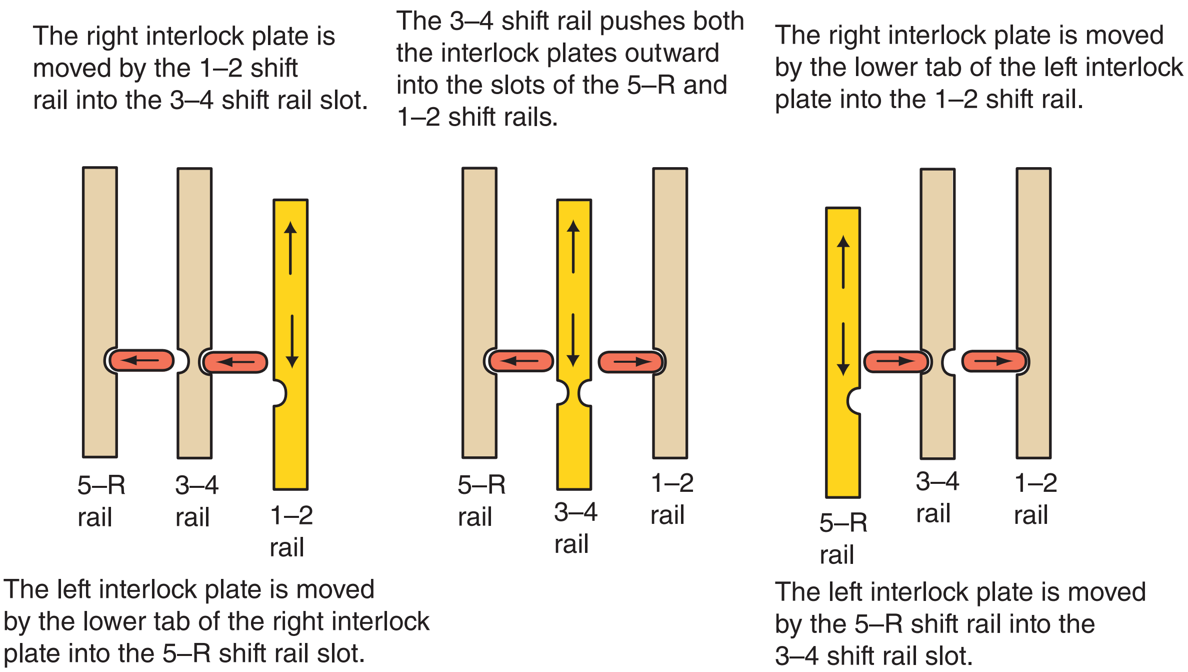


FIGURE 38–24 Interlock pins prevent the selection of one or more gears.

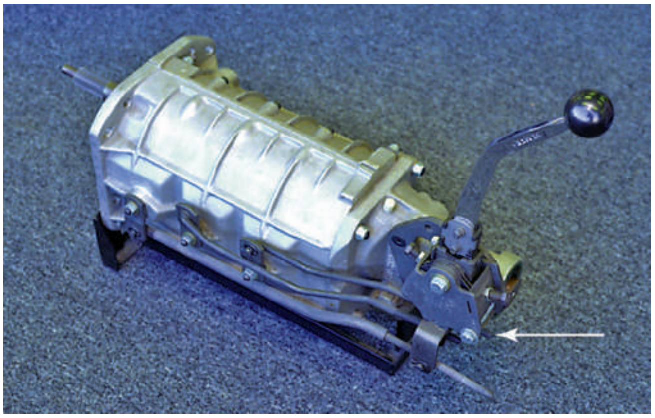


FIGURE 38–25 An external shifter assembly mounted to the transmission.

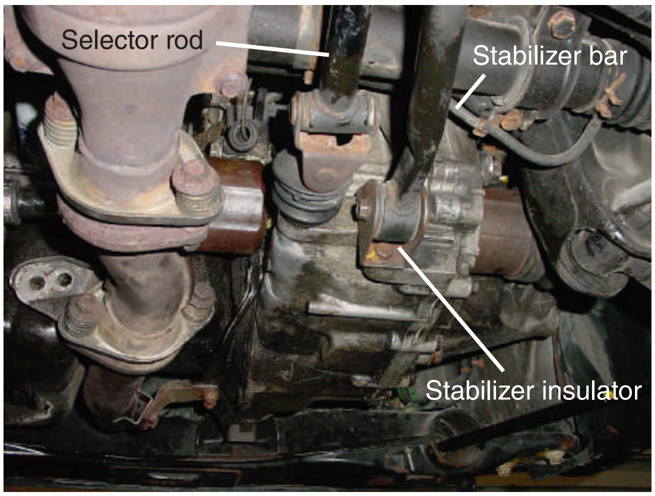


FIGURE 38–26 A remote gearshift showing linkage, selector rod, and stabilizer (stay bars).

Second Gear

When the shift from first to second gear is made, the shift fork disengages the first/second synchronizer from the first speed gear and moves it until it locks the second speed gear to the mainshaft. Power flow is still through the input shaft and clutch gear to the countergear. However, now the second countergear on the cluster transfers power to the second speed gear locked on the mainshaft. Power flows from the second speed gear through the synchronizer to the mainshaft (output shaft) and driveline **(Figure 38–29)**.

In second gear, the need for vehicle speed and acceleration is greater than the need for maximum torque multiplication. To meet these needs, the second speed gear on the mainshaft is designed slightly smaller than the first speed gear.

Third Gear

When the shift from second to third gear is made, the shift fork returns the first/second synchronizer to its neutral position. A second shift fork slides the third/fourth synchronizer until it locks the third speed gear to the mainshaft. Power flow now goes through the third gear of the countergear to the third speed gear, through the synchronizer to the mainshaft, and driveline **(Figure 38–30)**.

Third gear permits a further decrease in torque and increase in speed. As you can see, the third speed gear is smaller than the second speed gear.

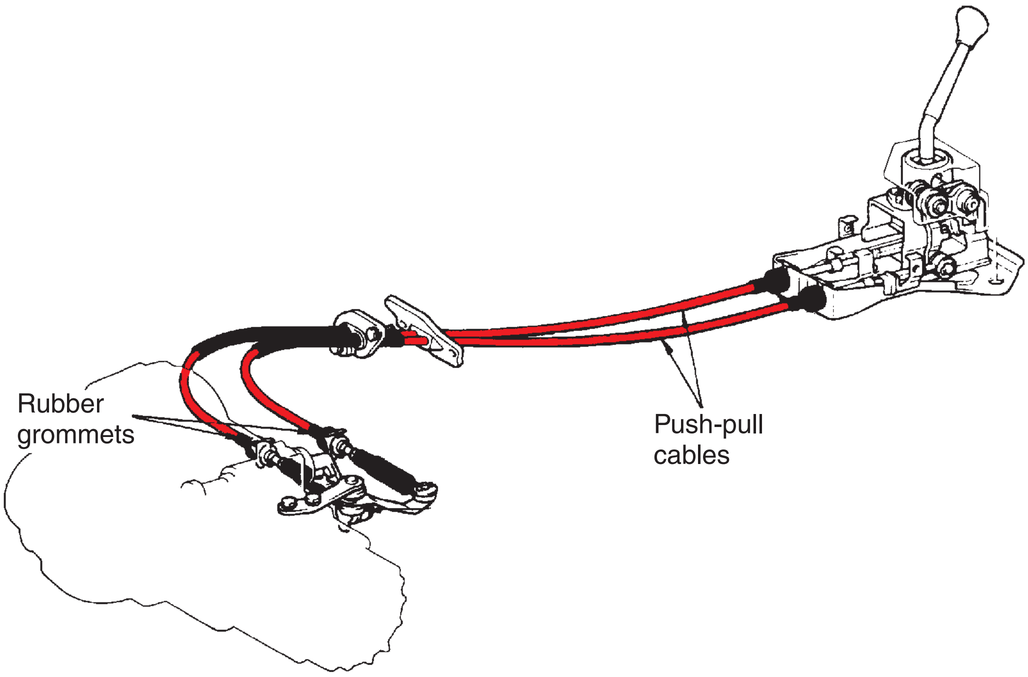


FIGURE 38–27 A cable-type external gearshift linkage used in a transaxle application.

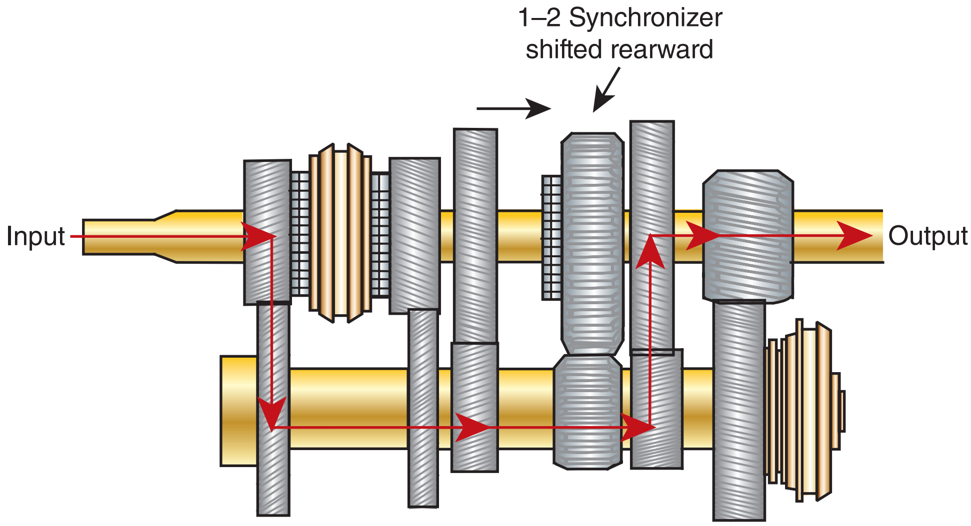


FIGURE 38–28 Power flow in first gear.

Fourth Gear

In fourth gear, the third/fourth synchronizer is moved to lock the clutch gear on the input shaft to the mainshaft. This means power flow is directly from the input shaft to the mainshaft (output shaft) at a gear ratio of 1:1 **(Figure 38–31)**. This ratio results in maximum speed output and no torque multiplication. Fourth gear has no torque multiplication because it is used at cruising speeds to promote maximum fuel economy. The vehicle is normally downshifted to lower gears to take advantage of torque multiplication and acceleration when passing slower vehicles or climbing grades.

Fifth Gear

When fifth gear is selected, the fifth gear synchronizer engages fifth gear to the mainshaft **(Figure 38–32)**. This causes a large gear on the countershaft to drive a smaller gear on the mainshaft, which results in an overdrive condition. Overdrive permits an engine speed reduction at higher vehicle speeds.

Reverse

In reverse gear, it is necessary to reverse the direction of the mainshaft (output shaft). This is done by introducing a reverse idler gear into the power flow

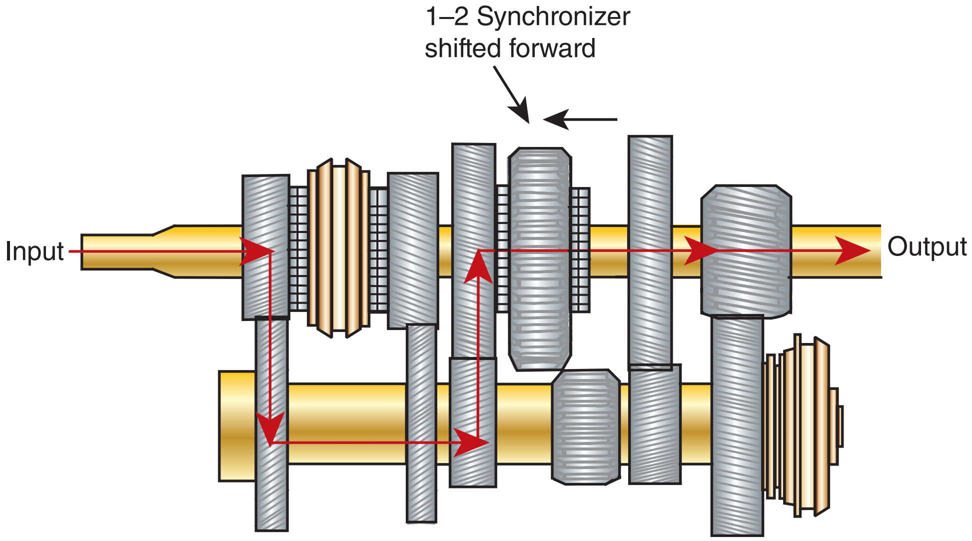


FIGURE 38-29 Power flow in second gear.

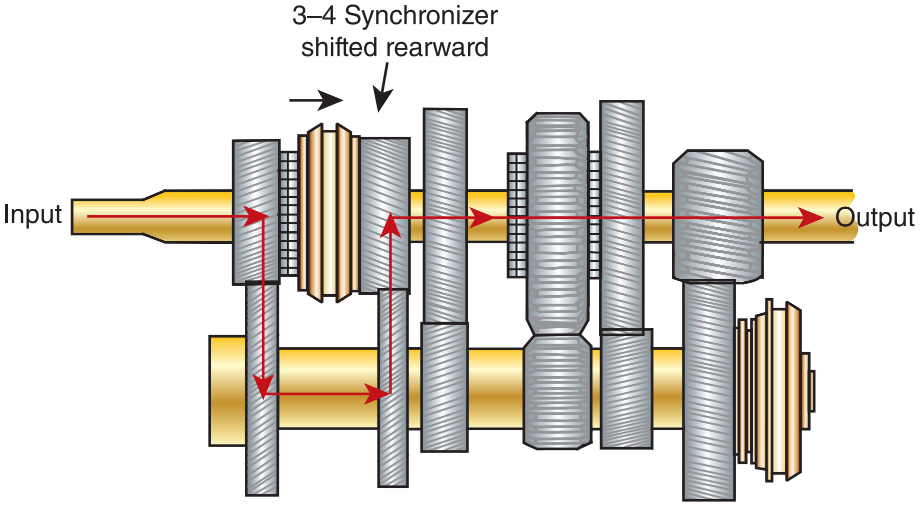


FIGURE 38-30 Power flow in third gear.

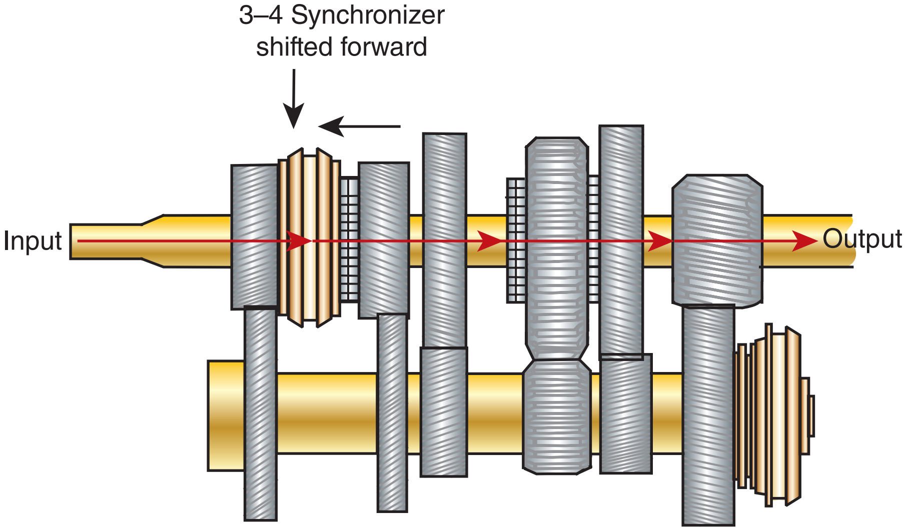


FIGURE 38-31 Power flow in fourth gear.

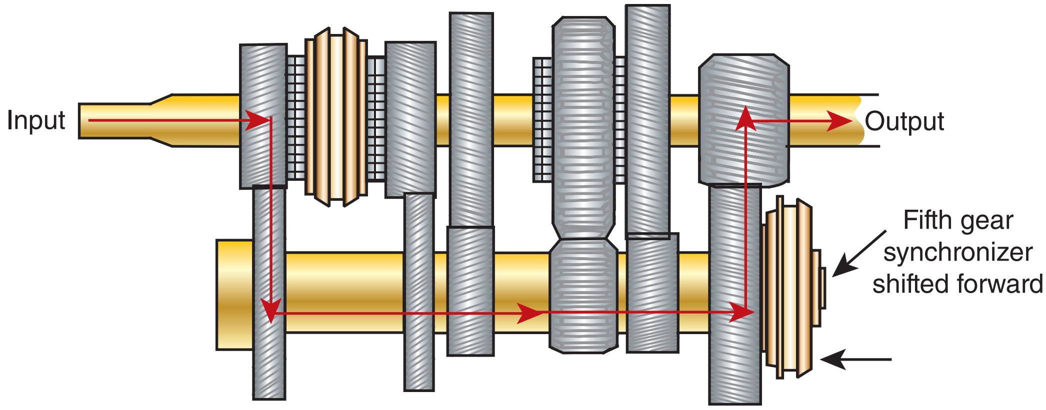


FIGURE 38–32 Power flow in fifth gear.

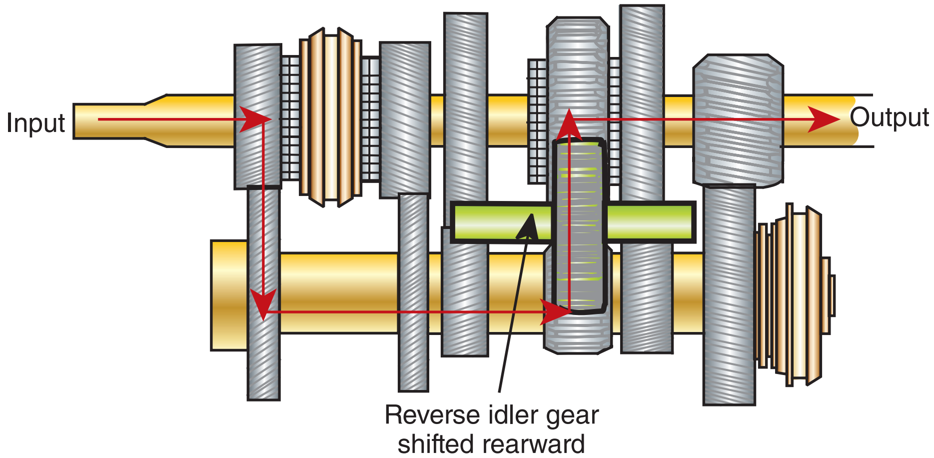


FIGURE 38–33 Power flow in reverse gear.

path. The idler gear is located between the countershaft reverse gear and the reverse speed gear on the mainshaft. The idler assembly is made of a short drive shaft independently mounted in the transmission case parallel to the countershaft. The idler gear may be mounted near the midpoint of the shaft.

The reverse speed gear is actually the external tooth sleeve of the first/second synchronizer.

When reverse gear is selected, both synchronizers are disengaged and in the neutral position. In the transmission shown in **(Figure 38–33)**, the shifting linkage moves the reverse idler gear into mesh with the first/second synchronizer sleeve. Power flows through the input shaft and clutch gear to the countershaft. From the countershaft, it passes to the reverse idler gear, where it changes rotational direction. It then passes to the first/second synchronizer sleeve. Rotational direction is again reversed. From the sleeve, power passes to the mainshaft and driveline.

Not all transmissions use speed and idler gears for reverse. For example, reverse gears in most Ford transmissions are helical gears that are in constant mesh with the first gear.

SHOP TALK

In Figure 38–33, the reverse idler gear is drawn below the countershaft. This is not where it really is. It is actually between the first/second synchronizer and the countershaft. To place it there in the drawing would make the illustration unclear.

Transaxle Power Flows

When studying the power flow patterns in the following section, keep in mind that the views are based on you standing by the right front fender and looking into the engine compartment. This will give an accurate idea of the true rotational direction of the gears and shaft. The transaxles used in these examples are five-speed, three-shaft units.

Neutral

When a transaxle is in its "neutral" position, no power is applied to the differential. Because the synchronizer collars are centered between their gear positions, the meshed drive gears are not locked to the output shaft. Therefore, the gears spin freely on the shaft and the output shaft does not rotate.

Forward Gears

When first gear is selected **(Figure 38–34)**, the first/second gear synchronizer engages with first gear. Because the synchronizer hub is splined to the output shaft, first gear on the input shaft drives its mating gear (first gear) on the output shaft. This causes the output shaft to rotate at the ratio of first gear and to drive the differential ring gear at that same ratio.

As the other forward gears are selected, the appropriate shift fork moves to engage the selected synchronizer with the gear. Because the synchronizer's hub is splined to the output shaft, the desired gear on the input shaft drives its mating gear on the output shaft **(Figures 38–35**, **38–36**, **38–37**, **and 38–38)**. This causes the output shaft to rotate at the ratio of the selected gear and drive the differential ring gear at that same ratio.

Reverse

When reverse gear is selected on transaxles that use a sliding reverse gear **(Figure 38–39)**, the shifting fork forces the gear into mesh with the input and output shafts. The addition of this third gear reverses the normal rotation of first gear and allows the car to change direction.

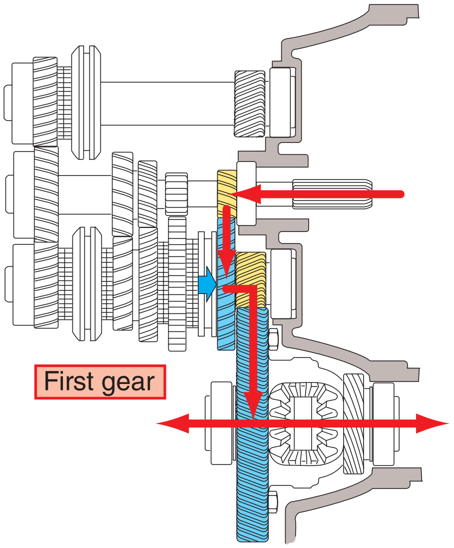
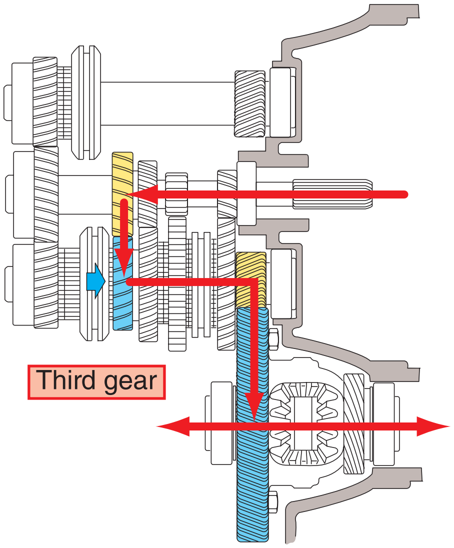
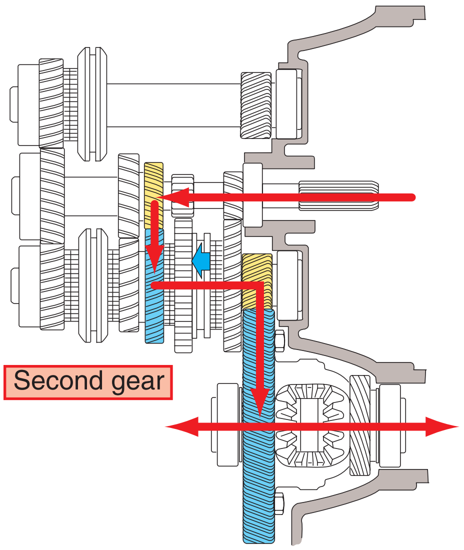


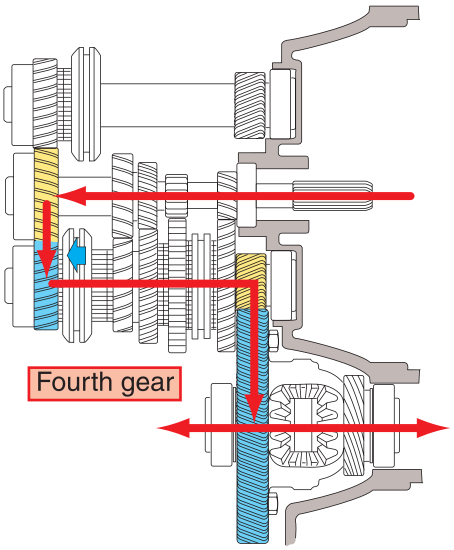
FIGURE 38–34 Power flow in first gear.



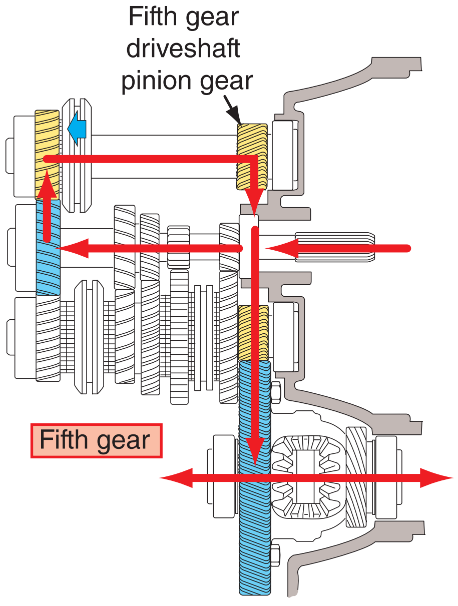
FIGURES 38–36 Power flow in third gear.



FIGURES 38–35 Power flow in second gear.



FIGURES 38–37 Power flow in fourth gear.



FIGURES 38-38 Power flow in fifth gear.

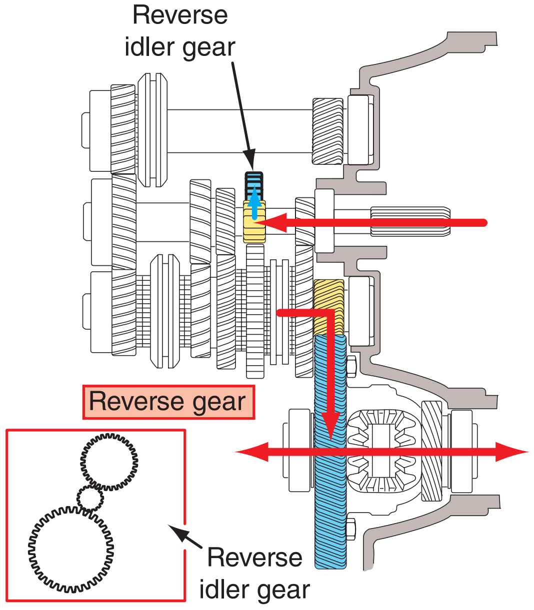


FIGURE 38-39 Power flow in reverse gear.

Differential Action

The final drive ring gear is driven by the transaxle's output shaft. The ring gear then transfers the power to the differential case. The case holds the ring gear with its mating pinion gear. The differential side gears are connected to the drive axles.

One major difference between the differential in a RWD car and the differential in a transaxle is direction of power flow. In a RWD differential, the power flow changes 90 degrees between the drive pinion gear and the ring gear. This change in direction is not needed with most FWD cars. The transverse engine position places the crankshaft so that it already is rotating in the correct direction. Therefore, the purpose of the differential is only to provide torque multiplication and divide the torque between the drive axle shafts so that they can rotate at different speeds.

Some transaxles need the 90-degree power flow change in the differential. These units are used in rear-engine with RWD applications in longitudinally positioned engines with FWD or some AWD vehicles.

Final Drive Gears and Overall Ratios

All vehicles use a gearset to provide an additional gear reduction (torque increase) above and beyond what the transmission or transaxle gearing can produce. This is known as the **final drive gear**.

In a transmission-equipped vehicle, the differential gearing is located in the rear axle housing. In a transaxle, however, the final reduction is produced by the final drive gears housed in the transaxle case.

A transaxle's final drive gears provide a way to transmit the transmission's output to the differential section of the transaxle. The pinion and ring gears and the differential assembly are normally located within the transaxle. There are four common configurations used as the final drives on FWD vehicles: helical gear, planetary gear, hypoid gear, and chain drive. The helical, planetary, and chain final drive arrangements are found with transversely mounted engines. Hypoid final drive gear assemblies are normally found in vehicles with a longitudinally placed engine. The hypoid assembly is basically the same unit as would be used on RWD vehicles and is mounted directly to the transmission.

Dual Clutch Transmissions

Dual clutch transmissions (DCTs) are being used in more vehicles. This is because of the many advantages it has over a conventional automatic and manual transmission. These benefits outweigh their increased costs. Their basic design allows them to change gears faster than a skilled driver or any other geared transmission. Not only are they more efficient, they are lighter, more durable, and require no regular maintenance. They also do not rely on a torque converter or planetary gearsets that can waste engine power. As a result, fuel consumption

can decrease by 10 percent or more and the driver will feel increased control over the engine's power output.

A dual clutch transmission is essentially a fully-automated, manual transmission with a computer-controlled clutch. DCTs have gear shafts fitted with helical and spur gears (just like most manual transmissions) to provide the various speed ratios. However, DCTs can operate in a fully automatic mode and drive like a very efficient automatic transmission. Current DCTs have six or seven forward speeds and are available from several manufacturers and each may call the DCT by a different name and may have slightly different control mechanisms.

Input from the Engine

Dual clutch transmissions use wet and/or dry clutch assemblies. These clutches are very similar; both have a compact multi-plate design **(Figure 38–40)**. Some transmissions have a wet and dry clutch. Dry clutches are typically used in DCTs with low power engines, and in FWD vehicles **(Figure 38–41)**. They are smaller, lighter, more reliable, less expensive to manufacture, and can provide better fuel economy than wet clutch equipped transmissions. This is due to their high clamping pressures that reduce the power lost as torque flows from the engine to the transmission and speed gears. DCTs have two separate clutch assemblies. The disadvantage of a dry clutch is that they wear quickly.

A wet clutch is commonly used with large, powerful engines. In a wet clutch assembly, the clutch discs are housed in a drum and are completely submerged in oil. The oil cools the discs, which allows the discs to have a relatively long service life. The cooling of the oil is also the reason why transmissions

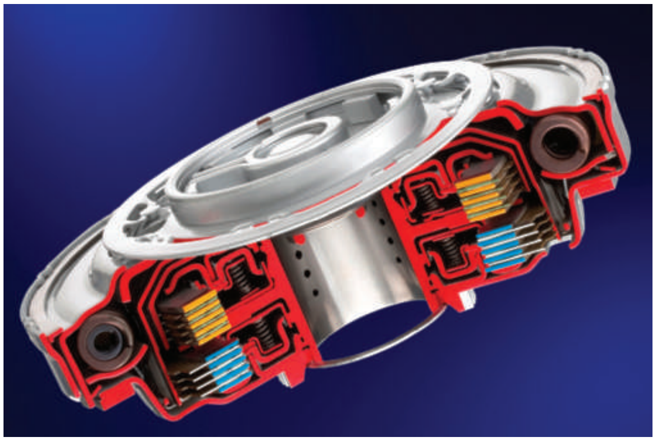


Photo Courtesy of BorgWarner.

FIGURE 38–40 A dual clutch assembly uses two clutch packs to alternately connect the engine's output to one of the two input shafts in the transmission.

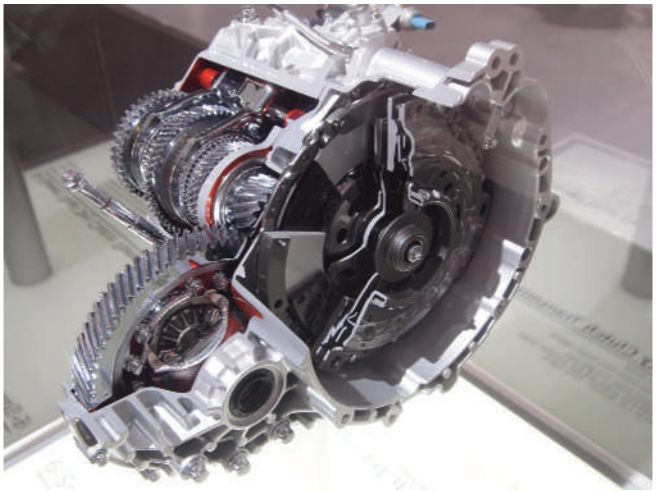


FIGURE 38–41 A six-speed DCT with dry clutches for a FWD vehicle.

fitted to powerful engines have wet clutches. A typical wet clutch assembly has friction discs, friction plates, and a pressure plate within the drum. When engaged, hydraulic pressure forces the parts together and passes engine torque to the appropriate input shaft.

Operation

A DCT is really two separate manual transmissions, housed in the same case, that work in parallel. Each of these transmissions has their own clutch assembly. One of the basic transmission assemblies consists of the even numbered gears, while the other contains the odd numbered gears. For example: in a six-speed DCT, one clutch and transmission assembly is for 1st, 3rd, and 5th gears; the other clutch and transmission is for 2nd, 4th, and 6th gears. In order to do this, a two-part input shaft is used. Again each part of the shaft works with the even or odd gears. The outer input shaft is hollow and has the inner shaft running through it **(Figure 38–42)**. Reverse gear is typically tied to the odd shaft.

A DCT has no clutch pedal. The clutches are engaged and disengaged by electro-hydraulic actuators. The actual shifting of gears is completed by computer-controlled solenoids and hydraulics. Dual clutch transmissions can be shifted either manually or automatically. In the automatic mode, the computer selects the proper gear for the conditions. To operate the unit manually, the driver changes gears with buttons, paddles, or a shifter. Most dual clutch transmissions have a traditional P-R-N-D shift pattern **(Figure 38–43)**. The transmission can shift automatically in either normal (D) or sport (S) modes.

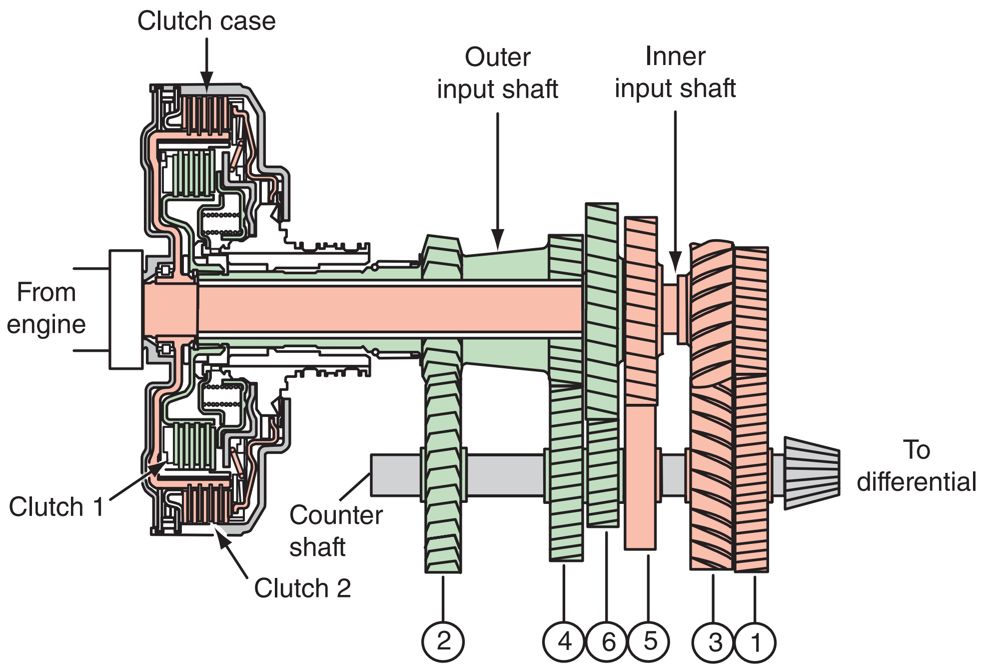


FIGURE 38–42 The basic layout for a six-speed DCT.

FIGURE 38–43 Shifter positions for a DSG transmission, to manually control the gears the shifter is moved to the right.

FIGURE 38–44 A shift paddle for a DSG.

While in the normal mode, the DCT shifts into the higher gears early in order to minimize engine noise and maximize fuel economy. When the sport mode is selected, the transmission holds the lower gears longer for improved performance. The driver can also elect to operate the transmission manually by either sliding the shift lever to the side or pulling one of the paddles on the steering wheel **(Figure 38–44)**.

Instantaneous shifting is accomplished by complex electronic controls that change the powerflow from one clutch and transmission assembly to the other, when a change in gears is ordered **(Figure 38–45)**. The electronic controls also have a predictive feature that pre-selects the next gear in the sequence.

To understand this concept, consider the powerflow through a DCT. When the vehicle is at a standstill and the driver begins to accelerate, transmission #1 is in first gear while transmission #2 is in second. Clutch 1 engages and the vehicle moves in first gear. When it is time to upshift, clutch 2 engages while clutch 1 disengages. Since second gear was already engaged, the vehicle is now operating in second gear. As soon as clutch 1 is disengaged, transmission 1 immediately shifts into third gear. This sequence continues when it is time to upshift again, clutch 1 engages and the vehicle is operating in third gear. At the same time, clutch 2

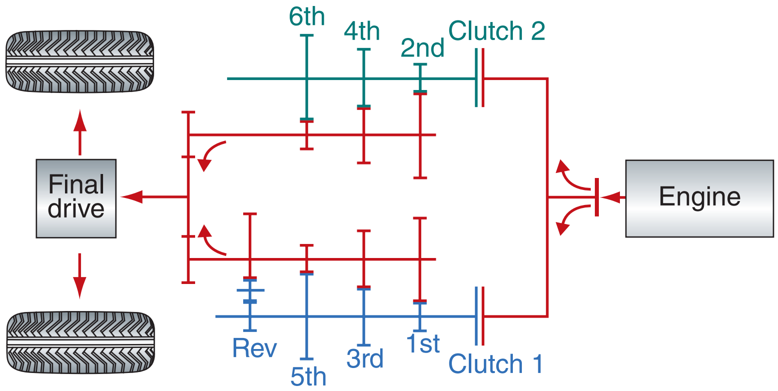


FIGURE 38–45 Power flow through a DCT.

disengages and transmission 2 is shifted into fourth gear. In all cases, the pre-selected gear will not affect the performance of the operating gear because no input torque is reaching it.

As a result of these actions, torque is smoothly passed through without interruption. The pre-selection of gears allows for very quick gear changes. Most systems require only 8 milliseconds to complete an upshift.

A DCT is also capable of skipping gears and will perform double-clutch downshifts when needed. Downshifting, however, is not as quick as upshifting. It takes about 600 milliseconds to complete a downshift. This is due to the time required for the throttle blip, which matches transmission speed to engine speed. Downshifting will also take longer if the driver skips some gears. This is especially true if the vehicle is operating in sixth gear and the driver wants to downshift into second. Second and sixth gears are on the same shaft and operate with the same clutch. To provide this change, the transmission must first downshift into fifth gear because it is on the other shaft. Then the transmission can engage second gear and the associated clutch. Typically this sequence takes 900 milliseconds; this is not a long time but is longer than upshifting.

Volkswagen/Audi Direct Shift Gearbox (DSG)

Dual clutch transmissions were first put into production by BorgWarner. This transmission was called a "DualTronic" unit. Volkswagen licensed the technology and uses BorgWarner clutches and control modules for their dual clutch transmissions. Dual clutch transmissions initially appeared in an Audi with the name Direct-Shift Gearbox (DSG), sometimes called a dual shaft transmission. Since then it has been available in several other Audi and Volkswagen models. The use of a DCT in the Bugatti Veyron EB 16.4 demonstrates that this transmission can handle large amounts of engine power. The Veyron's W-16 engine is rated at 987 peak horsepower.

Currently, the Volkswagen Group has more models available with a DCT than any other manufacturer. The most common is a six-speed transaxle with dry clutches. DSGs with seven speeds and wet clutches are also found in VW group vehicles. The DSG' s electronic control unit (ECU) is mounted to the transaxle. The ECU has adaptive learning, which allows it to learn how the vehicle is typically driven and will attempt to match the shift points to the driver. The ECU controls a hydro-mechanical unit. The control module is the most complex component of a DSG transmission **(Figure 38–46)**. The transmission can be operated totally by the ECU or the driver can manually shift gears with a shift lever or steering wheel-mounted paddles. The ECU controls the clutches, input and output shafts, transaxle cooling, gear selection and timing, and hydraulic pressures. In addition to the various DSG specific sensors, the ECU relies on bus data to determine the current operating conditions.

Ford's PowerShift

The dual clutch Ford PowerShift transmission is a six-speed transmission with dry clutches **(Figure 38–47)**. Ford has designed a dry clutch system that can handle engines with a broad torque range. Also, dry clutch systems are smaller, lighter, easier to service, more reliable and cheaper than wet clutch systems. A dry clutch transfers power and torque through typical clutch disc facings. Because the clutches are dry, a dedicated oil pump with oil lines is not required. This reduced the weight and complexity of the transmission.

The transmission has the same basic design as other DCTs, in that, there are two input clutches and

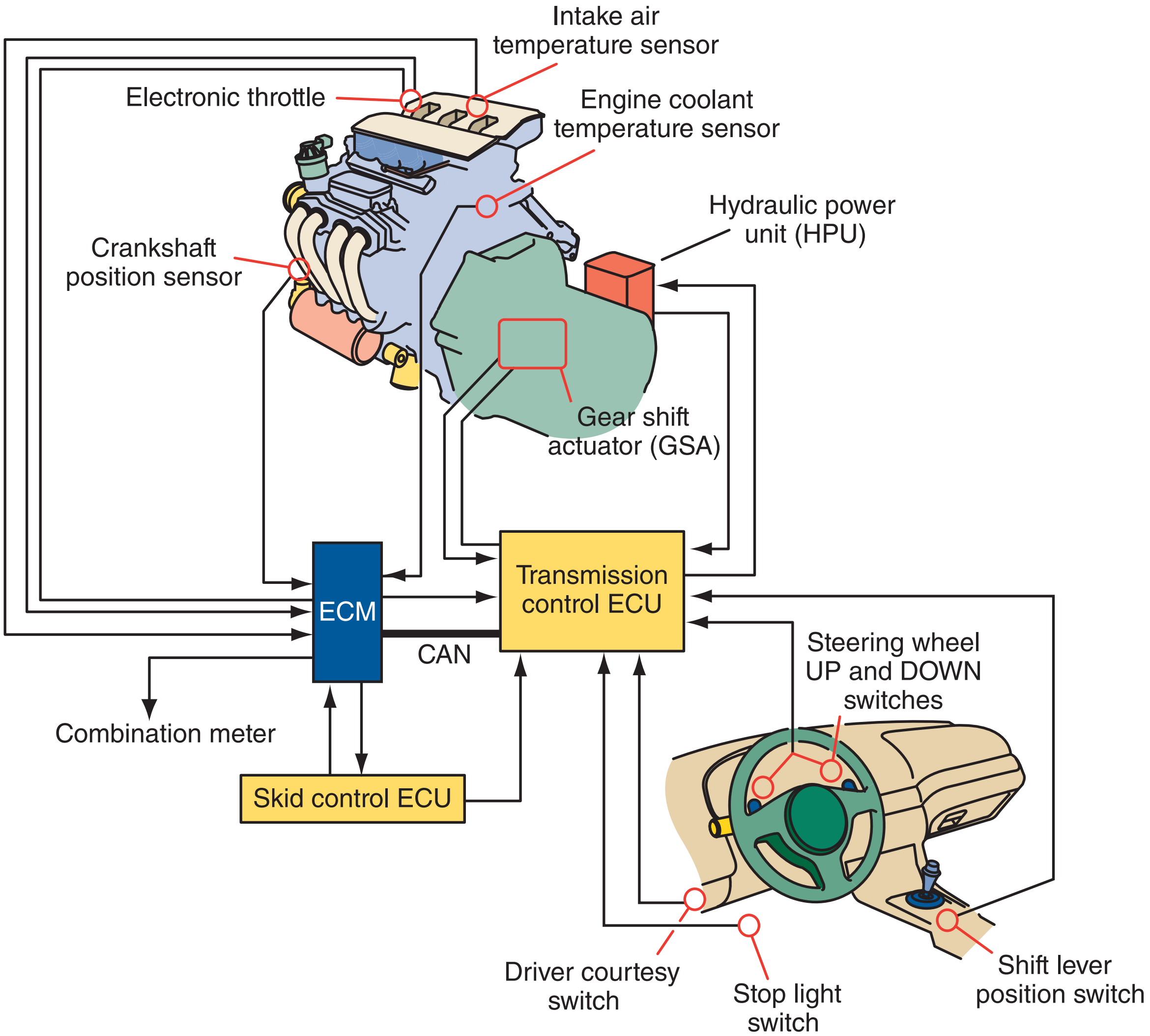


FIGURE 38-46 The main control components for a DSG.

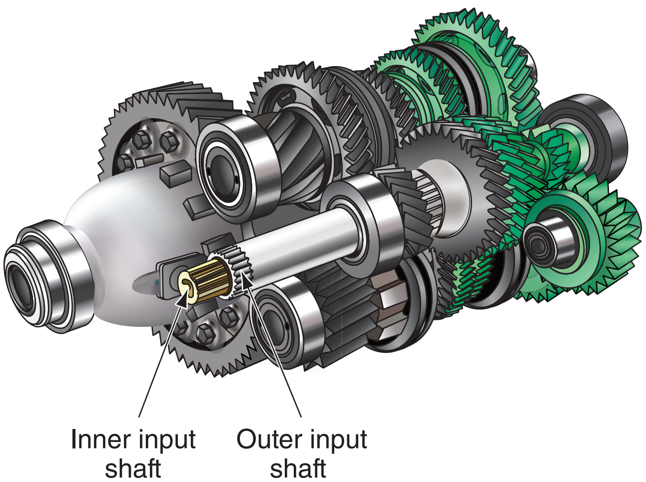


FIGURE 38-47 The gear train for a PowerShift transaxle.

shafts; each transferring power to odd or even forward gears. Control of the clutches and the mechanisms to shift gears is accomplished by an electronic control module and is based on inputs from a number of different systems and conditions. The two clutches simultaneously engage and disengage to provide seamless torque delivery to the drive wheels with little negative effect on acceleration. Although Ford's current DCT operates in the same way as other DCTs, it currently does not equip its vehicles with paddle shifters.

Ford's PowerShift does offer some other interesting features, such as:

- Neutral coast down—disengages the transmission during idle and coasting, which results in improved coasting downshifts and increased overall efficiency by not using engine power while the car is sitting still.
- Precise clutch control—allows for just the right amount of clutch slippage to reduce noise, vibration and harshness (NVH) during low engine speeds.

- Creep mode with integrated brake pressure—controls the vehicle's tendency to roll forward or backward when stopped and the transmission is in a forward or reverse gear.
- Hill mode or launch assist—prevents the car from rolling back when it is stopped on a steep grade. The system's computer controls brake pressure and the engine to hold the car where it is.
- SelectShift—allows the driver to change gears, up or down, by pressing a button on the shift handle.
- Overspeed control—prevents the driver from downshifting too aggressively, which can cause engine damage by over-revving it.

Porsche Dual Clutch (PDK)

Porsche was one of the early developers of a dual clutch transmission. They offer the Porsche Dual Clutch (PDK) transmission (the official name is *Porsche-Doppelkupplung*) in many different model vehicles. This is a seven-speed dual clutch transmission. Like other DCTs, the drive unit is made up of two transmissions, two wet clutches, and a hydraulic control system **(Figure 38–48)**. Gear selection is done by steering wheel paddles or at the shifter.

This transmission is a transaxle located at the rear wheels, and was designed for high output engines. The transmission offers three automatic shifting modes: Normal, Sport, and Sport Plus (on vehicles with the Sport Chrono option). Normal mode controls all shifting to provide for good driveability while using the least amount of fuel. Sports mode

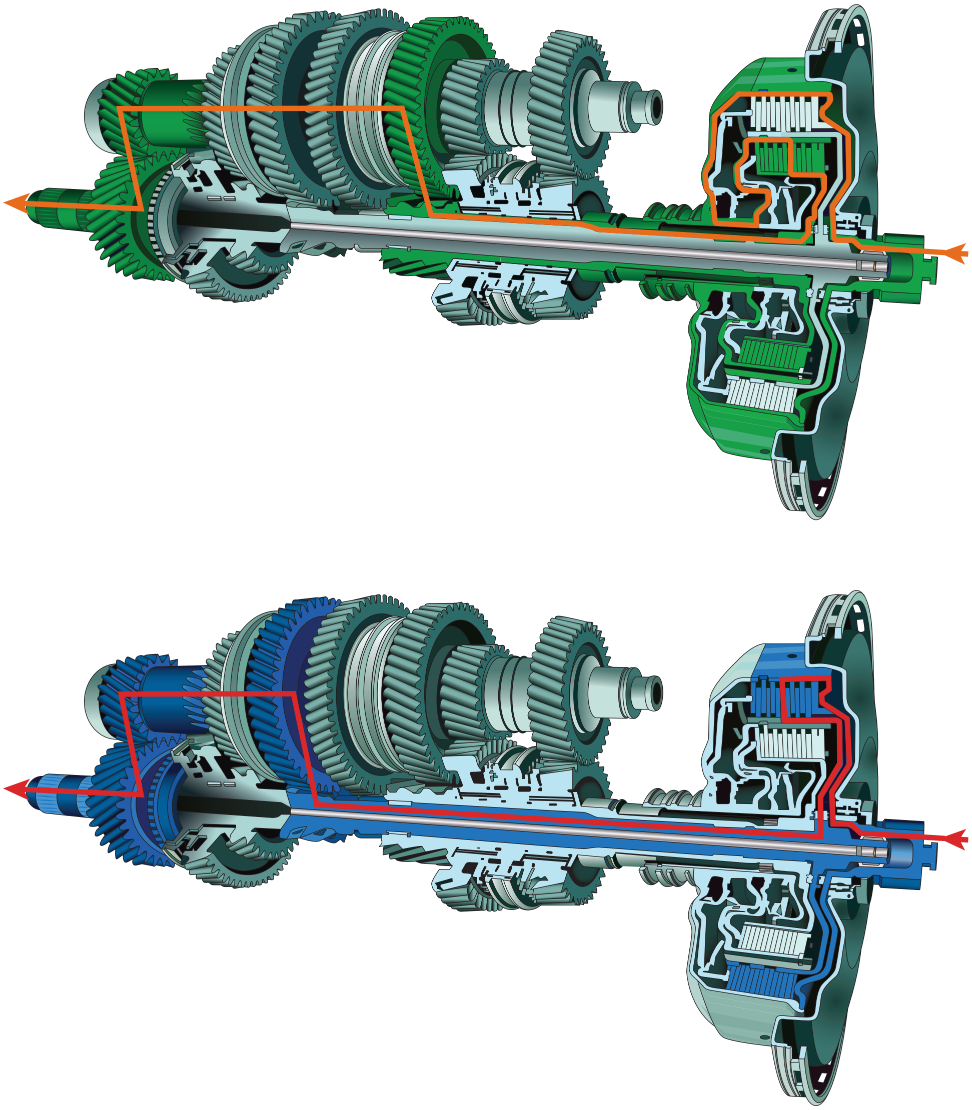


FIGURE 38–48 The powerflow through the two inputs shafts of this PDK.

delays the shifts and allows the engine to reach higher speeds before shifting. The Sports Plus mode delays the shifts even further, and provides extremely quick gear changes. In this mode, seventh gear is not available. The control unit relies on inputs available on the CAN bus, plus four distance sensors, two pressure sensors, one temperature sensor, and two engine-speed sensors (combined into one housing) to choose the correct gear and shift timing.

The PDK can also be operated in a full manual mode. While set in the manual mode, the transmission will not shift on its own unless the engine's speed exceeds a particular speed limit. It will also not downshift on its own unless engine speed drops too low. The system does include a kickdown switch that is activated by fully opening the throttle. This switch allows for instantaneous maximum acceleration when it is needed. An example of this is when cruising at a moderate speed in seventh gear and there is a need to quickly accelerate. When the switch is activated, the transmission will downshift into fourth, third, or second gear. During kickdown, the transmission will not only downshift, but it stays in that gear until the engine redlines, then it will upshift one gear at a time as long as the throttle is fully depressed.

Cars equipped with the optional Sports Chrono Plus package have a launch-control program that closes the clutch automatically from 6,500 rpm after the brake pedal is depressed, the throttle is opened completely, and the brake pedal is released. This allows the car to accelerate under full power without wheel slip or an interruption of traction.

Electrical Systems

Although most manual transmissions are not electrically operated or controlled, a few accessories of the car are controlled or linked to the transmission. The transmission may also be fitted with sensors that give vital information to the computer that controls other car systems. There are a few transmissions that have their shifting controlled or limited by electronics.

Reverse Lamp Switch

All vehicles sold in North America after 1971 have been required to have back-up (reverse) lights. Back-up lights illuminate the area behind the vehicle and warn other drivers and pedestrians that the vehicle is moving in reverse. Most manual transmissions are equipped with a separate switch located on the transmission **(Figure 38–49)** but can be mounted to the shift linkage away from the transmission. If the switch is mounted in the transmission, the shifting fork closes the switch and completes the electrical circuit whenever the transmission is shifted into reverse gear. If the switch is mounted on the linkage, the switch is closed directly by the linkage.

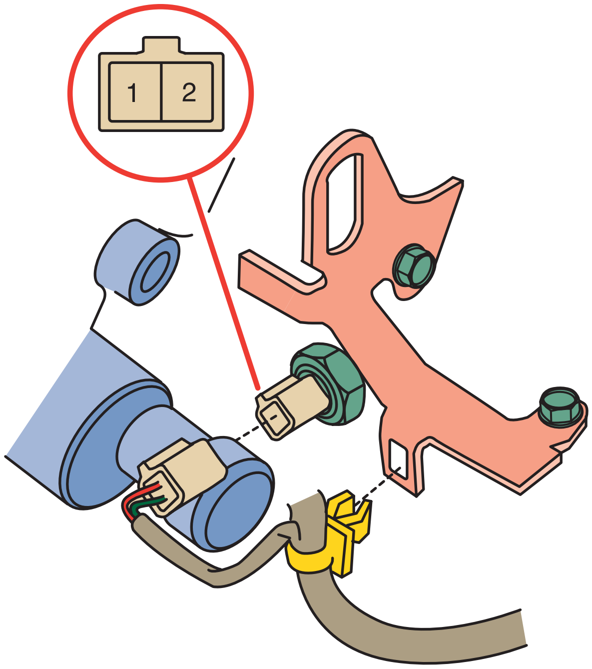


FIGURE 38–49 A typical back-up light switch for a transaxle.

Vehicle Speed Sensor

Most late-model transmissions and transaxles are fitted with a VSS. This sensor sends an electrical signal to the vehicle's PCM. This signal represents the speed of the transmission's output shaft. The PCM then calculates the speed of the vehicle. This information is used for many systems, such as cruise control, fuel and spark management, and instrumentation. Affected instrumentation includes the speedometer, odometer, and upshift lamp.

Reverse Lockout System

Some vehicles electrically prevent the transmission from being shifted into reverse when the vehicle is moving. These systems are typically called reverse lockout systems **(Figure 38–50)**. Normally, when the vehicle is moving at a speed of 12 mph (20 km/h) or more, a signal from the PCM energizes the reverse lockout solenoid. The solenoid pushes a cam and lock pin down. This action makes it impossible for the transmission to be shifted into reverse. When the vehicle is sitting still or traveling at lower speeds, the solenoid is not energized. A return spring holds the lock pin away from the interlock assembly and the shifter is free to move into reverse.

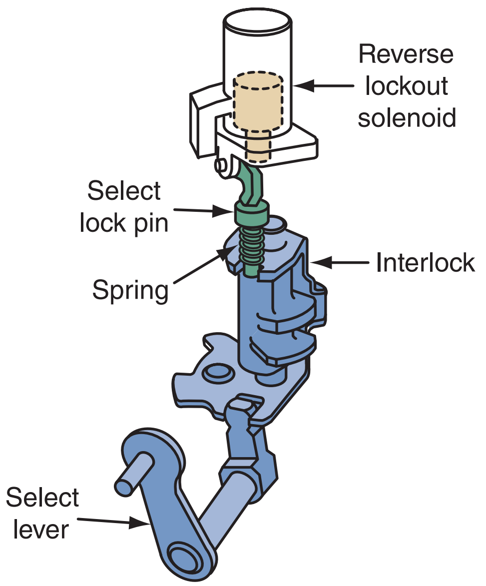


FIGURE 38-50 A PCM-controlled reverse lockup assembly.

Shift Blocking

Some six-speed transmissions have a feature called shift blocking that prevents the driver from shifting into second or third gears from first gear, when the engine's coolant temperature is below a specified degree, the speed of the car is between 12 and 22 mph (20 and 29 km/h), and the throttle is opened less than 35 percent. Shift blocking helps improve fuel economy. These transmissions are also equipped with reverse lockout, as are some others. This feature prevents the engagement of reverse whenever the vehicle is moving forward.

Shift blocking is controlled by the PCM. A "skip shift" solenoid is used to block off the shift pattern from first gear to second and third gears. The driver moves the gearshift from its up position to a lower position, as if shifting into second gear, but fourth gear is selected.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 1995	**Make:** Ford	**Model:** Mustang	**Mileage:** 115,941	**RO:** 15865
Concern:	Customer states the transmission won't go into gear easily and it makes noise when shifting gears.			
After confirming the complaint, the technician inspects the clutch slave cylinder, fluid line, and then the master cylinder. The clutch operation is as it should be and no evidence of a clutch problem is present. He also inspects the shifter and does not find a cause for the complaint. Because of the age and mileage of the vehicle, he suspects the problem may be with the synchronizers and recommends removing the transmission and disassembling it for inspection.				
Cause:	Suspected wear of the synchronizers.			
Correction:	Customer declines repairs due to cost of rebuilding transmission. Installed a used transmission.			

KEY TERMS

Cluster gear
Countershaft
External gear
Final drive gear
Gear pitch
Helical gear
Idler gear
Input shaft
Shift forks
Shift rail
Spur gear
Synchronizer

SUMMARY

- A transmission or transaxle uses meshed gears of various sizes to give the engine a mechanical advantage over its driving wheels.
- Transaxles contain the gear train plus the differential gearing needed to provide the final drive gear ratios. Transaxles are commonly used on front-wheel drive vehicles.
- Transmissions are normally used on rear-wheel drive vehicles.
- Gears in the transmission/transaxle transmit power and motion from an input shaft to an output shaft. These shafts are mounted parallel to one another.

- Spur gears have straight cut teeth, while helical gears have teeth cut at an angle. Helical gears run without creating gear whine.
- When a small gear drives a larger gear, output speed decreases but torque (power) increases.
- When a large gear drives a smaller gear, output speed increases but torque (power) decreases.
- When two external toothed gears are meshed and turning, the driven gear rotates in the opposite direction of the driving gear.
- Synchronizers bring parts rotating at different speeds to the same speed for smooth clash-free shifting. The synchronizer also locks and unlocks the driven (speed) gears to the transmission/transaxle output shaft.
- Idler gears are used to reverse the rotational direction of the output shaft for operating the vehicle in reverse.
- In typical five-speed transmission shift linkage, there are three separate shift rails and forks. Each shift/rail shift fork is used to control the movement of a synchronizer.
- Gear ratios indicate the number of times the input drive gear is turning for every turn of the output driven gear. Ratios are calculated by dividing the number of teeth on the driven gear by the number of teeth on the drive gear. You can also use the rpm speeds of meshed gears to calculate gear ratios.
- A gear ratio of less than one indicates an overdrive condition. This means the driven gear is turning faster than the drive gear. Speed is high, but output torque is low.
- All vehicles use a gearset in the final drive to provide additional gear reduction (torque increase) above and beyond what the transmission or trans-axle gearing can produce.

REVIEW QUESTIONS

Short Answer

1. What determines whether a conventional transmission or a transaxle is used?
2. Define the purpose of the final drive gears.
3. The number of gear teeth per unit of measurement of the gear's diameter (such as teeth/inch) is known as gear ___.
4. What does a shift blocking system do, and how does it basically work?
5. Explain the role of shift rails and shift forks in the operation of a transmission or transaxle.

True or False

1. *True or False?* A reverse idler gear changes the direction of torque flow to the opposite direction of engine rotation.
2. *True or False?* A set of gears can be configured or used in three different ways.
3. *True or False?* In most transmissions and transaxles, there is one synchronizer assembly for each speed gear.
4. *True or False?* The cone on a synchronizer's blocking ring serves as a cone-clutch assembly while changing gears.

Multiple Choice

1. Which of the following gear ratios indicates an overdrive condition?
   a. 2.15:1
   b. 1:1
   c. 0.85:1
   d. None of the above
2. Which type of gear develops gear whine at high rotational speeds?
   a. Spur gear
   b. Helical gear
   c. Both a and b
   d. Neither a nor b
3. When an idler gear is placed between the driving and driven gears, the driven gear:
   a. rotates the opposite direction as the drive gear
   b. rotates the same direction as the drive gear
   c. reduces the torque transfer from the drive gear to the driven gear
   d. none of the above
4. The component used to ensure that the mainshaft (output shaft) and main (speed) gear locked to it are rotating at the same speed is known as a ___.
   a. synchronizer
   b. shift detent
   c. shift fork
   d. transfer case

5. In a transaxle, the pinion gear on the pinion shaft meshes with the ___.
   a. reverse idler gear
   b. ring gear
   c. countershaft drive gear
   d. input gear
6. Which of the following gear ratios provides the highest torque multiplication?
   a. 0.85:1
   b. 2.67:1
   c. 5.23:1
   d. 0.50:1

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that most transaxles have a countershaft between the main and output shafts. Technician B says that a countershaft is always in motion when the engine is running. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. While discussing the various types of transmissions found on today's vehicles: Technician A says that one type is the sliding gear transmission. Technician B says that one type is the sliding collar transmission. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. Technician A says that the countergear or cluster gear is actually several gears machined out of single piece of iron or steel. Technician B says that the countergear is driven by the clutch gear and drives the mainshaft speed gears. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. Technician A says that reverse lamp switches are activated at the transmission/transaxle by the gearshift lever. Technician B says that reverse lamp switches are activated by a sensor at the input shaft. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. Technician A says that if a single idler gear is used to obtain reverse gear, its size and number of teeth must be used to calculate gear ratios. Technician B says that an idler gear is often used for reverse gear because it causes the output shaft to rotate in the reverse direction of the input shaft. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. Technician A says that in a conventional transmission, the speed gears freewheel around the mainshaft until they are locked to it by the appropriate synchronizer. Technician B says that speed gears are an integral part of the countershaft assembly. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. While discussing the power flow through a five-speed transmission while it is in first gear: Technician A says that power enters on the input shaft, which rotates the countershaft that is engaged with first gear. Technician B says that the first gear synchronizer engages with the clutching teeth of first gear and locks the gear to the main shaft, allowing power to flow from the input gear through the countershaft and to first gear and the main shaft. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

8. Technician A says that double-cone synchronizers have friction material on both sides of the synchronizer rings. Technician B says that multiple-cone synchronizers are used with larger engines and require a larger transmission housing. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. Technician A says that some synchronizer assemblies use frictional material on the blocking rings to reduce slippage. Technician B says that the inside of some blocking rings is shaped like a cone lined with many sharp grooves. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. While discussing shift mechanisms: Technician A says that the interlock notches hold the transmission in the selected gear. Technician B says that the detent notches prevent the selection of more than one gear during operation. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 39

MANUAL TRANSMISSION/ TRANSAXLE SERVICE

OBJECTIVES

- Perform a visual inspection of transmission/transaxle components for signs of damage or wear.
- Check transmission oil level correctly, detect signs of contaminated oil, and change oil as needed.
- Describe the steps taken to remove and install transmissions/transaxles, including the equipment and safety precautions used.
- Identify common transmission problems and their probable causes and solutions.
- Describe the basic steps and precautions taken during transmission/transaxle disassembly, cleaning, inspection, and reassembly procedures.

When properly operated and maintained, a manual transmission/transaxle normally lasts the life of the vehicle without a major breakdown. All units are designed so the internal parts operate in a bath of oil circulated by the motion of the gears and shafts. Some units also use a pump to circulate oil to critical wear areas that require more lubrication than the natural circulation provides.

Maintaining good internal lubrication is the key to long transmission/transaxle life. If the amount of oil falls below minimum levels, or if the oil becomes too dirty, problems result.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 1999	**Make:** Ford	**Model:** F150	**Mileage:** 226,410	**RO:** 15877
Concern:	Customer states the transmission is hard to get into gear and jumps out of gear while driving.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

SHOP TALK

Whenever you are diagnosing or repairing a transaxle or transmission, make sure you refer to the appropriate service information before you begin.

Prior to beginning any diagnosis, service, or repair work, be sure you know exactly which transmission you are working on. This will ensure that you are following the correct procedures and specifications and are installing the correct parts. Proper identification can be difficult because transmissions cannot be accurately identified by the way they look. The only positive way to identify the exact design of the transmission is by its identification numbers.

Transmission identification numbers are found either as numbers stamped on the case or on a metal tag held by a bolt head. Use the service information to decipher the identification number. Most identification numbers include the model, gear ratios, manufacturer, and assembly date **(Figure 39–1)**. Whenever you work with a transmission with a metal ID tag, make sure the tag is put back on the transmission so that the next technician will be able to properly identify the transmission.

If the transmission does not have an ID tag, the transmission must be identified by comparing it with those in the vehicle's service information.

Lubricant Check

The transmission/transaxle gear oil level should be checked at the intervals specified in the service information. Normally, these range from every 7,500 to 30,000 miles (12,000 to 48,000 km). For service convenience, many units are now designed with a dipstick **(Figure 39–2)** and filler tube accessible from beneath the hood. Check the oil with the engine off and the vehicle resting in a level position. If the engine has been running, wait 2 to 3 minutes before checking the gear oil level.

Some vehicles have no dipstick. Instead, the vehicle must be placed on a lift, and the oil level checked through the fill plug opening on the side of the unit. Clean the area around the plug before loosening and removing it. Normally, lubricant should be level with, or not more than, ½ inch (12.7 mm) below the fill hole. Always check the service information for the proper level. Add the proper grade lubricant as needed using a filler pump.

Manual transmission/transaxle lubricants in use today include single- and multiple-viscosity gear oils, engine oils, special hydraulic fluids, and automatic transmission fluid. Always refer to the service information to identify the correct lubricant for the vehicle and operating conditions **(Figure 39–3A and B)**.

DCT Maintenance Most DCTs require no special maintenance. Although DCTs are maintenance free,

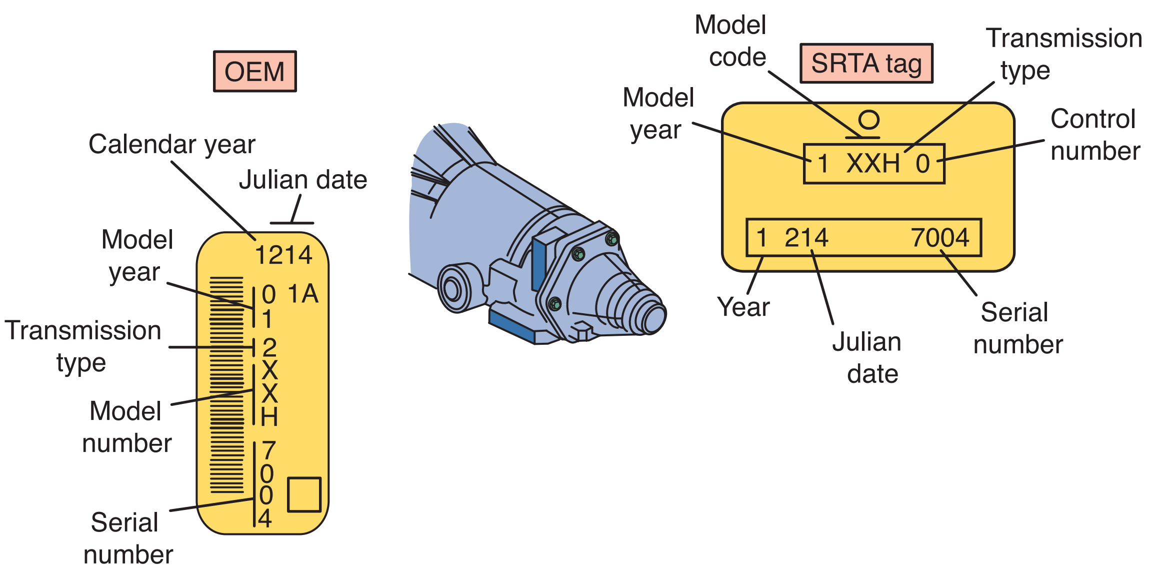


FIGURE 39-1 The location of and the information found on GM transmission ID decals.

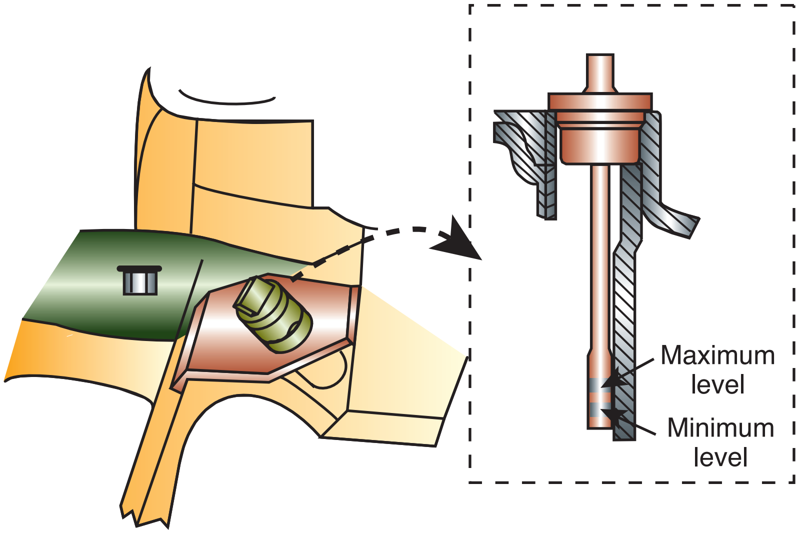
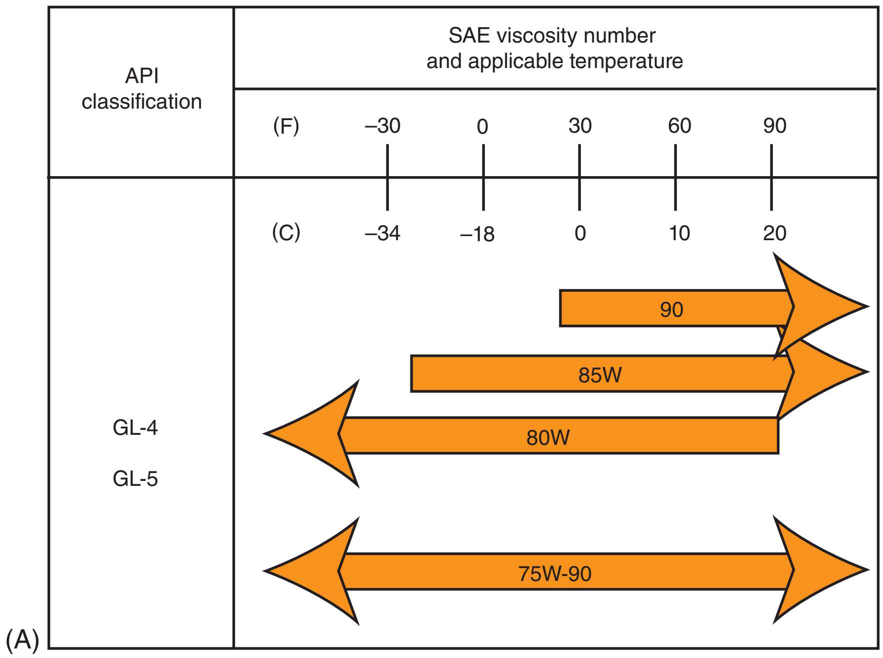


FIGURE 39-2 An example of a dipstick found on some manual transaxles.



(B)

Vehicle	Recommended Fluid
Camaro Aisin AY6 8-speed	SAE 75W-90 GL-5
Camaro Tremec 6-speed	Manual Transmission Fluid (Dex III ATF)
Mustang	Motorcraft Full-Synthetic Manual Transmission Fluid
Honda	Honda Manual Transmission Fluid (MTF) or SAE 10W-30 or 10W-40 as a temporary replacement
Mazda	SAE 75W-90 GL4/5
Nissan	SAE 75W-90 GL4/5
Subaru	SAE 75W-90 GL4/5

FIGURE 39-3 (A) Typical transmission/transaxle gear oil classification and viscosity range data. (B) Examples of modern manual transmission lubricant requirements.

the fluid should be changed at some point. How soon depends on the manner the car has been driven. However, the required lubricant varies with the type of DCT. Always check the service information to see what lubricant should be used in the transmission, as well as when service is required.

Typically a DCT with dry clutches requires the same gear oil used in manual transmissions. If the DCT is equipped with wet clutches, a special blend of automatic transmission fluid and gear oil must be used. You should also be aware that some DCTs require two separate types of fluids. These DCTs have dual sumps, one to lubricate the transmission's bearings, shafts, and gears; and the other to supply hydraulic pressure for the operation of the wet clutches.

Lubricant Leaks

Normally, the location and cause of a transmission fluid leak can be quickly identified by a visual inspection. The following are common causes for fluid leakage **(Figure 39–4)**:

1. An excessive amount of lubricant in the transmission or transaxle.
2. The use of the wrong type of fluid; it will foam excessively and leave through the vent.
3. A loose or broken input shaft bearing retainer.
4. A damaged input shaft bearing retainer O-ring and/or lip seal.
5. Loose or missing case bolts.
6. Case is cracked or has a porosity problem.
7. A leaking shift lever seal.
8. Gaskets or seals are damaged or missing.
9. The drain plug is loose.
10. Bad axle seals.
11. A plugged vent allowing pressure to build in the case.

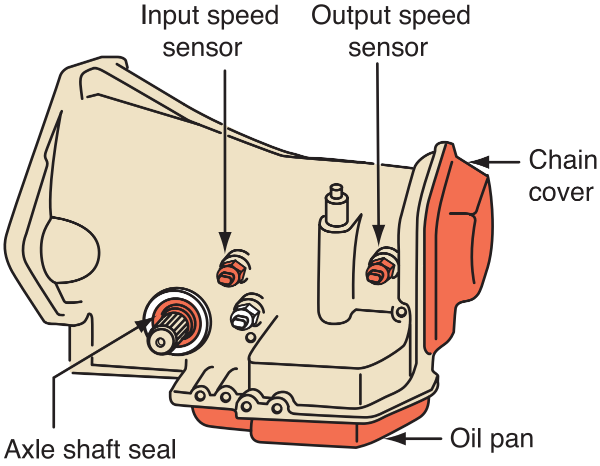


FIGURE 39–4 Possible sources of fluid leaks.

Fluid leaks from the seal of the extension housing can be corrected with the transmission in the car. Often, the cause for the leakage is a worn extension housing bushing, which supports the sliding yoke. When the drive shaft is installed, the clearance between the sliding yoke and the bushing should be minimal. If the clearance is satisfactory, a new oil seal will correct the leak. If the clearance is excessive, the repair requires that a new seal and a new bushing be installed. If the seal is faulty, the transmission vent should be checked for blockage. If the vent is plugged, the oil will be under high pressure when the transmission is hot, and this pressure can cause seal leakage.

An oil leak at the speedometer cable can be corrected by replacing the O-ring seal. An oil leak stemming from the mating surfaces of the extension housing and the transmission case may be caused by loose bolts. To correct this problem, tighten the bolts to the specified torque.

Fluid Changes

The manufacturers of most transmissions do not recommend intervals for manual transmission fluid replacement. Older transmissions typically had 20,000-mile fluid change intervals. When the vehicle is operated under severe conditions, such as in high heat or dusty road conditions, the fluid may need to be periodically changed. Check the service information for the manufacturer's recommendations.

To change the transmission fluid, drive the vehicle to warm the fluid. Then raise the vehicle on a hoist. Make sure the car is level so that all of the fluid can drain out. Locate the oil drain plug in the bottom of the transmission case or extension housing. Wipe the area around the plug and remove it. Catch the fluid in a catch pan positioned below the hole. Let the transmission drain completely. The fluid is normally very thick and it takes some time to drain it all out.

Inspect the drained fluid for gold color metallic and other particles. The gold color particles come from the brass blocking rings of the synchronizers. Metal shavings are typically from the wearing of gears. After the fluid is drained, take a small magnet and insert it into the drain hole. Sweep the magnet around the inside to remove all metal particles. Because brass is not magnetic, the magnet will not attract brass particles. To remove brass shavings, insert a small brush or the end of a rag. Be careful to pull the shavings out, not push them in. Large amounts of metal particles indicate severe problems.

Before refilling the transmission, reinstall the drain plug with a new washer. Some manufacturers

CUSTOMER CARE

Just because the technician gets a little dirty in the course of a repair does not mean the vehicle should, too. Treat every car that enters the shop with the utmost care and consideration. Scratches from belt buckles or tools, and grease smears on the steering wheel, upholstery, or carpeting are inexcusable and a sure way of losing business. Always use fender, seat, and floor covers when the job requires them. Check your hands for cleanliness before driving a vehicle or operating the windows and dash controls.

recommend that a sealer be used on the plug. Remove the filler plug, which is normally located above the drain plug; Check the service information to identify the proper type and quantity of fluid for that transmission. Normally the case should be filled until the oil just starts to run out the filler hole or until it is at the bottom of the bore. Reinstall the plug with a new washer. Check the transmission housing vent to make sure it is not blocked with dirt. If the case is not properly vented, the fluid can easily break down and the pressure buildup can cause leaks. Make sure you fill the transmission with the correct type and amount of fluid. Too much or too little fluid can destroy a transmission.

In-Vehicle Service

Much service and maintenance work can be done to transmissions while they are in the car. Only when a complete overhaul or clutch service is necessary does the transmission need to be removed from the car. The following are procedures for common service operations: the replacement of a rear oil seal and bushing, linkage adjustments, and replacement of the back-up light switch and the speedometer cable retainer and drive gear.

Rear Oil Seal and Bushing Replacement

Procedures for the replacement of the rear oil seal and bushing on a transmission vary little with each car model. Typically, to replace the rear bushing and seal, follow these steps:

PROCEDURE

Replacement of Rear Oil Seal and Bushing

STEP 1 Remove the drive shaft.

STEP 2 Remove the old seal from the extension housing.

STEP 3 Pull the bushing from the housing **(Figure 39–5)**.

STEP 4 Drive a new bushing into the extension housing.

STEP 5 Lubricate the lip of the seal; then install the new seal in the extension housing **(Figure 39–6)**.

STEP 6 Install the drive shaft.

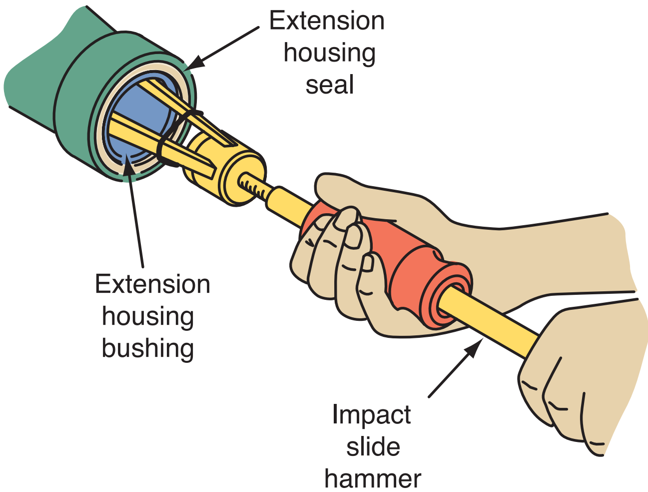


FIGURE 39-5 Removing the extension housing's seal and bushing.

Linkage Adjustment

Transmissions with internal linkage have no provision for adjustments. However, external linkages can be adjusted. Linkages are adjusted at the factory, but worn parts may make adjustments necessary. Also, after a transmission has been reassembled, adjustments may be necessary.

To begin the adjustment procedure, raise the car and support it on jack stands. Then follow the procedure given in the service information.

Back-Up Light Switch Service

To replace the back-up light switch, disconnect the electrical lead to the switch. Put the transmission into

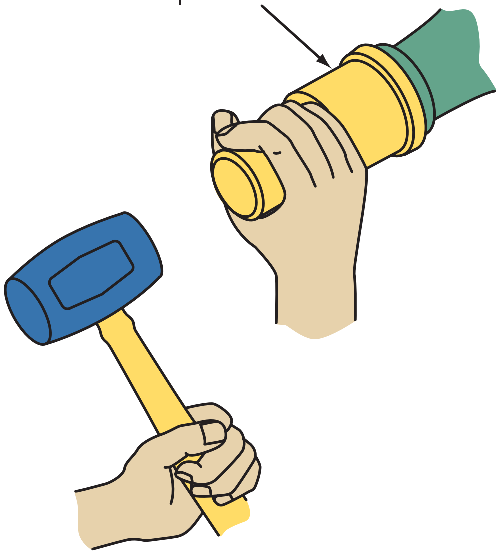


FIGURE 39–6 Drive the new seal in place with a hammer and seal driver.

reverse gear and remove the switch. Never shift the transmission until a new switch has been installed. To prevent fluid leaks, wrap the threads of a new back-up light switch with Teflon tape in a clockwise direction before installing it. Tighten the switch to the correct torque and reconnect the electrical wire to it.

Speedometer Drive Gear Service

Begin to remove the speedometer cable retainer and drive gear by cleaning off the top of the speedometer cable retainer **(Figure 39–7)**. Then remove the hold-down screw that keeps the retainer in its bore. Carefully pull up on the speedometer cable, pulling the speedometer retainer and drive gear assembly from its bore. Unscrew the speedometer cable from the retainer.

To reinstall the retainer, lightly grease the O-ring on the retainer and gently tap the retainer and gear assembly into its bore while lining the groove in the retainer with the screw hole in the side of the clutch housing case. Install the holddown screw and tighten it in place.

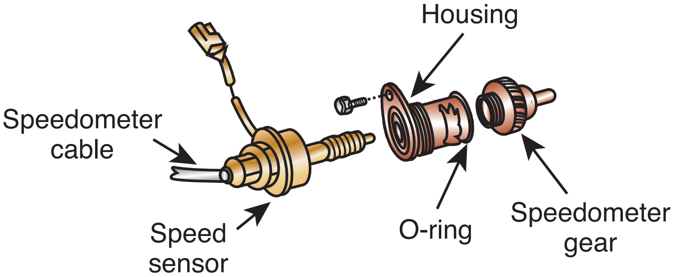


FIGURE 39–7 Oil leaks at the speed sensor can be caused by loose bolts or a bad seal.

Diagnosing Problems

Proper diagnosis involves locating the exact source of the problem. Many problems that seem transmission/transaxle related may actually be caused by problems in the clutch driveline or differential. Check these areas along with the transmission/transaxle, particularly if you are considering removing the transmission/transaxle for service.

Table 39–1 is a troubleshooting chart for common transmission and transaxle problems.

Remember to begin all diagnostics with an interview of the customer. Then verify the customer's complaint or concern. Also, after repairs are made, make sure you verify the repair.

Visual Inspection

Visually inspect the transmission/transaxle at regular intervals. Perform the following checks:

1. Check for lubricant leaks at all gaskets and seals.
2. Check the case body for signs of porosity that show up as leakage or seepage of lubricant.
3. Push up and down on the unit. Watch the transmission mounts to see if the rubber separates from the metal plate. If the case moves up but not down, the mounts require replacement.
4. Move the clutch and shift linkages around and check for loose or missing components. Cable linkages should have no kinks or sharp bends, and all movement should be smooth.
5. Transaxle drive axle boots should be checked for cracks, deformation, or damage.
6. The constant velocity joints on transaxle drive axles should be thoroughly inspected.

Transmission Noise

Noise concerns are quite common. Once again, be certain the noise is not coming from other components in the powertrain. Unusual noises may be a sign of trouble in the engine or transmission mounting system. Improperly aligned engines, improperly torqued mounting bolts, damaged or missing rubber mounts, cracked brackets, or even a stone rattling around inside the engine compartment can create noises that appear to be transmission/transaxle related.

TABLE 39-1 TRANSMISSION/TRANSAXLE TROUBLESHOOTING CHART

Concern	Possible Cause
Gear clash when shifting	Incorrect clutch adjustment Clutch linkage or cable binding Lubricant level low or incorrect lubricant Gearshift components or synchronizer blocking rings worn or damaged
Does not shift into one gear	Gearshift internal linkage or shift rail worn, damaged, or incorrectly assembled Shift rail detent plunger worn, spring broken, or plug loose Gearshift lever worn or damaged Synchronizer sleeves or hubs damaged or worn
Locked in one gear—cannot be shifted out of that gear	Shift rails worn or broken, shifter fork bent, setscrew loose, center detent plug missing or worn Broken gear teeth on countershaft gear input shaft, or reverse idler gear Gearshift lever broken or worn, shift mechanism incorrectly assembled or broken, worn or damaged gear train components
Slips out of gear	Clutch housing misaligned Gearshift mechanisms, shift forks, shift rail, detent plugs, springs, or shift cover worn or damaged Clutch shaft or roller bearings worn or damaged Gear teeth worn or tapered, synchronizer assemblies worn or damaged, excessive end play Pilot bushing worn
Shifts hard	Clutch adjustment incorrect Clutch linkage binding Shift rail binding Internal bind in transmission caused by shift forks, selector plates, or synchronizer assemblies Clutch housing misalignment Incorrect lubricant
Clicking noise in any one gear range	Damaged gear teeth
Rough growling noise from transmission and heard in all gears	Shaft bearings worn or damaged
Rough growling noise in transmission—noise heard in all gears except direct drive	Worn or damaged output shaft bearings
Rough growling noise when engine operating with transmission	Input shaft, countershaft, or countergear bearings worn or damaged

SHOP TALK

If during the test drive you hear a noise you suspect is coming from inside the transmission/transaxle, bring the vehicle to a stop. Disengage the clutch. If the noise stops with the engine at idle and the clutch disengaged, the noise is probably inside the unit.

Once you have eliminated all other possible sources of noise, concentrate on the transmission unit. Noises from inside the transmission may indicate worn or damaged bearings, gear teeth, or synchronizers. A noise that changes or disappears in different gears can indicate a specific problem area in the transmission.

The type of noise detected will help identify the problem.

> **Caution!** When the transmission/transaxle is in gear and the engine is running, the driving wheels and related parts turn. Avoid touching moving parts. Severe physical injury can result from contact with spinning drive axles and wheels.

Rough, Growling Noise This can be a sign of several problems in a transaxle or transmission depending on when it occurs. If the noise occurs when the transaxle is in neutral and the engine running, the problem may be the input shaft roller bearings. The input shaft is supported on either end by tapered roller bearings, and these are the only bearings in operation when the transaxle is in neutral. In its early stages, the problem should not cause operational difficulties, but left uncorrected, it grows worse until the bearing race or rolling element fractures. Solving the problem involves transaxle disassembly and bearing replacement.

When the vehicle is moving, both the input and mainshaft (output shaft) are rotating in the transmission. If the noise occurs in forward and reverse gears, but not in neutral, the output, countershaft, countergear, or mainshaft bearings are the likely failed component.

If the growling occurs in all gears except direct drive, the bearing at the rear of the transmission input shaft may be at fault. This bearing supports the pilot journal at the front of the transmission's output shaft. In all forward gears except direct drive, the input shaft and output shaft turn at two different speeds. In reverse, the two shafts turn in opposite directions. In direct drive, the two shafts are locked together and this bearing does not turn. Disassembly, inspection, and replacement of damaged parts is needed.

If the rough growling noise occurs when the engine is running, the clutch engaged, and the transmission in neutral, the front input shaft bearing is likely at fault.

Clicking or Knocking Noise Normally, helical gears are quiet because the gear teeth are constantly in contact. (When spur cut gear teeth are used for reverse gearing, clicking or a certain amount of **gear whine** is normal, particularly when backing up at faster speeds.)

Clicking or whine in forward gear ranges may indicate worn helical gear teeth. This problem may not require immediate attention. However, chipped or broken teeth are dangerous because the loose parts can cause severe damage in other areas of the transmission/transaxle. Broken parts are usually indicated by a rhythmical knocking sound, even at low speeds. Complete disassembly, inspection, and replacement of damaged parts is the solution to this problem.

Gear Clash

Gear clash is indicated by a grinding noise during shifting. The noise is the result of one gearset remaining partly engaged while another gearset attempts to turn the mainshaft. Gear clash can be caused by incorrect clutch adjustment or binding of the clutch or gearshift linkage. Damaged, worn, or defective synchronizer blocking rings can cause gear clash, as can use of an incorrect gear lubricant.

Hard Shifting

If the shift lever is difficult to move from one gear to another, check the clutch linkage adjustment. Hard shifting may also be caused by damage inside the transmission/transaxle, or by a lubricant that is too thick. Common hard shifting includes badly worn bearings and damaged clutch gears, control rods, shift rails, shift forks, and synchronizers.

Jumping Out of Gear

If the car jumps out of gear into neutral, particularly when decelerating or going down hills, first check the shift lever and internal gearshift linkage. Excessive clearance between gears and the input shaft or badly worn bearings can cause jumping out of gear. Other internal transmission/transaxle parts to inspect are the clutch pilot bearing, gear teeth, shift forks, shift rails, and springs or detents.

Locked in Gear

If a transmission or transaxle locks in one gear and cannot be shifted, check the gearshift lever linkage for misadjustment or damage. Low lubricant level can also cause needle bearings, gears, and synchronizers to seize and lock up the transmission.

If these checks do not identify the problem, the transmission or transaxle must be removed from the vehicle and disassembled. After disassembly, inspect the countergear, clutch shaft, reverse idler, shift rails, shift forks, and springs or detents for damage. Also, check for worn support bearings.

If the problem seems to be in the clutch assembly, make sure the transmission is out of gear, set the

parking brake, and start the engine. Increase the engine speed to about 1,500 to 2,000 rpm and gradually apply the clutch until the engine's torque causes tension at the drive train mounts. Watch the reaction of the engine. If the engine's reaction to the torque appears to be excessive, broken or worn drive train mounts may be the cause and not the clutch.

The engine mounts on FWD cars are important to the operation of the clutch and transaxle **(Figure 39–8)**. Any engine movement may change the effective length of the shift and clutch control cables and therefore may affect the engagement of the clutch and/or gears. A clutch may slip due to clutch linkage changes as the engine pivots on its mounts. To check the condition of

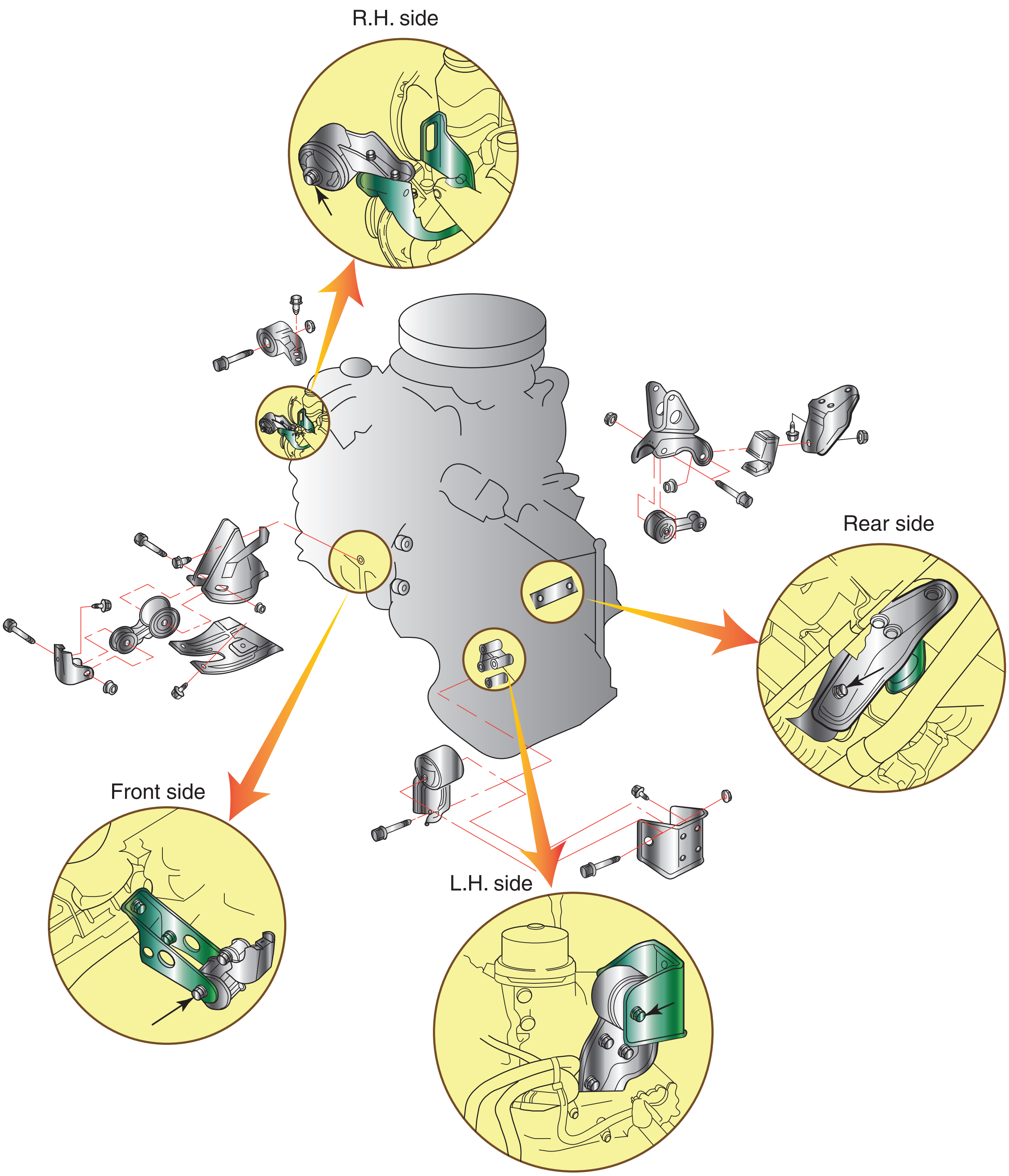


FIGURE 39–8 Typical engine and transaxle mounts.

the transaxle mounts, pull up and push down on the transaxle case while watching the mount. If the mount's rubber separates from the metal plate or if the case moves up but not down, replace the mount. If there is movement between the metal plate and its attaching point on the frame, tighten the attaching bolts to the appropriate torque.

If it is necessary to replace the transaxle mount, make sure you follow the procedure for maintaining the alignment of the drive line. Some manufacturers recommend that a holding fixture or special bolt be used to keep the unit in its proper location.

A broken clutch cable may be caused by worn mounts and improper cable routing. Inspect all clutch and transaxle linkages and cables for kinks or stretching. Often transaxle problems can be corrected by replacing or repairing the clutch or gearshift cables and linkage.

Shift Linkage

Check the shift linkage for smooth movement and full travel. If the linkage cannot move enough to fully engage a gear, the transmission will jump out of gear while it is under a load. Some FWD cars have experienced the problem of jumping out of second or fourth gear due to improper shifter-to-shifter boot clearances. This prevents the shift forks from moving far enough to fully engage the synchronizer collars to their mating gears. If this is not the cause, check the engine and transmission mounts. Apparent linkage problems can actually be internal transaxle problems.

USING SERVICE INFORMATION

Referring to the correct service information is absolutely necessary when performing any type of transmission/transaxle disassembly work. Not only will the material clearly illustrate all components and their disassembly procedure but it will also list many vital specifications, such as shaft and gear thrust (side) clearances, synchronizer ring and cone clearances, and bolt torque values. Special service tools, such as transmission service stands, oil seal presses, bearing replacers, shaft removers, pullers, and installing tools are also illustrated and explained.

Although not as common with newer vehicles, the shift linkage may require periodic lubrication. Dry linkage sockets can cause binding, making the transmission hard to shift. Refer to the service information for specific lubrication points and the recommended type of lubricant.

Transmission/Transaxle Removal

Removing the transmission from a RWD vehicle is generally more straightforward than removing one from a FWD model, because there is typically one cross member, one drive shaft, and easy access to the cables, wiring, and bell housing bolts. Transmissions in FWD cars, because of their limited space, can be more difficult to remove as you may need to disassemble or remove large assemblies such as engine cradles, suspension components, brake components, splash shields, or other pieces that would not usually affect RWD transmission removal. The engine may also need to be supported with fixtures while removing the transmission.

GO TO Chapter 10 for a detailed discussion on how to remove an engine and/or transmission from a vehicle.

RWD Vehicles

The correct procedure for removing a transmission varies with each year, make, and model of vehicle; always refer to the service information for the correct procedure. Normally the procedure begins with placing the vehicle on a hoist.

Once the vehicle is in position, disconnect the negative battery cable and place it away from the battery. Carefully check under the hood to identify anything that may interfere with transmission removal. Then raise the vehicle and disconnect the parts of the exhaust system that may get in the way. Disconnect all electrical connections and the speedometer cable at the transmission. Make sure you place these away from the transmission so they are not damaged during transmission removal or installation.

Place a drain pan under the transmission and drain the transmission's fluid. Then move the drain pan to the rear of the transmission. Before removing the drive shaft, use chalk to show the alignment of the rear U-joint and the pinion flange **(Figure 39–9)**. Then remove the drive shaft.

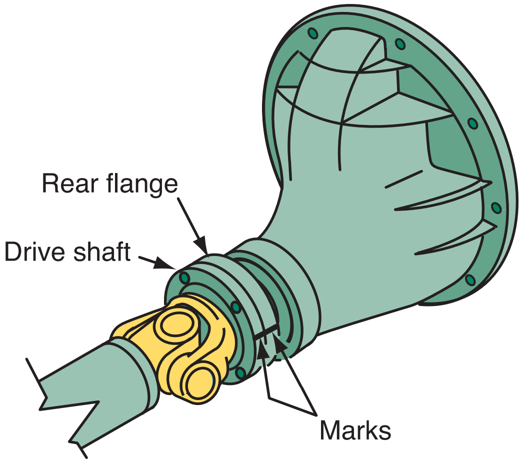


FIGURE 39–9 To ensure proper balance and phasing of the drive shaft, make alignment marks on the rear flange and the rear yoke.

Disconnect and remove the transmission linkage. It is best to do this by disconnecting as little as possible.

Place a transmission jack under the transmission and secure the transmission to it. Then loosen and remove the lower bell housing-to-engine block bolts and the cross member at the transmission. After the mount is free from the transmission, lower the transmission slightly so you can easily access the top transmission-to-engine bolts. Loosen and remove the remaining transmission-to-engine bolts.

Slowly and carefully move the transmission away from the engine until the input shaft is out of the clutch assembly. Then slowly lower the transmission. Once the transmission is out of the vehicle, carefully move it to the work area and mount it to a stand or bench.

On some cars, the engine and transmission must be removed as a unit. The assembly is lifted with an engine hoist or lowered underneath the car.

FWD Vehicles

On some vehicles, the recommended procedure may include removing the engine with the transaxle. Always refer to the service information before proceeding to remove the transaxle. Identify any special tool needs and precautions recommended by the manufacturer. You will waste much time and energy if you do not check the service information first.

Begin removal by placing the vehicle on a lift. Working under the hood, disconnect the battery before loosening any other components. Then disconnect all electrical connectors and the speedometer cable at the transaxle.

Now disconnect the shift linkage or cables and the clutch cable. Identify the transaxle-to-engine bolts that cannot be removed from under the vehicle and remove them. Install the engine support fixture to hold the engine in place while removing the transaxle. Disconnect and remove all items that will interfere with the removal of the transaxle.

Loosen the large nut that retains the outer CV joint, which is splined shaft to the hub. It is recommended that this nut be loosened with the vehicle on the floor and the brakes applied. This will make the job easier and reduces the chance of damaging the CV joints and wheel bearings.

Now raise the vehicle and remove the front wheels. Tap the splined CV joint shaft with a soft-faced hammer to see if it is loose. Most will come loose with a few taps. Some vehicles have an interference fit spline at the hub and you will need a special puller for this type of CV joint. The tool pushes the shaft out and on installation pulls the shaft back into the hub.

The lower ball joint must now be separated from the steering knuckle. The ball joint will either be bolted to the lower control arm or held in the knuckle with a pinch bolt. Once the ball joint is loose, the control arm can be pulled down and the knuckle can be pushed outward to allow the splined CV joint shaft to slide out of the hub. The inboard joint can be pried out or will slide out. Some transaxles have retaining clips that must be removed before the inner joint can be removed. Pull the drive axles out of the transaxle **(Figure 39–10)**.

While removing the axles, make sure the brake lines and hoses are not stressed. Suspend them with wire to relieve the weight on the hoses and to keep them out of the way.

On some cars, the inner CV joints have flange-type mountings. These must be unbolted for removal of the shafts. In some cases, the flange-mounted

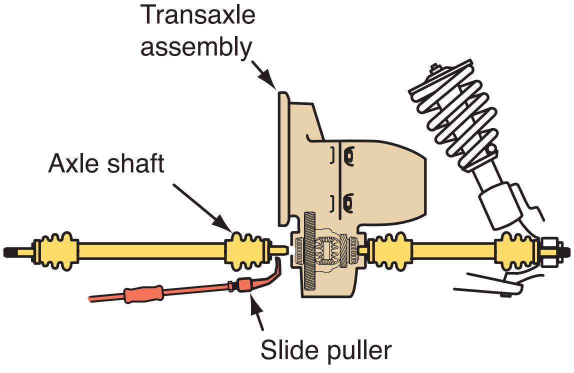


FIGURE 39–10 The inboard joints are normally pulled out of the transaxle.

drive shafts may be left attached to the wheel and hub assembly and only unbolted at the transmission flange. The free end of the shafts should be supported and placed out of the way.

Now the remaining shift linkages, electrical connections, and speedometer cables should be disconnected. The exhaust system may also need to be lowered or partially removed.

Remove the starter. The starter's wiring may be left connected or you may remove the starter from the vehicle to get it totally out of the way.

With the transmission jack supporting the transmission, remove the transaxle mounts. If the car is equipped with an engine cradle that will separate, remove the half of the cradle that allows for transaxle removal. Then remove all remaining transaxle to engine bolts. Slide the transaxle away from the engine. Make sure the input shaft is out of the clutch assembly before lowering the transmission.

Cleaning and Inspection

Disassembly and overhaul procedures vary greatly between transmission designs; always follow the exact steps outlined in the service information.

Clean the transmission with a steam cleaner, degreaser, or cleaning solvent. As you begin to disassemble the unit, pay close attention to the condition of its parts. Using a dial indicator, measure and record the endplay of the input and main shafts **(Figure 39–11)**. This information will be needed during the reassembly of the unit for selecting the appropriate selective shims and washers.

Remove the bell housing from the transmission case, extension housing **(Figure 39–12)**, and the side or top cover. The seal and bushing should be removed from the extension housing (tail shaft) prior to cleaning. With the housing and cover removed, the gears, synchronizers, and shafts are exposed and the shift forks can be removed **(Figure 39–13)**.

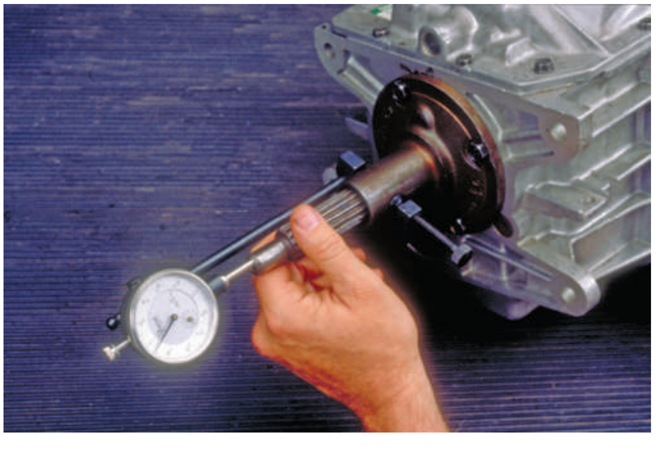


FIGURE 39–11 Use a dial indicator to measure the end play of the shafts before disassembling the unit.

SHOP TALK

Before disassembling a transmission, observe the effort it takes to rotate the input shaft through all the forward gears and reverse. Extreme effort in any or all gears may indicate an endplay or preload problem.

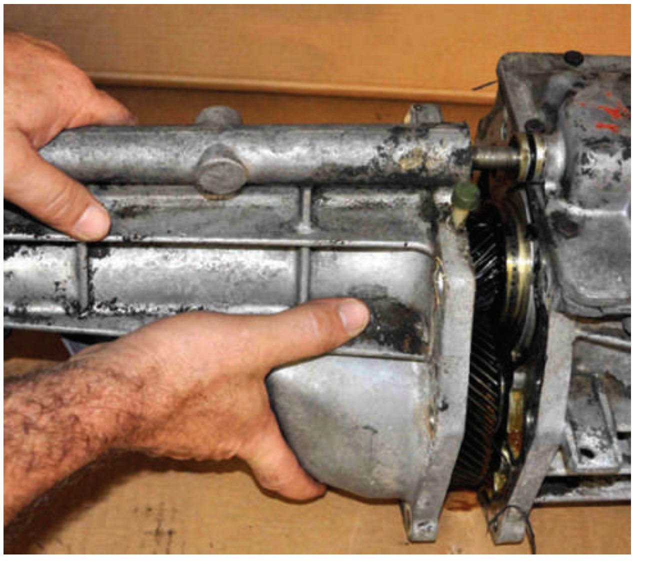


FIGURE 39–12 Slide the extension housing off the output shaft.

Each transmission design has its own specific service procedures. Always refer to the appropriate service information prior to overhauling a transmission or transaxle.

In some cases the countershaft must be removed before the input and mainshaft **(Figure 39–14)**. In other cases, the mainshaft is removed with the extension housing. It may be removed through the shift cover opening. To avoid difficulty in disassembly, follow the recommended sequence. A gear puller or hydraulic press is often needed to remove

SHOP TALK

It is a good practice to lay the parts on a clean rag as you remove them, and to keep them in order to aid you during reassembly.

FIGURE 39–13 Remove the top cover and the shift linkage.

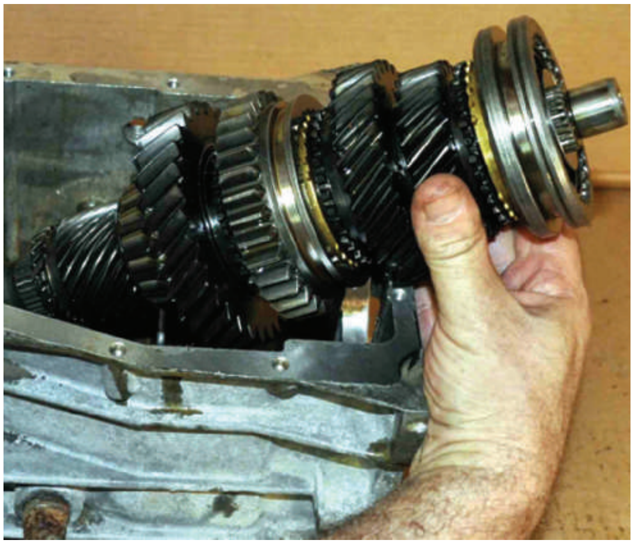


FIGURE 39–14 Lift the output shaft from the case and then remove the countershaft's rear bearing cup from the case.

gears and synchronizer assemblies from transmission/transaxle pinion shafts.

Bearing removal and installation procedures require that the force applied to remove or install the bearing should always be placed on the tight bearing race. In some cases, the inner race is tight on the shaft, while in others it is the outer race that is tight in its bore. Removal or installation force should be applied to the tight race. Serious damage to the bearing can result if this practice is not followed.

Use a soft-faced hammer or a brass drift and ball-peen hammer if tapping is required. Never use excessive force or hammering.

During assembly of the transmission, never attempt to force parts into place by tightening the front bearing retainer bolts or extension housing bolts. All parts must be fully in place before tightening any bolts. Check for free rotation and shifting. New gaskets and seals should always be used.

The following are some general cleaning and inspection guidelines that result in quality workmanship and service:

1. Wash all parts, except sealed ball bearings and seals, in solvent. Brush or scrape all dirt from the parts. Remove all traces of the old gasket. Wash the roller bearings in solvent; dry them with a clean cloth. Never use compressed air to spin the bearings.
2. Inspect the front of the transmission case for nicks or burrs that could affect its alignment with the flywheel housing. Remove all nicks and burrs with a fine stone (cast-iron casing) or fine file (aluminum casing).
3. Replace any cover that is bent or distorted. If there are vent holes in the case, make certain they are open.
4. Inspect the seal and bushing in the extension housing. Measure the inside diameter of the bushing and compare that to specifications. Replace them if they are worn or damaged.
5. Inspect the ball bearings by holding the outer ring stationary and rotating the inner ring several times. Inspect the raceway of the inner ring from both sides for pits and spalling. Light particle indentation is acceptable wear, but all other types of wear merit replacement of the bearing assembly. Next, hold the inner ring stationary and rotate the outer ring. Examine the outer ring raceway for wear and replace as needed.
6. Examine the external surfaces of all bearings. Replace the bearings if there are radial cracks on the front and rear faces of the outer or inner rings, cracks on the outside diameter or outer ring, or deformation or cracks in the ball cage.
7. Lubricate the cleaned bearing raceways with a light coat of oil. Hold the bearing by the inner ring in a vertical position. Spin the outer ring several times by hand. If roughness or vibration is felt, or the outer ring stops abruptly, replace the bearing.
8. Replace any roller bearings that are broken, worn, or rough. Inspect their respective races. Replace them as needed.
9. Replace the counter (cluster) gear if its gear teeth are chipped, broken, or excessively worn **(Figure 39–15)**. Replace the countershaft if the

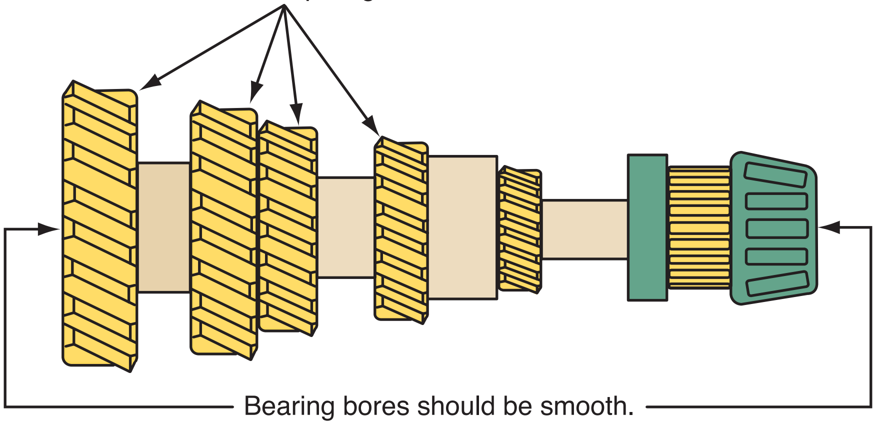


FIGURE 39–15 Carefully inspect the countergear assembly.

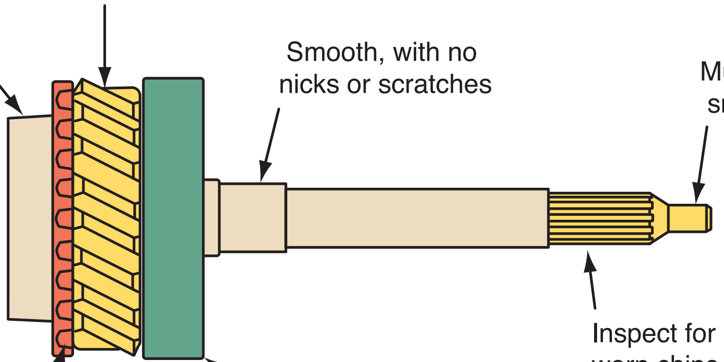


FIGURE 39–16 The input shaft, including the splines, should also be carefully inspected.

shaft is bent, scored, or worn. Also, inspect the bore for the countershaft. If the bore is excessively worn or damaged, the needle bearings will not seat properly against the shaft.

10. Replace the reverse idler gear or sliding gear if its teeth are chipped, worn, or broken. Replace the idler gear shaft if it is bent, worn, or scored.
11. Replace the input shaft and gear if its splines are damaged or if the teeth are chipped, worn, or damaged **(Figure 39–16)**. If the roller bearing surface in the bore of the gear is worn or rough, or if the cone surface is damaged, replace the gear and the gear rollers.
12. Replace all main or speed gears that are chipped, broken, or worn **(Figure 39–17)**.
13. Check the synchronizer sleeves for free movement on their hubs **(Figure 39–18)**. Alignment marks (if present) should be properly indexed.
14. Inspect the synchronizer blocking rings for widened index slots, rounded clutch teeth, and smooth internal surfaces. Remember, the blocking rings must have machined grooves on their internal surfaces to cut through lubricant **(Figure 39–19)**. Units with worn, flat grooves must be replaced. Also, check the clearance between the block ring and speed gear clog teeth against service specifications **(Figure 39–20)**.

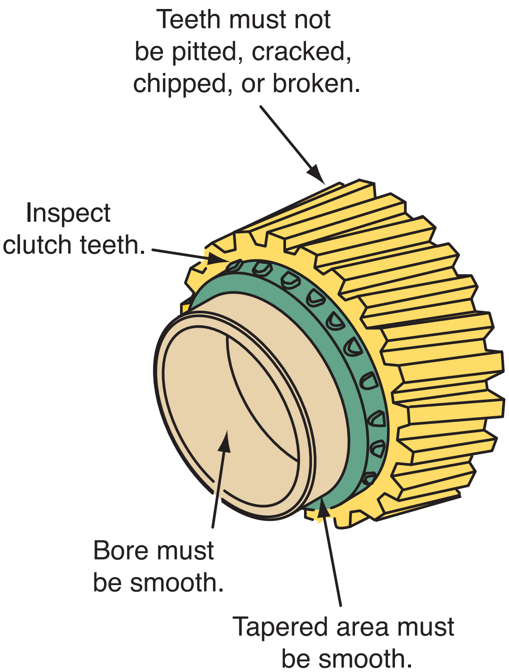


FIGURE 39–17 Every gear should be checked.

FIGURE 39–18 The movement of each synchronizer unit should be checked.

15. Replace the speedometer drive gear if its teeth are stripped or damaged. Install the correct size replacement gear.

16. Replace the output shaft if there is any sign of wear or runout or if any of the splines are damaged.

Aluminum Case Repair

Normally, the case is replaced if it is cracked or damaged. However some manufacturers recommend the use of an epoxy-based sealer on some

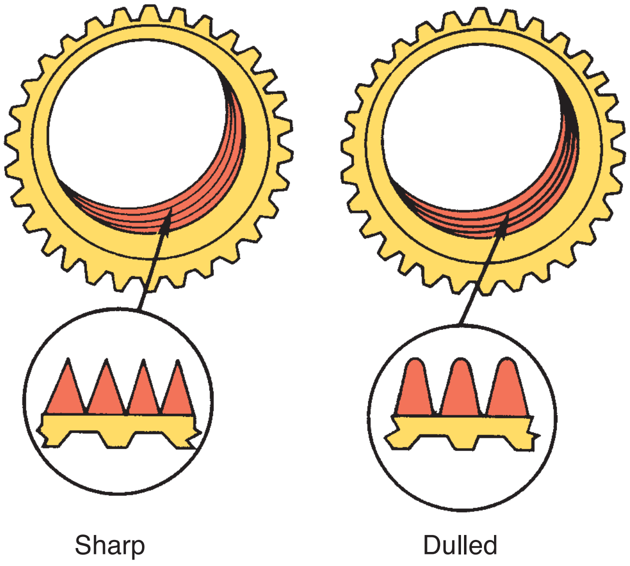


FIGURE 39–19 Grooves on the internal surface of the synchronizer blocker ring must be sharp.

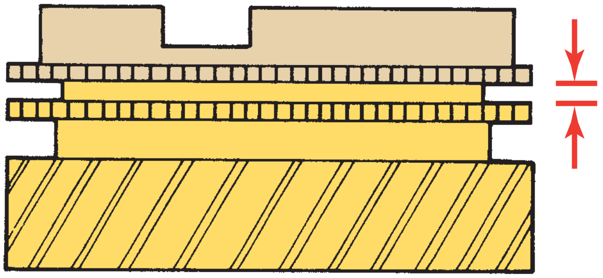


FIGURE 39–20 The clearance between the synchronizer blocker ring and the gear's clutching teeth must meet specifications.

types of leaks in some locations on the transmission **(Figure 39–21)**. Refer to the manufacturer's recommendations before attempting to repair a crack or correct for porosity leaks.

If a threaded area in an aluminum housing is damaged, helicoil-type service kits can be used to insert new threads in the bore. Some threads should never be repaired; check the service information to identify which ones can be repaired.

After all parts are inspected and the defective parts replaced, you can begin to reassemble the transmission/transaxle. While you are doing so, coat all parts with gear lube.

Many late-model transmissions and transaxles have specifications for end play, backlash, and preload; make sure these specifications are met. Follow the procedures given in the service information for the particular transmission/transaxle being worked


(A)

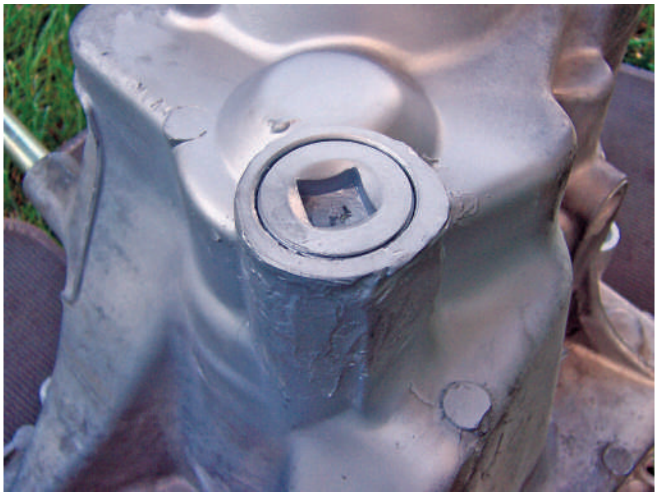

(B)

FIGURE 39–21 (A) A crack around the filler plug opening. (B) The crack was repaired with epoxy.

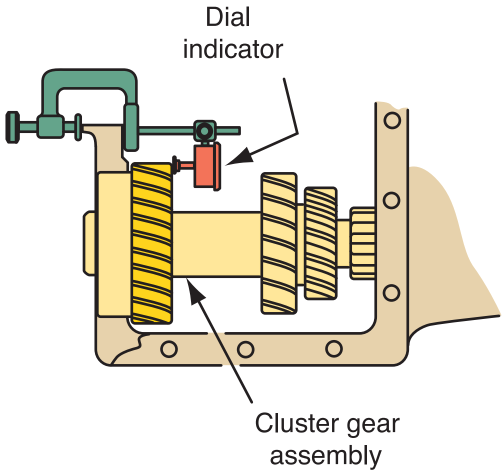


FIGURE 39–22 A typical setup for checking countershaft end play.

SHOP TALK

If the transmission/transaxle is fitted with paper type blocking rings, soak them in ATF prior to installing them.

on **(Figure 39–22)**. For most transmissions, there are specifications for the end play and preload of the input shaft, the countershaft, and the differential. These are usually set by shims under the bearing caps. Reuse the original shims, if possible.

Specific repair and assembly instructions will vary from transaxle to transaxle and from transmission to transmission. Therefore, before beginning to reassemble the unit, gather the specific information about the unit you are working on.

Disassembly and Reassembly of the Differential Case

Although it is a part of the transaxle, the differential is often kept together while making a repair to the transmission part of the transaxle. The differential case normally can be removed as soon as the transaxle case has been separated **(Figure 39–23)**. It may be the source of the problem and be the only part of the transaxle that needs service. Therefore, the disassembly and reassembly of the differential is set aside from the procedures listed for the transaxle **(Figure 39–24)**.

FIGURE 39–23 Once the transaxle case is opened up, the differential unit can be removed.

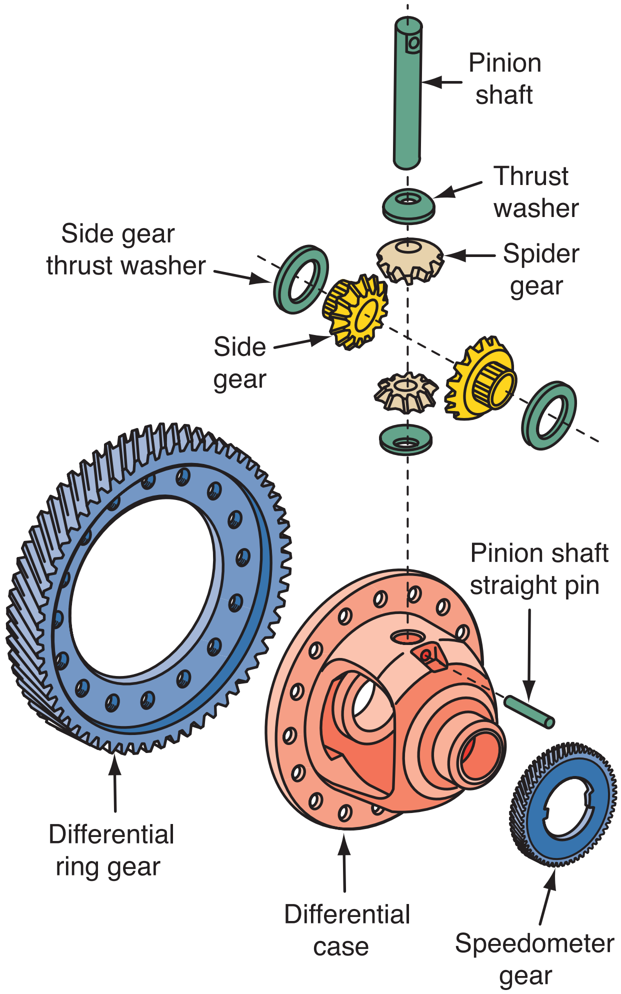


FIGURE 39–24 The differential assembly for a transaxle.

Begin the disassembly by separating the ring gear from the differential case. Then remove the pinion shaft lock bolt. Remove the pinion shaft, then remove the gears and thrust washers from the case. If the differential side bearings are to be replaced, use a puller to remove the bearings. Use the correct installer for reinstallation of the side bearings.

Clean and inspect all parts. Replace any damaged or worn parts. Install the gears and thrust washers into the case and install the pinion shaft and lock bolt. Tighten the bolt to the specified torque. Attach the ring gear to the differential case and tighten to the specified torque.

Shim Selection

While you are disassembling the differential or transaxle, make sure to keep all shims and bearing races together and identified for reinstallation in their original location. Carefully inspect the bearings for wear and/or damage and determine if a bearing should be replaced. Replacement tapered roller bearings will be available with a nominal thickness service shim. A nominal thickness service shim will handle reshimming the input shaft and output shaft bearings during normal repair.

When it is necessary to replace a bearing, race, or housing, refer to the manufacturer's recommendation for nominal shim thickness. If only other parts of the differential or transaxle are replaced, reuse the original shims. When repairs require the use of a service shim, discard the original shim. Never use the original shim together with the service shim. The shims must be installed only under the bearing cups at the transaxle case end of both the input and output shafts.

Reassembly/Reinstallation of Transmission/Transaxle

Transmission/transaxle reassembly and reinstallation procedures are basically the reverse of disassembly. Once again, refer to the service information for any special procedures. New parts are installed as needed, and new gaskets and seals are always used.

Serviceable gears are pressed onto the main shaft using special press equipment. Separate needle bearings should be held in place with petroleum jelly so shafts can be inserted into place. During reassembly, measure shaft end play of all shafts. Adjust them to specifications with shims, spacers, or snaprings of different thicknesses **(Figure 39–25)**. In addition to checking end play, some manufacturers

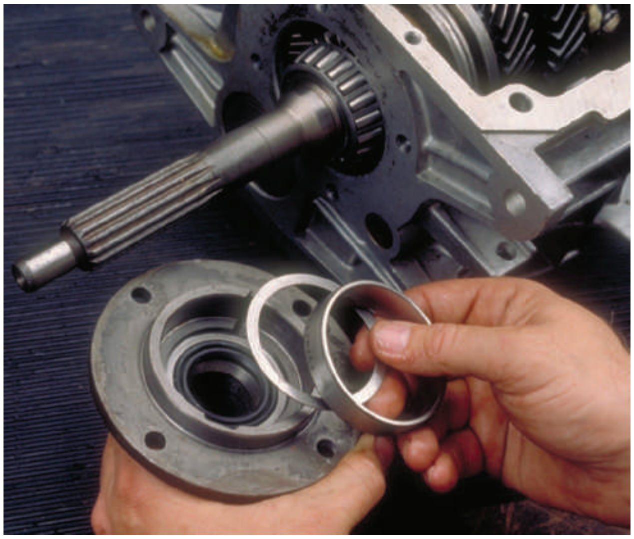


FIGURE 39–25 End play is controlled by shims.

SHOP TALK Always check for free rotation of the transmission in all gears before installing in a vehicle. If the shafts do not rotate freely, identify the cause and correct it.

suggest that the torque required to rotate an assembly be checked. This is simply done with a torque wrench. All fasteners should be tightened to the manufacturer's torque specifications.

Soft-faced mallets can be used to tap shafts and other parts into place. After reassembly, secure the transmission to a transmission jack with safety chains and raise it into place. Before the transmission is reinstalled, inspect and service the clutch as necessary.

Installing the Transmission/Transaxle

After the unit is together, install the clutch assembly, and a new throw-out bearing, prior to installing the transmission/transaxle. Generally, installation is the reverse procedure as removal. When installing the transmission, never let the transmission hang by its input shaft. Use a transmission jack to hold the transmission while you guide it into place. The input shaft should be lightly coated with grease prior to installation to aid installation and serve as a lubricant for the pilot bearing. Avoid putting too much grease on the shaft, because the excess may fly off and get on the clutch disc, causing it to slip and/or burn.

Most transmissions are doweled to the engine or bell housing. Use the dowels to locate and support the transmission during installation. Tighten the mounting bolts evenly, making sure nothing is caught between the housings. Then lightly coat the drive shaft's slip joint and carefully insert it into the extension housing to prevent possible damage to the rear oil seal. Reattach and adjust the shift linkage and fill the transmission with the proper fluid.

Warning! If the transmission/transaxle does not fit snugly against the engine block or if you cannot move the transmission into place, do not force it. Pull the transmission back and lower it. Inspect the input shaft splines for dirt or damage. Also check the mating surfaces for dirt or obstructions. If you try to force the transmission into place by tightening the bolts, you may break the case.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 1999	**Make:** Ford	**Model:** F150	**Mileage:** 226,410	**RO:** 15877
Concern:	Customer states the transmission is hard to get into gear and jumps out of gear while driving.			
After confirming the complaint, the technician suspects the shift rails are worn or damaged but transmission removal and disassembly are required to confirm his diagnosis.				
Cause:	Removed, disassembled, and inspected transmission. Found severely worn shift rails and forks along with a lot of wear on gear teeth.			
Correction:	Due to age and mileage, a low-mileage used transmission was installed.			

KEY TERM

Gear whine

SUMMARY

- Proper lubrication is vital to long transmission/transaxle life. The transmission gear lubricant must be checked and changed at manufacturer's suggested intervals.
- Metal particles or shavings in the gear lubricant indicate extensive internal wear or damage.
- The first step in diagnosing transmission/transaxle problems is to confirm that the problem exists inside the transmission/transaxle. Clutch and driveline problems may often appear to be transmission/transaxle problems.
- The initial visual inspection should include checks for lubricant leakage at gaskets and seals,

transmission mount inspection, clutch and gearshift linkage checks, and drive axle and CV joint inspection.

- Rough growling noise inside the transmission/transaxle housing is an indication of bearing problems.
- A clicking noise may indicate excessive gear tooth wear. Rhythmical knocking is a sign of loose or broken internal components.
- Hard shifting can be caused by shift linkage problems, improper lubricant, or worn internal components, such as bearings, gears, shift forks, or synchronizers.
- Jumping out of gear can be caused by misaligned drivetrain mounts, a worn or poorly adjusted shift linkage, excessive clearance between gears, or badly worn bearings.
- Low lubricant levels, poorly adjusted shift linkages, or damaged internal components can result in transmission/transaxle lockup.
- Always follow service information recommendations for removing the transmission/transaxle from the vehicle and disassembling it.
- Use recommended bearing pullers, gear pullers, and press equipment to remove and install gears and synchronizers on shafts.
- Clean and inspect all parts carefully, replacing worn or damaged components. Never force components in place during reassembly. Follow all clearance specifications listed in the service information.
- Always use new snaprings, gaskets, and seals during reassembly.

REVIEW QUESTIONS

Short Answer

1. After draining gear oil from a transaxle, the technician notices that the oil has shiny, metallic particles in it. What does this indicate?
2. List five checks that should be made during the visual inspection of the parts of a transmission/transaxle.
3. List three causes of noise that are not transmission related but may appear to be.
4. What tool is often required to remove gears and synchronizer assemblies from the mainshaft?
5. When removing or installing bearings, where should the force be applied?
6. List five common sources for transmission fluid leaks.
7. What should you do to properly identify the type of transmission you are working on?
8. List at least five items that are typically removed when removing a transaxle.

True or False

1. *True or False?* Some manufacturers recommend the use of heavy oil in the transaxle; others may recommend the use of automatic transmission fluid in the transaxle.
2. *True or False?* Bearing noise increases under load and is usually described as a growl that gets louder with speed.

Multiple Choice

1. A rough, growling noise that is heard from a transaxle while it is in neutral with the engine running, the vehicle stationary, and the clutch engaged is a likely indication that there is a problem in the ___.
   a. transaxle input shaft bearings
   b. transaxle main (intermediate) shaft bearings
   c. first/second synchronizer assembly
   d. pinion and ring gear interaction
2. A clicking noise during transmission/transaxle operation may be an indication of ___.
   a. worn mainshaft (input shaft) bearings
   b. faulty synchronizer operation
   c. failed oil seals
   d. worn, broken, or chipped gear teeth
3. Worn teeth on a speed gear can cause ___.
   a. gear clash
   b. hard shifting
   c. the transmission to shift into a gear
   d. the gear to jump out
4. Using a lubricant that is thicker than the specified lubricant can lead to ___.
   a. the gear to jump out
   b. hard shifting
   c. gear lockup
   d. gear slippage
5. A poorly adjusted shift linkage can cause which of the following problems?
   a. Gear clash
   b. Hard shifting
   c. The gear to jump out
   d. All of the above

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that the transmission rear seal at the driveline is particularly prone to leakage. When Technician B pushes up and down on the transmission, he says that the mounts require replacement because the case moves up and down. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. A noise occurs in forward and reverse gears but not in neutral: Technician A says that the input shaft bearing may be bad. Technician B says that the mainshaft bearing may be bad. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. A rough, growling noise occurs when a vehicle with a manual transmission is moving in any gear: Technician A says that the rear input shaft bearing may be at fault. Technician B says that this condition indicates the countergear bearings may be faulty. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. A car jumps out of gear into neutral, particularly when decelerating or going down hills: Technician A checks the shift lever and external gearshift linkage first. Technician B says that the clutch pilot bearing could be the problem. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. While diagnosing a noise from a transmission: Technician A says that the noise is caused by something internal if it is most noticeable during a test drive. Technician B says that the noise is caused by the clutch if it disappears when the clutch is disengaged. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. Technician A says that broken or worn engine and transaxle mounts can cause a transaxle to have shifting problems. Technician B says that poor shift boot alignment can cause a transaxle to jump out of gear. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. Technician A says that shims may be used to adjust shaft end play. Technician B says that snap rings may be used to adjust shaft end play. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. During a test drive, a noise that appears to be transmission related disappears when the driver brings the vehicle to a stop and disengages the clutch with the engine at idle. Technician A says that the noise may be caused by an internal transmission problem. Technician B says that the problem may be something interfering with the flywheel or pressure plate. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. While inspecting the synchronizers of a transaxle: Technician A says that if the clutch teeth of the synchronizer are rounded, the synchronizer assembly must be replaced. Technician B says that the movement of the synchronizer sleeve on the shaft should be checked. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. Technician A says that the proper fluid level for a transmission is normally to the bottom of the filler hole. Technician B says that low lubricant levels can cause a transmission to clash during shifting. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 40

DRIVE AXLES AND DIFFERENTIALS

OBJECTIVES

- Name and describe the components of a front-wheel drive axle.
- Describe the operation of a front-wheel drive axle.
- Diagnose problems in CV joints.
- Explain the difference between CV joints and universal joints.
- Name and describe the components of a rear-wheel drive axle.
- Describe the operation of a rear-wheel drive axle.
- Explain the function and operation of a differential and drive axles.
- Describe the various differential designs, including complete, integral carrier, removable carrier, and limited slip.
- Describe the two common types of driving axles.
- Explain the function of the main driving gears, drive pinion gear, and ring gear.
- Describe the different types of axle shafts and axle shaft bearings.

The drive axle assembly transmits torque from the engine and transmission to drive the vehicle's wheels. The drive axle changes the direction of the power flow, multiplies torque, and allows different speeds between the two drive wheels. Drive axles are used for both front-wheel drive and rear-wheel drive vehicles.

Basic Diagnosis and Service

It is important that you consider that basic drive system of the vehicle before diagnosing or servicing it. FWD, RWD, and 4WD system have unique systems and therefore unique ways to diagnose and service the systems.

Basically you need to understand the customer's concerns and the vehicle itself, before moving toward detailed diagnosis and repair. **Figure 40–1** lists common vibration and noise concerns and their characteristics. This chart can help identify the cause of a customer's complaint.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2004	**Make:** Dodge	**Model:** Ram 1500 4WD	**Mileage:** 141,895	**RO:** 15890
Concern:	Customer says loud noises are heard from left front wheel area.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

PROBLEM			VEHICLE SPEED						RELATIONSHIP
AREA	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**TO SPEED**
Worn or damaged motor mounts	Y	Y	Y	?					Engine speed sensitive
Loose engine drive belts		?	Y	Y	?				Engine speed sensitive
Loose accessory mounts	?	Y	Y	?					Engine speed sensitive
Uneven tire wear			?	Y	Y	Y	Y	Y	Vehicle speed sensitive
Excessive lateral tire runout						?	Y	Y	Vehicle speed sensitive
Excessive radial tire runout		?	Y	Y	Y	Y	Y	Y	Vehicle speed sensitive
Incorrect tire balance			?	Y	Y	Y	?		Vehicle speed sensitive
Worn wheel bearing	Y	Y	Y	Y	Y	Y	Y	Y	Vehicle speed sensitive
Bad U-joints				?	Y	Y	Y	Y	Vehicle speed sensitive
Worn CV-joint					?	Y	Y	Y	Vehicle speed sensitive
Incorrect drive shaft angles	Y	Y	?	?	Y	Y	Y	?	Vehicle speed sensitive
Worn U-joint				Y	Y	Y	Y	?	Accel/decel sensitive
Bad CV-joint					?	Y	Y	Y	Accel/decel sensitive
Worn extension housing bushing			?	Y	Y	Y	Y	Y	Accel/decel sensitive
Worn rear suspension parts	Y	Y	?						Accel/decel sensitive
Bad axle bearings		?	Y	Y	Y	Y	Y	Y	Accel/decel sensitive

FIGURE 40–1 Common vibration and noise concerns and their characteristics.

Front-Wheel Drive (FWD) Axles

Front-wheel drive (FWD) axles, also called axle shafts, typically transfer engine torque from the transaxle's differential to the front wheels. One of the most important components of FWD axles is the constant velocity (CV) joint. These joints are used to transfer uniform torque at a constant speed, while operating through a wide range of angles.

On FWD or four-wheel drive cars, operating angles of as much as 40 degrees are common **(Figure 40–2)**. The drive axles must transmit power from the engine to front wheels that must drive, steer, and cope with the severe angles caused by the up-and-down movement of the vehicle's suspension. To accomplish this, these cars must have a compact joint that ensures the driven shaft is rotated at a constant velocity, regardless of angle. CV joints also allow the length of the axle assembly to change as the wheel travels up and down.

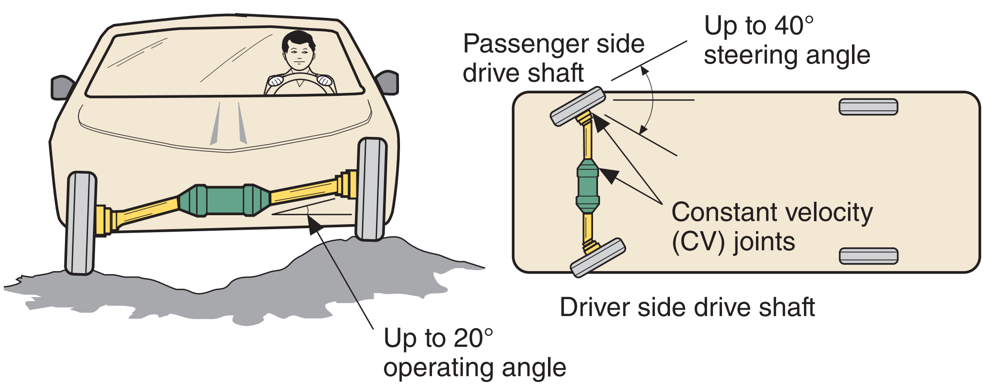


FIGURE 40–2 FWD drive axle shaft angles.

Types of CV Joints

CV joints come in a variety of styles. The different types of joints can be referred to by position (inboard or outboard), by function (fixed or plunge), or by design (ball-type or tripod).

Inboard and Outboard Joints

On FWD vehicles, two CV joints are used on each half shaft **(Figure 40–3)**. The joint nearer the transaxle is the inner or **inboard joint**, and the one nearer the wheel is the outer or **outboard joint**. In a RWD vehicle with independent rear suspension, the joint nearer the differential can also be referred to as the inboard joint. The one closer to the wheel is the outboard joint.

Fixed and Plunge Joints

CV joints are either a **fixed joint** (meaning it does not plunge in and out to compensate for changes in length) or a **plunge joint** (one that is capable of in-and-out movement).

In FWD applications, the inboard joint is a plunge joint. This joint allows for a change in the effective length of the axle by allowing it to move in and out on its connection to the transaxle's axle gear. The outboard joint is a fixed joint. The outboard joint must also be able to handle the much greater operating angles required for steering (up to 40 degrees).

In RWD applications with IRS, one joint on each axle shaft can be fixed and the other a plunge or both can be plunge joints. Because the wheels are not used for steering, the operating angles are not as great. Therefore, plunge joints can be used at either or both ends of the axle shafts.

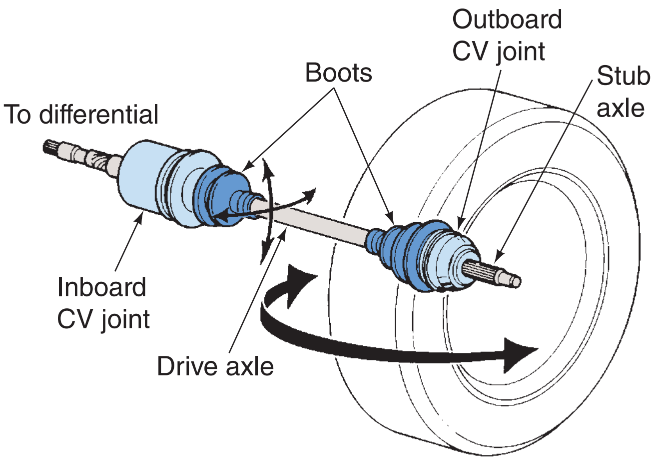
Ball-Type Joints

There are two basic varieties of CV joints: the ball-type and **tripod-type joints**. Both types are used as either inboard or outboard joints, and both are available in fixed or plunge designs.

Fixed Ball-Type CV Joints The **Rzeppa joint**, or fixed ball-type joint, consists of an inner ball race, six balls, a cage to position the balls, and an outer housing **(Figure 40–4)**. Tracks machined in the inner race and outer housing allow the joint to flex. The inner race and outer housing form a ball-and-socket arrangement. The six balls serve both as bearings between the races and the means of transferring torque from one to the other.

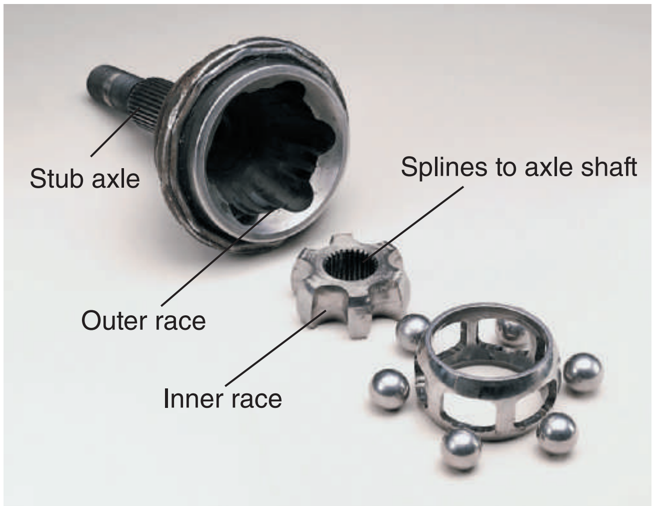
If viewed from the side, the balls within the joint always bisect the angle formed by the shafts on either side of the joint regardless of the operating angle. This reduces the effective operating angle of the joint by half and virtually eliminates all vibration problems. The input speed to the joint is always equal to the output velocity of the joint—thus the description "constant velocity." The cage helps to maintain this alignment by holding the six balls snugly in its windows. If the cage windows become worn or deformed over time, the resulting play between ball and window typically results in a clicking noise when turning. It is important to note that opposing balls in a Rzeppa CV joint always work together as a pair. Heavy wear in the tracks of one ball almost always results in identical wear in the tracks of the opposing ball.

Plunging Ball-Type Joints There are two basic styles of plunging ball-type joints: the **double-offset** and the **cross groove joints**. This is a more compact



Courtesy of Federal-Mogul Corporation.

FIGURE 40-3 CV joints pivot during steering.



Courtesy of Federal-Mogul Corporation.

FIGURE 40-4 A Rzeppa ball-type fixed CV joint.

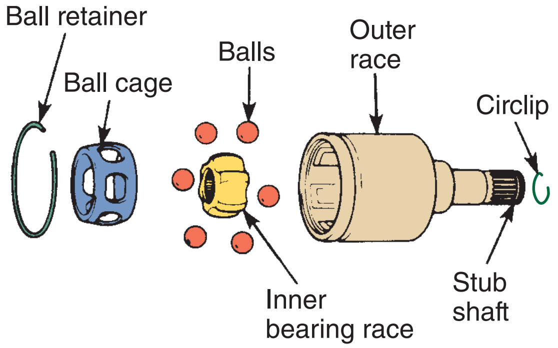


FIGURE 40-5 A double-offset CV joint.

design with a flat, doughnut-shaped outer housing and angled grooves.

The double-offset joint **(Figure 40–5)** uses a cylindrical outer housing with straight grooves and is typically used in applications that require higher operating angles (up to 25 degrees) and greater plunge depth (up to 2.4 inches [60 mm]). This type of joint can be found at the inboard position on some FWD half shafts as well as on the propeller shaft of some FWD shafts.

The cross groove joint **(Figure 40–6)** has a much flatter design than any other plunge joint. It is used as the inboard joint on FWD half shafts or at either end of a RWD independent rear suspension axle shaft.

The feature that makes this joint unique is its ability to handle a fair amount of plunge (up to 1.8 inches [46 mm]) in a relatively short distance. The inner and outer races share the plunging motion equally, so less overall depth is needed for a given amount of plunge. The cross groove can handle operating angles up to 22 degrees.

Tripod CV Joints

As with ball-type CV joints, tripod joints come in two varieties: plunge and fixed.

Tripod Plunging Joints Tripod plunging joints **(Figure 40–7)** consist of a central drive part or tripod (also known as a "spider"). This has three trunnions fitted with spherical rollers on needle bearings and an outer housing (sometimes called a "tulip" because of its three-lobed, flowerlike appearance). On some tripod joints, the outer housing is closed, meaning the roller tracks are totally enclosed within it. On others, the tulip is open and the roller tracks are machined out of the housing. Tripod joints are most commonly used as FWD inboard plunge joints.

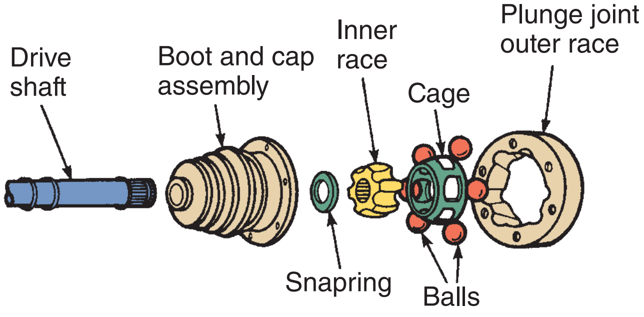


FIGURE 40-6 A cross-groove joint.

Fixed Tripod Joints The fixed tripod joint is sometimes used as the outboard joint in FWD applications. In this design, the trunnion is mounted in the outer housing and the three roller bearings turn against an open tulip on the input shaft. A steel locking spider holds the joint together.

The fixed tripod joint has a much greater angular capability. The only major difference from a service standpoint is that the fixed tripod joint cannot be removed from the drive shaft or disassembled because of the way it is manufactured. The complete joint and shaft assembly must be replaced if the joint goes bad.

Front-Wheel Drive Applications

FWD half shafts can be solid or tubular, of equal **(Figure 40–8)** or unequal length **(Figure 40–9)**, and come with or without damper weights. Equal-length shafts are used in some vehicles to help reduce torque steer (the tendency to steer to one side as engine power is applied). In these applications, an intermediate shaft is used as a link from the transaxle to one of the half shafts. This intermediate shaft can use an ordinary Cardan universal joint (described later in this chapter) to a yoke at the transaxle. At the outer end is a support bracket and bearing assembly. Looseness in the bearing or bracket can create vibrations. These items should be included in any inspection of the drivetrain components. The small damper weight, called a torsional damper, that is sometimes attached to one half shaft serves to dampen harmonic vibrations in the drivetrain and to stabilize the shaft as it spins, not to balance the shaft **(Figure 40–10)**.

Regardless of the application, outer joints typically wear faster than inner joints because of the increased range of operating angles to which they are subjected. Inner joint angles may change only 10 to 20 degrees as the suspension travels through jounce and rebound. Outer joints can undergo changes of up to 40 degrees in addition to jounce and rebound as the

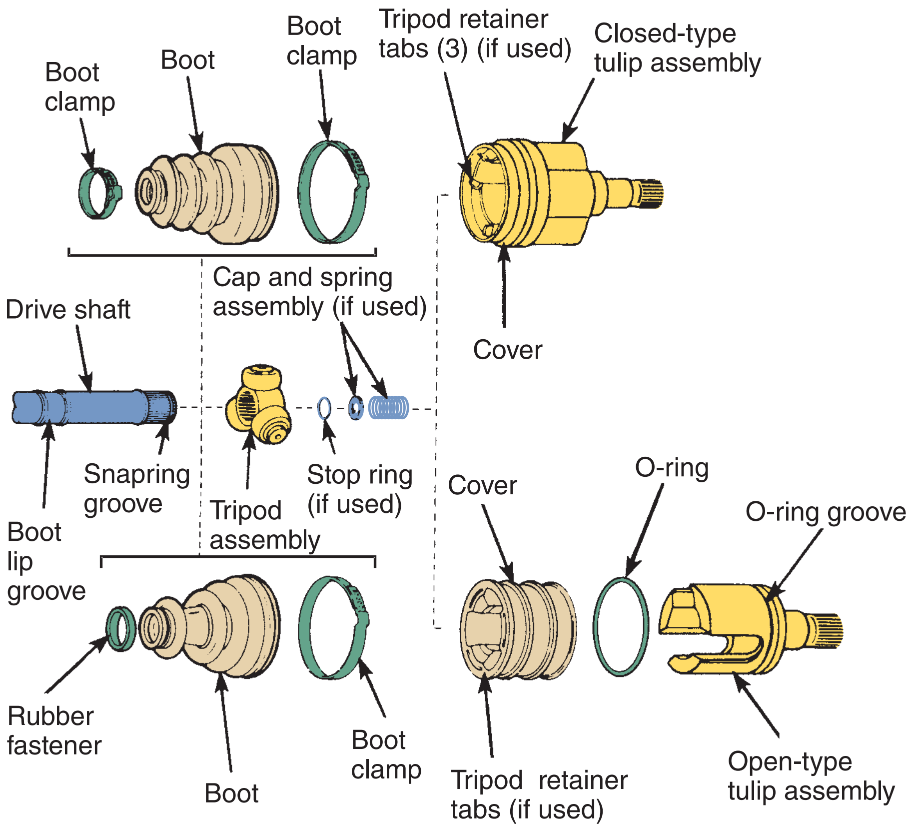


FIGURE 40–7 Inner tripod plunge-type joints: closed housing and open housing.

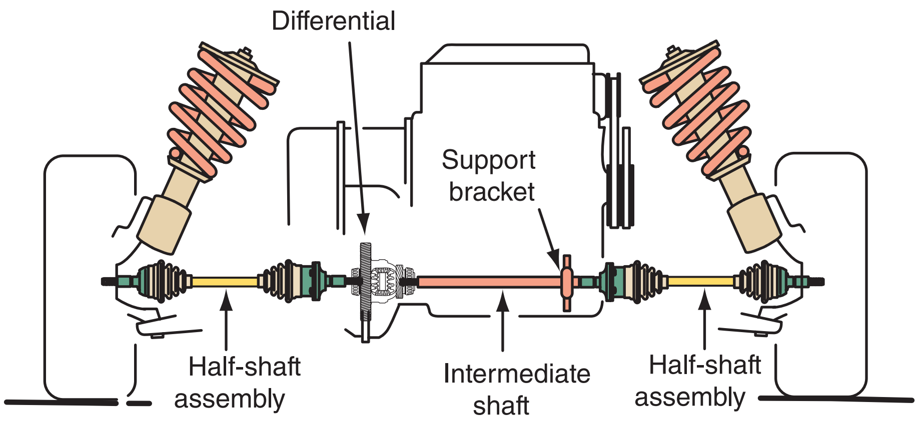


FIGURE 40–8 Equal-length FWD half shafts with an intermediate shaft.

wheels are steered. That, combined with more flexing of the outer boots, is why outer joints have a higher failure rate. On average, nine outer CV joints are replaced for every inner CV joint. That does not mean the technician should overlook the inner joints. They wear too. Every time the suspension travels through jounces and rebound, the inner joints must plunge in and out to accommodate the different arcs between the drive shafts and suspension. Tripod inner joints tend to develop unique wear patterns on each of the three rollers and their respective tracks in the housing, which can lead to noise and vibration problems.

Other Applications

CV joints are also found on the front axles of many four-wheel-drive vehicles and on vehicles with rear independent suspension systems **(Figure 40–11)**. Their use in these designs offers the same benefits as when they are used for FWD.

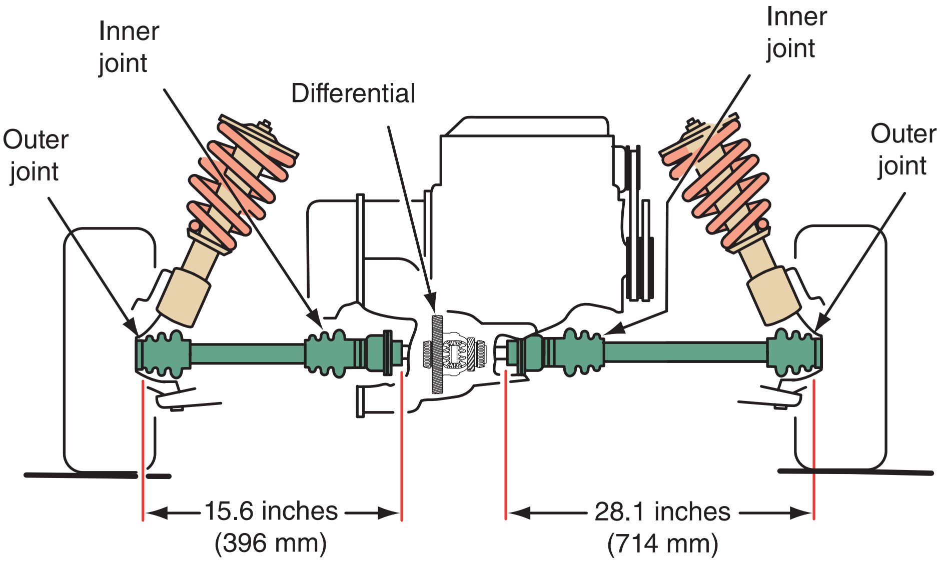


FIGURE 40–9 Unequal length FWD half shafts.

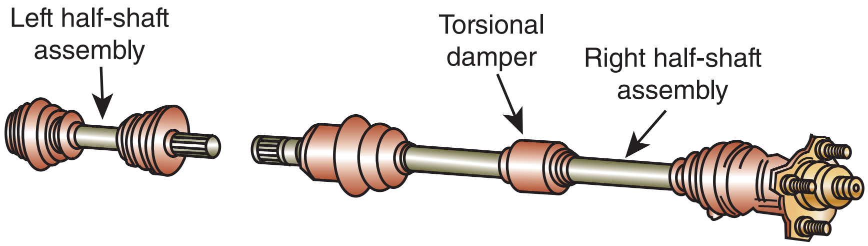


FIGURE 40–10 Some long drive axles are fitted with a torsional damper.

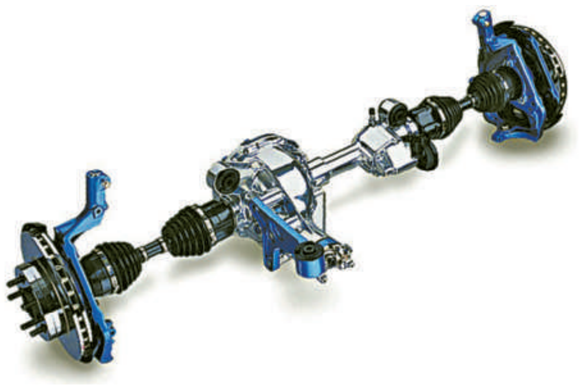


FIGURE 40–11 A CV joint-equipped rear axle assembly for a vehicle with independent rear suspension.

CV Joint Service

With proper service, CV joints can have a long life, despite having to perform extremely difficult jobs in hostile environments. They must endure extreme heat and cold and survive the shock of hitting potholes at high speeds. Fortunately, high-torque loads during low-speed turns and many thousands of high-speed miles normally do not bother the CV joint. It is relatively trouble free unless damage to the boot or joint goes unnoticed.

All CV joints are encased in a protective rubber (neoprene, natural, or silicone) or thermoplastic (Hycrel) boot **(Figure 40–12)**. The job of the boot is to retain grease and to keep dirt and water out. The importance of the boot cannot be overemphasized because without its protection the joint does not survive. For all practical purposes, a CV joint is lubed for life. Once packed with grease and installed, it requires no further maintenance. A loose or missing boot clamp, or a slit, tear, or a small puncture in the boot itself allows grease to leak out and water or dirt to enter. Consequently, the joint is destroyed.

Although outboard joints tend to wear faster than the inboard ones, the decision as to whether to replace both joints when the half shaft is removed depends on the circumstances. If the vehicle has low miles and joint failure is the result of a defective boot, there is no reason to replace both joints. On a high-mileage vehicle where the bad joint has actually just worn itself out, it might be wise to save the expense and inconvenience of having the half shaft removed twice for CV joint replacement.

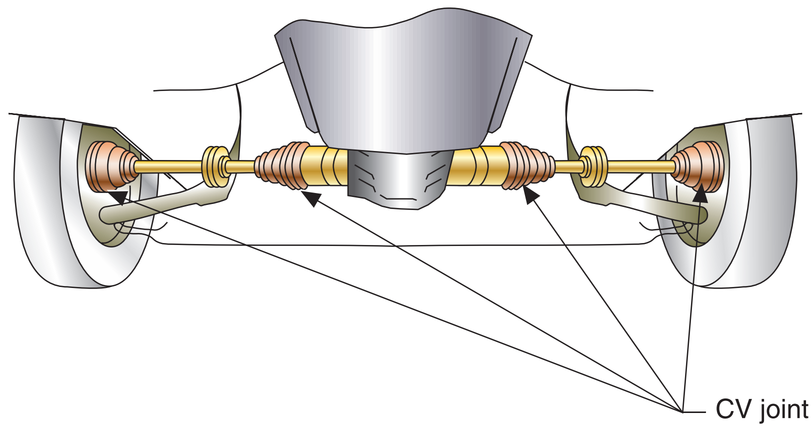


FIGURE 40–12 Location of the CV joint boots.

Diagnosis and Inspection

Any noise in the engine, drive axle, steering, or suspension is a good reason for a thorough inspection of the vehicle. A road test on a smooth surface is a good place to begin. The test should include driving at average highway speeds, some sharp turns, acceleration, and coasting. To help diagnose the cause of the customer's concern, refer to **Table 40–1**.

Begin CV joint inspection **(Figure 40–13)** by checking the condition of the boots. Splits, cracks, tears, punctures, or thin spots caused by rubbing call for immediate boot replacement. If the boot appears rotted, this indicates improper greasing or excessive heat, and it should be replaced. Squeeze all boots. If any air escapes, replace the boot.

If the inner boot appears to be collapsed or deformed, venting it (allowing air to enter) might solve the problem. Place a round-tipped rod between the boot and drive shaft. This equalizes the outside and inside air and allows the boot to return to its normal shape.

Make sure that all boot clamps are tight. Missing or loose clamps should be replaced. If the boot appears loose, slide it back and inspect the grease inside for possible contamination. A milky or foamy appearance indicates water contamination. A gritty feeling when rubbed between the fingers indicates dirt. In most cases, a water- or dirt-contaminated joint should be replaced.

The drive axles should be checked for signs of contact or rubbing against the chassis. Rubbing can be a symptom of a weak or broken spring or engine mount, as well as chassis misalignment. On FWD transaxles with equal-length half shafts, inspect the intermediate shaft U-joint, bearing, and support bracket for looseness by rocking the wheel back and forth and watching for any movement. Oil leakage around the inner CV joints indicates a faulty transaxle shaft seal. To replace the seal, the half shaft must be removed.

Obtaining CV Repair Parts and FWD Axles

Normally when an axle is bad, the entire shaft should be replaced. The aftermarket offers a complete line of original equipment drive shafts for FWD vehicles. These shafts come fully assembled and ready for installation. This eliminates the need to tear down and rebuild an old shaft.

If only the CV joints need service, a CV joint service kit should be installed. Joint service kits typically include a CV joint, boot, boot clamps and seals, special grease for lubrication (various joints require different amounts of grease; the correct quantity is packed in each kit), retaining rings, and all other attachment parts.

Manufacturers also produce a line of complete boot sets for each application, including new clamps and the appropriate type and amount of grease for the joint. CV joints require a special high-temperature, high-pressure grease. Substituting any other type of grease may lead to premature failure of the joint. Be sure to use all the grease supplied in the joint or boot kit. The same rule applies to the clamps. Use only those clamps supplied with the replacement boot. Follow the directions for positioning and securing them.

Old boots should never be reused when replacing a CV joint. In most cases, failure of the old joint is caused by some deterioration of the old boot. Reusing an old boot on a new joint usually leads to the quick destruction of the joint.

Photo Sequence 32 shows the procedure for removing a typical drive axle and replacing a CV joint boot. Always refer to the service information for the exact service procedure.

To show the importance of installing the correct drive axles and associated parts, examine the drive axle shown in **Figure 40–14**. This axle was replaced

TABLE 40-1 PROBLEM DIAGNOSIS AND SERVICE FOR FWD DRIVELINES

Concern	Possible Cause	Corrective Remedy
Vibrations in steering wheel at highway speeds	Front-wheels out-of-balance	Front wheels must be balanced
Vibrations throughout vehicle	Worn inner CV joints	Replace joint
Vibrations throughout vehicle at low speed	Bent axle shaft	Replace axle shaft
Vibrations during acceleration	Worn or damaged outer or inner CV joints Fatigued front springs	Replace joint Correct or replace front springs
Grease dripping on ground or sprayed on chassis parts	Ripped or torn CV joint boots	Replace CV joint and/or boot
Clicking or popping noise heard when turning curves and corners	Worn or damaged outer CV joint Bent axle shaft	Replace joint Replace axle shaft
A clunk during accelerating, decelerating, or putting an automatic transaxle into drive	Excessive play in the inner joint	Replace joint
A clunking noise when putting an automatic transmission into gear or when starting out from a stop	Excessive play in an inner or outer joint	Replace the bad joint
A humming or growling	Inadequate lubrication of either the inner or outer CV joint. It is more often due to worn or damaged wheel bearings, a bad intermediate shaft bearing on equal-length half-shaft transaxles, or worn shaft bearings within the transmission.	Lubricate or repair as necessary
A shudder or vibration when accelerating	Excessive play in either the inboard or outboard joint or a bad intermediate shaft bearing on transaxles with equal-length half shafts	Replace the faulty joint
A cyclic vibration that comes and goes between 45 and 60 mph (72 and 100 km/h)	A bad inner tripod CV joint	Replace the joint

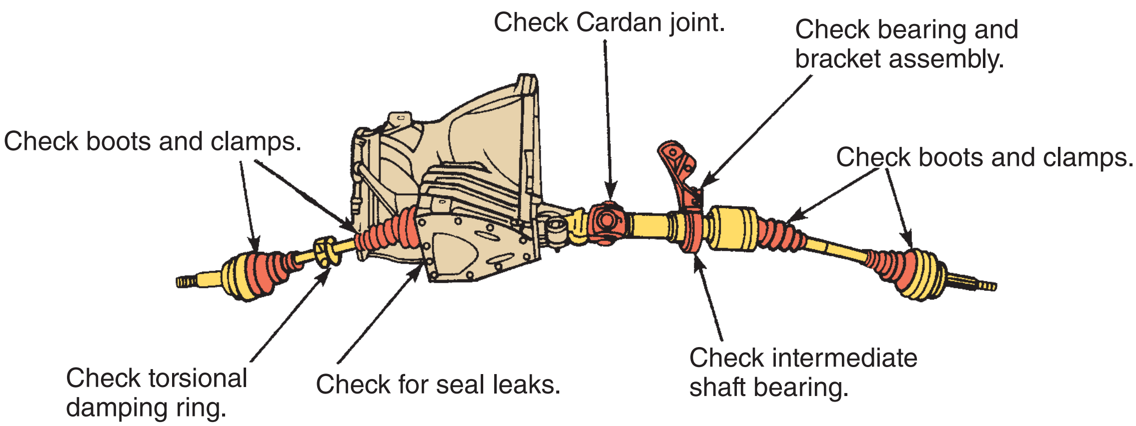


FIGURE 40-13 Inspection points for a FWD vehicle.

FIGURE 40–14 An axle replacement with an incorrect part allowed the axle to come out of the front differential.

FIGURE 40–15 A comparison of the incorrect (left) and correct (right) axles for the truck.

recently. The customer complaint was of noise from the left front of his truck. It became quite obvious when the axle shaft was removed and compared to a replacement, that the one recently installed was not of the same length as it should be **(Figure 40–15)**. Installing the correct axle shaft took care of the problem.

CV Joint Service Guidelines

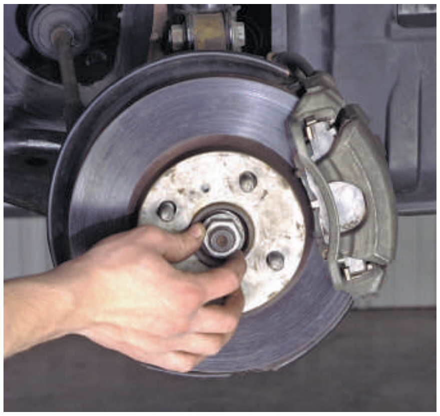
The following are some guidelines to follow when servicing CV joints:

- Always support the control arm when doing on-the-car balancing of the front wheels to avoid high-speed operation at a steep half-shaft angle. Off-the-car balancing might be a wiser choice.
- Do not use half shafts as lift points for raising a car.
- Use a plastic or metal shield over rubber boots to protect them from accidental tool damage when performing other wheel, brake, suspension, or steering system maintenance **(Figure 40–16)**.
- Clean the axle boots with only soap and water and avoid contact with gasoline, oil, or degreaser compounds.
- Never jerk or pull on the axle shaft when removing it from a vehicle with tripod inner joints. Doing so may pull the joint apart, allowing the needle bearings to fall out of the roller. Pull on the inner housing, and support the outer end of the shaft until the shaft is completely out.
- Always install new hub nuts and torque them to specifications. This is absolutely necessary to properly preload the wheel bearings. Do not guess or use an impact wrench to seat the nut. The specifications can vary from 75 to 235 ft.-lb (101 to 318 N-m) or more. Some axle hub nuts are staked in place after they have been tightened **(Figure 40–17)**. Others have a castellated nut that is secured with a cotter pin.
- Never use an impact wrench to loosen or tighten axle hub nuts. Doing so may damage the wheel bearings as well as the CV joints.
- On vehicles with antilock brakes, use care to protect the wheel speed sensor and tone ring on the outer CV joint housings. If misaligned or damaged during joint replacement, it can cause wheel speed sensor problems.
- Always recheck the alignment after replacing CV joints. Marking the camber bolts is not enough, because camber can be off as much as three-quarters of a degree due to differences between the size of the camber bolts and their holes.

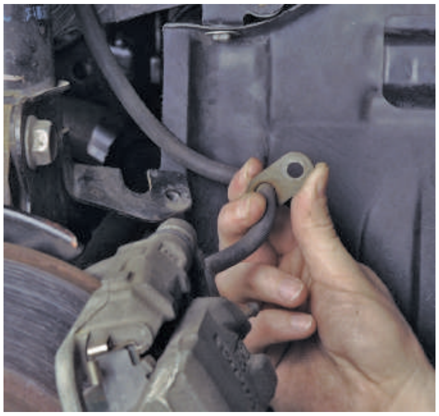
PHOTO SEQUENCE 32

Removing and Replacing a CV Joint Boot

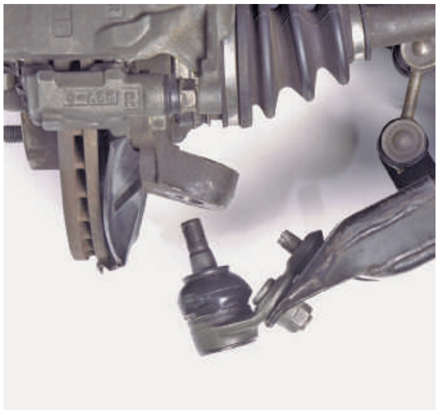
P32-1 Removing the axle from the car begins with the removal of the wheel cover and wheel hub cover. The hub nut should be loosened before raising the car and removing the wheel.



P32-2 After the car is raised and the wheel is removed, the hub nut can be unscrewed from the axle shaft.



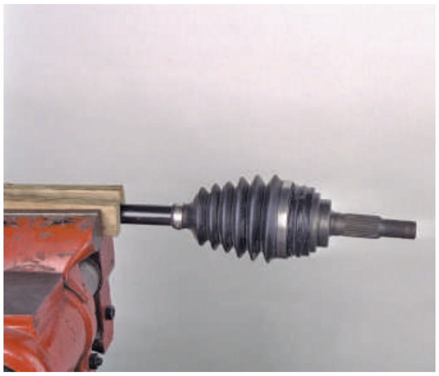
P32-3 The brake line holding clamp must be loosened from the suspension.



P32-4 The ball joint must be separated from the steering knuckle assembly. To do this, first remove the ball joint retaining bolt. Then pry down on the control arm until the ball joint is free.

P32-5 The inboard joint can be pulled free from the transaxle.

P32-6 A special tool is normally needed to separate the axle shaft from the hub allowing the axle to be removed from the car. Never hit the end of the axle with a hammer.



P32-7 The axle shaft should be mounted in a soft-jawed vise for work on the joint. Pieces of wood on either side of the axle work well to secure the axle without damaging it.

P32-8 Begin boot removal by cutting and discarding the boot clamps.

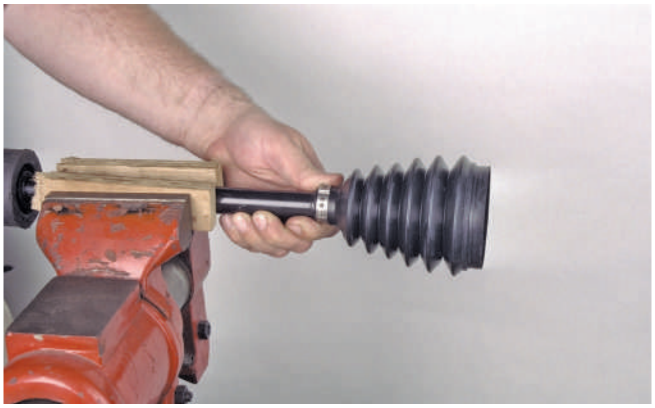
P32-9 Scribe a mark around the axle to indicate the boot's position on the shaft. Then move the boot off the joint.

Removing and Replacing a CV Joint Boot *(continued)*

P32-10 Remove the circlip and separate the joint from the shaft.

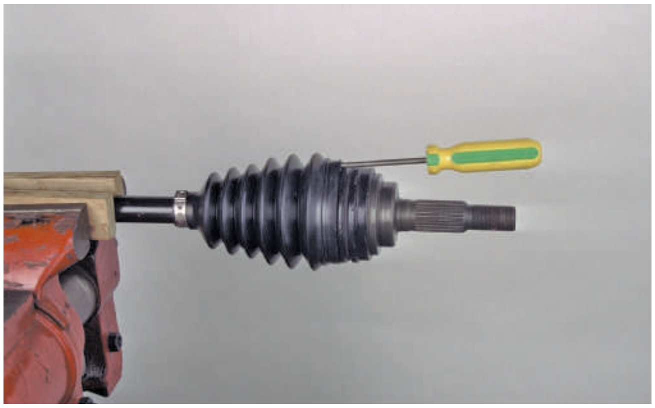
P32-11 Slide the old boot off the shaft.

P32-12 Clean and inspect the joint, then wipe the axle shaft clean and install the new boot onto the shaft.

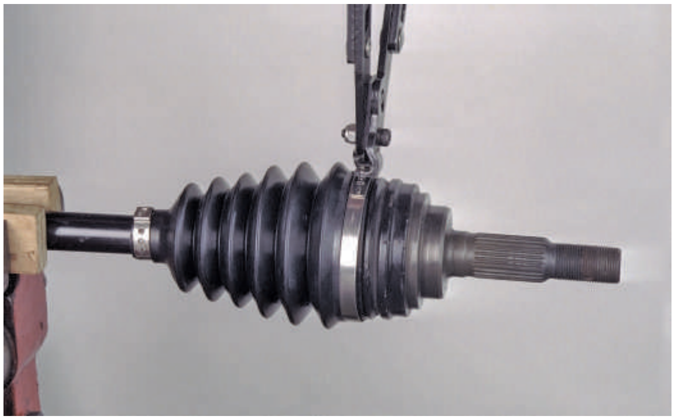


P32-13 Place the boot into its proper location on the shaft and install a new clamp.

P32-14 Using a new circlip, reinstall the joint on the shaft. Pack joint grease into the joint and boot. The entire packet of grease that comes with a new boot needs to be forced into the boot and joint.



P32-15 Pull the boot over the joint and into its proper position. Use a dull screwdriver to lift an edge of the boot up to equalize the pressure inside the boot with the outside air.



P32-16 Install the new large boot clamp and reinstall the axle into the car. Torque the hub nut after the wheels have been reinstalled and the car is sitting on the ground. Always follow the correct procedure for the clamp being installed.

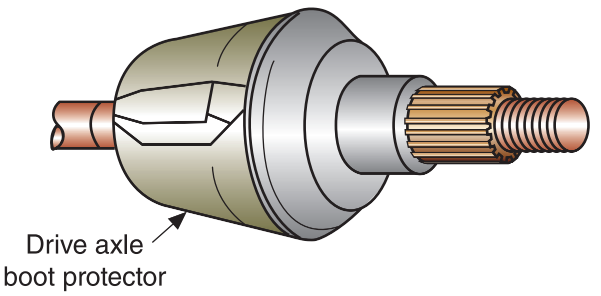
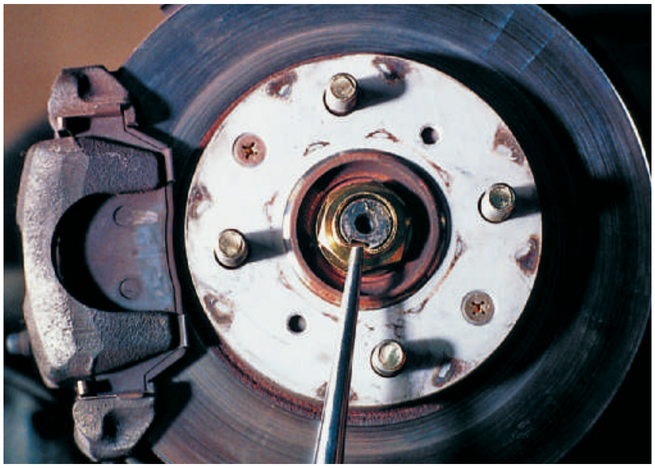


FIGURE 40–16 A typical axle boot protector.



Courtesy of Federal-Mogul Corporation.

FIGURE 40–17 Most axle hub nuts are staked after they are tightened to lock them in place.

Rear-Wheel Drive Shafts

A drive shaft must smoothly transfer torque while rotating, changing length, and moving up and down. The different designs of drive shafts all attempt to ensure a vibration-free transfer of the engine's power from the transmission to the differential. This goal is complicated by the fact that the engine and transmission are bolted solidly to the frame of the car, whereas the differential is mounted on springs. As the rear wheels go over bumps in the road or changes in the road's surface, the springs compress or expand, changing the angle of the drive shaft between the transmission and the differential, as well as the distance between the two. To allow for these changes, the Hotchkiss-type drive shaft is fitted with one or more U-joints to permit variations in the angle of the drive, and a slip joint that permits the effective length of the drive shaft to change.

Starting at the front or transmission end of a RWD shaft, there is a slip yoke, a universal joint, a drive shaft yoke, and a drive shaft **(Figure 40–18)**. At the rear or differential end, there is another drive shaft yoke and a second universal joint connected to the differential pinion flange.

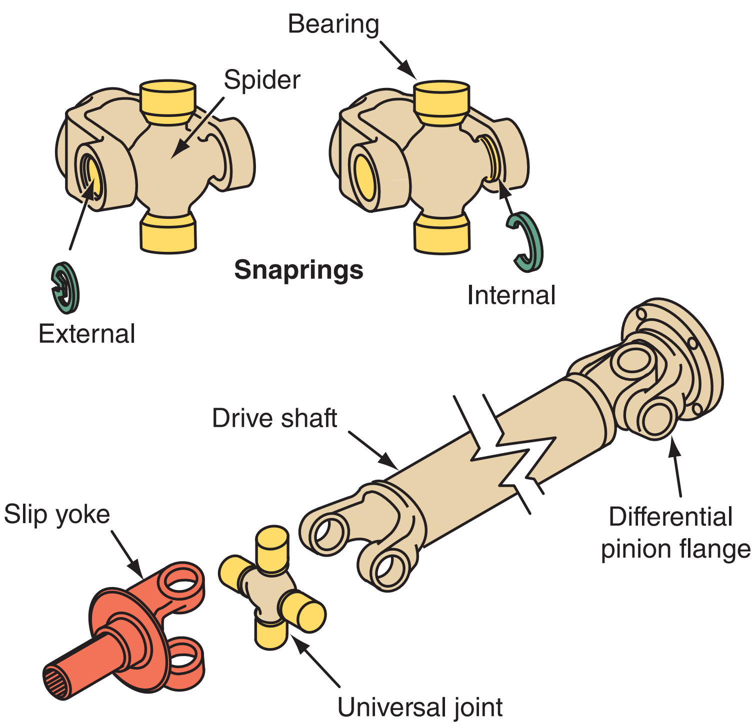


FIGURE 40–18 A drive shaft assembly with exploded U-joints.

SHOP TALK

When the ride height of a vehicle is intentionally raised or lowered, the length of the drive shaft should be changed to allow for normal travel of the slip yoke on the output shaft.

FIGURE 40–19 A center bearing assembly.

In addition to these basic components, some drivetrains have a drive shaft support bearing **(Figure 40–19)**. Large vehicles with long drive shafts often use a double U-joint arrangement, called a double Cardan joint or a CV U-joint, to help minimize drive line vibrations. These vehicles may also have a center bearing. The center bearing allows the length of the shaft to be divided in half. When a center bearing is used, the ends of the drive shaft that are going into the bearing are slip joints.

Slip Yoke

A sliding or **slip yoke (Figure 40–20)** is internally splined and its outside diameter is precisely machined to fit into the rear seal. The internal splines slip over the external splines of the output shaft. The slip yoke rotates at output shaft speed and can slide on the splines (hence the name slip yoke). The slip yoke allows the effective length of the drive shaft to change with the movement of the rear suspension and drive axle assembly.

Drive Shaft and Yokes

The drive shaft is nothing more than an extension of the transmission output shaft. The drive shaft, which is usually made from seamless steel tubing, transfers engine torque from the transmission to the rear driving axle. The yokes, which are either welded or pressed onto the shaft, provide a means of connecting two or

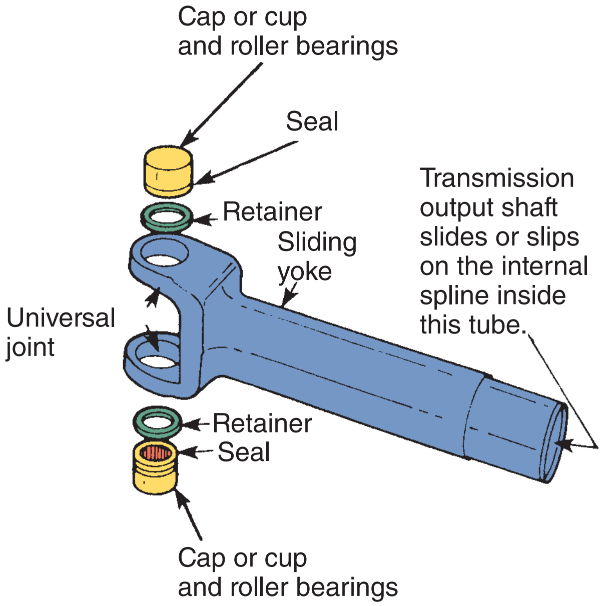


FIGURE 40–20 A typical slip or sliding yoke.

more shafts together. At the present time, a limited number of vehicles are equipped with fiber composite—reinforced fiberglass, graphite, and aluminum—drive shafts. The advantages of using these materials are weight reduction, torsional strength, fatigue resistance, easier and better balancing, and reduced interference from shock loading and torsional problems. Some drive shafts are fitted with a torsional damper to reduce torsional vibrations.

The drive shaft, like any other rigid tube, has a natural vibration frequency. If one end were held tightly, it would vibrate at its own frequency when deflected and released. It reaches its natural frequency at its critical speed. The critical speed of a rotating shaft is when it reaches its natural frequency, which greatly increases the vibration of the shaft. Critical drive shaft speed depends on the diameter of the tube and its length. Diameters are as large as possible and shafts as short as possible to keep the critical speed frequency above the driving speed range. It should be remembered that since the drive shaft generally turns three to four times faster than the tires, proper drive shaft balance is required for vibration-free operation.

Operation of U-Joints

The U-joint allows two rotating shafts to operate at a slight angle to each other. A French mathematician named Cardan developed the original joint in the sixteenth century. In 1902, Clarence Spicer modified Cardan's invention for the purpose of transmitting engine torque to an automobile's rear wheels.

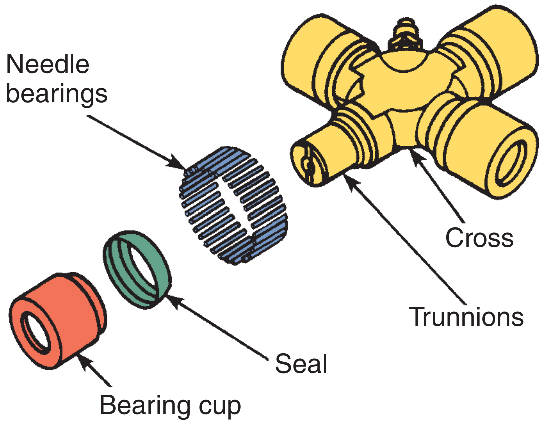


FIGURE 40–21 A Cardan joint.

The U-joint is basically a double-hinged joint consisting of two Y-shaped yokes, one on the driving or input shaft and the other on the driven or output shaft, plus a cross-shaped unit called the cross **(Figure 40–21)**. A U-joint is used to connect the yokes together. The four arms of the cross are fitted with bearings in the ends of the two shaft yokes. The input shaft's yoke causes the cross to rotate, and the two other trunnions of the cross cause the output shaft to rotate. When the two shafts are at an angle to each other, the bearings allow the yokes to swing around on their trunnions with each revolution. This action allows two shafts, at a slight angle to each other, to rotate together.

U-joints allow the drive shaft to transmit power to the rear axle through varying angles that are controlled by the travel of the rear suspension. Because power is transmitted on an angle, U-joints do not rotate at a constant velocity, nor are they vibration free.

Speed Variations (Fluctuations)

Although simple in appearance, the universal joint is more intricate than it seems because its natural action is to speed up and slow down twice in each revolution while operating at an angle. The amount that the speed changes varies according to the steepness of the U-joint's angle.

U-joint operating angle is determined by taking the difference between the transmission installation angle and the drive shaft installation angle. When the universal joint is operating at an angle, the driven yoke speeds up and slows down twice during each drive shaft revolution.

These four speed changes are not normally visible during rotation, but they may be understood more easily after examining the action of a U-joint. A universal joint is a coupling between two shafts not in direct alignment, usually with changing relative positions. It would be logical to assume that the entire unit simply rotates. This is true only for the U-joint's input yoke.

The output yoke's circular path looks like an ellipse because it can be viewed at an angle instead of straight on. This effect can be obtained when a coin is rotated by the fingers. The height of the coin stays the same even though the sides seem to get closer together.

This illusion might seem to be a merely visual effect, but it is more than that. The U-joint rigidly locks the circular action of the input yoke to the elliptical action of the output yoke. The result is similar to what would happen when changing a clock face from a circle to an ellipse.

Like the hands of a clock, the input yoke turns at a constant speed in its true circular path. The output yoke, operating at an angle to the other yoke, completes its path in the same amount of time. However, its speed varies, or is not constant, compared to the input.

Speed fluctuation is more easily visualized when looking at the travel of the yokes by 90-degree quadrants **(Figure 40–22)**. The input yoke rotates at a steady or constant speed through the complete 360-degree turn. The output yoke quadrants alternate between shorter and longer distance travel than the input yoke quadrants. When one point of the output yoke covers the shorter distance in the same amount of time, it must travel at a slower rate. Conversely, when traveling the longer distance (but only 90 degrees) in the same amount of time, it must move faster.

Because the average speed of the output yoke through the four 90-degree quadrants (360 degrees) equals the constant speed of the input yoke during the same revolution, it is possible for the two mating yokes to travel at different speeds. The output yoke is falling behind and catching up constantly. The resulting acceleration and deceleration produces a fluctuating torque and torsional vibrations characteristic of all Cardan U-joints. The steeper the U-joint angle, the greater the fluctuations in speed will be. Conversely, the smaller the angle, the speed will change less.

Phasing of Universal Joints

The torsional vibrations set up by the fluctuations in velocity are transferred down the drive shaft to the next U-joint. At this joint similar speed fluctuation occurs. Since these speed variations take place at equal and opposite angles to the first joint, they

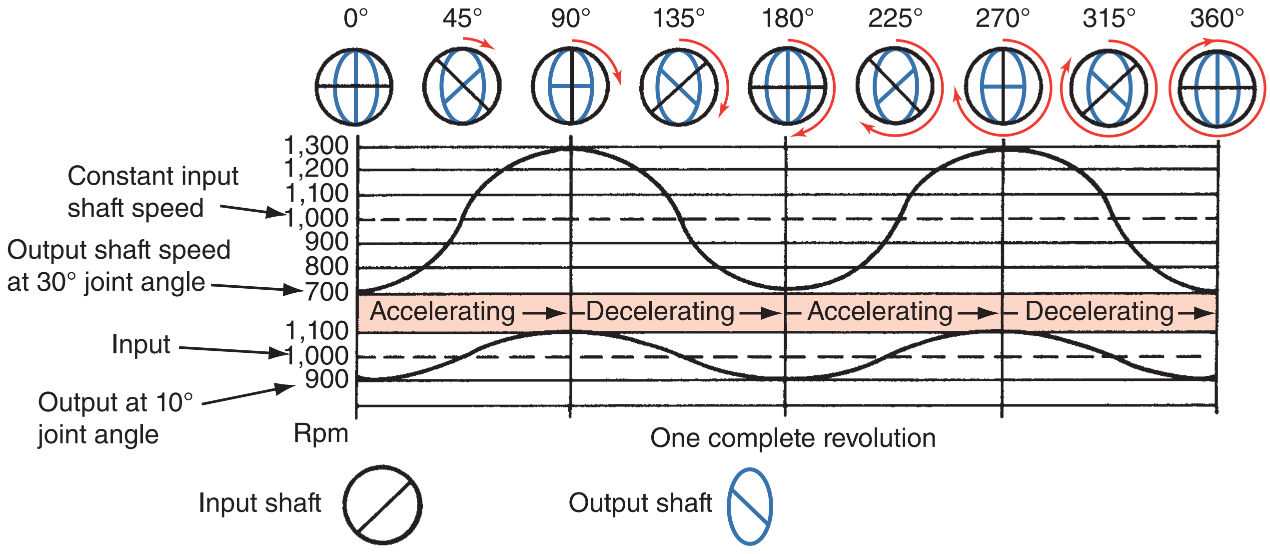


FIGURE 40–22 A graph showing typical drive shaft yoke speed fluctuations.

cancel out each other. To provide for this canceling effect, drive shafts have at least two U-joints in phase with each other **(Figure 40–23)**. When the yokes are properly aligned, the joints are said to be "in phase."

On a two-piece drive shaft, you may encounter problems if you are not careful. The center driving yoke is splined to the front drive shaft. If the yoke's position on the drive shaft is not indicated in some manner, the yoke could be installed in a position that is out of phase. Manufacturers use different methods of indexing the yoke to the shaft. Some use aligning arrows. Others machine a master spline that is wider than the others. The yoke and shaft cannot be reassembled until the master spline is aligned properly. When there are no indexing marks, you should index the yoke to the drive shaft before disassembling the U-joint. This saves time and frustration during reassembly.

Canceling Angles

Vibrations can be reduced by using canceling angles **(Figure 40–24)**. Carefully examine the illustration, and note that the operating angle at the front of the drive shaft is offset by the one at the rear of the drive shaft. The angle of the driveshaft in relation to that of the transmission and rear differential constitute the operating angle. The operating angles should be equal and opposite to each other and total angle should be less than 3 degrees. When the front U-joint

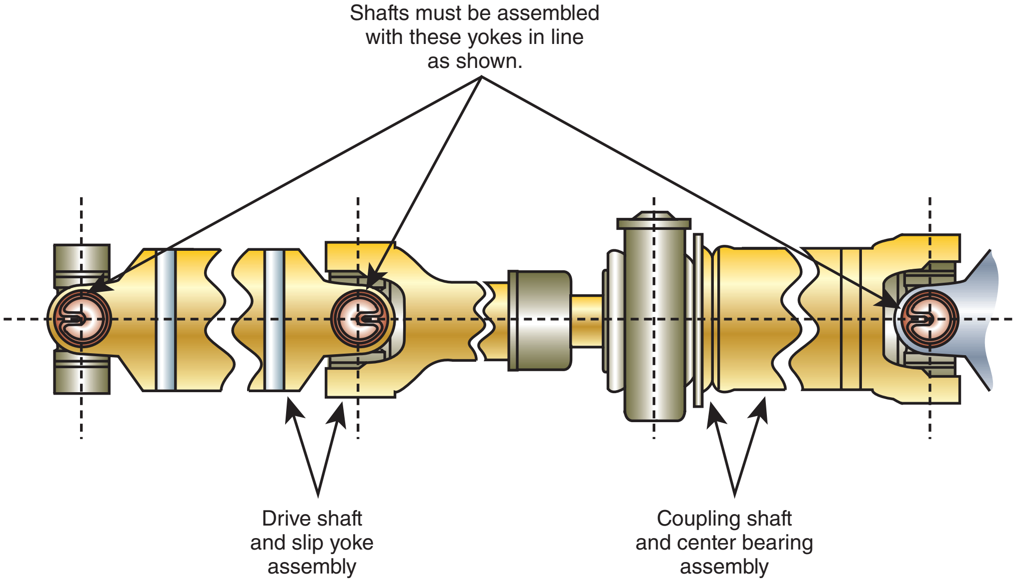


FIGURE 40–23 The yokes must be properly aligned to keep the driveshaft in phase.

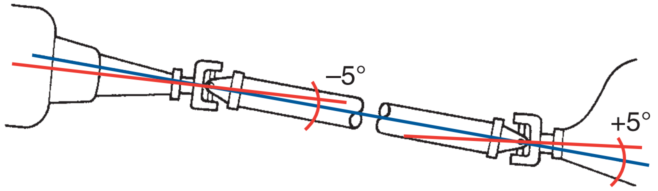


FIGURE 40–24 When a drive shaft's joints are in phase and have canceling angles, inherent vibrations are reduced.

accelerates, causing a vibration, the rear universal joint decelerates, causing a vibration. The vibrations created by the two joints oppose and dampen the vibrations from one to the other. The use of canceling angles provides a smoother drive shaft operation.

Types of U-Joints

There are three common designs of U-joints: single U-joints retained by either an inside or outside snapring, coupled U-joints, and U-joints held in the yoke by U-bolts or lock plates.

Single Universal Joints

The single Cardan/Spicer U-joint is also known as the cross or four-point joint. These two names aptly describe the single Cardan, since the joint itself forms a cross, with four machined trunnions or points equally spaced around the center of the axis. Needle bearings used to abate friction and provide smoother operation are set in bearing cups. The trunnions of the cross fit into the cup assemblies and the cup assemblies fit snugly into the driving and driven U-joint yokes. U-joint movement takes place between the trunnions, needle bearings, and bearing cups. There should be no movement between the bearing cup and its bore in the universal joint yoke. The bearings are normally held in place by snaprings that drop into grooves in the yoke's bearing bores. The bearing caps allow free movement between the trunnion and yoke. The needle bearing caps may also be pressed into the yokes, bolted to the yokes, or held in place with U-bolts or metal straps.

There are other styles of single U-joints. The method used to retain the bearing caps is the major difference between these designs. The Spicer style **(Figure 40–25A)** uses a snapring that fits into a groove machined in the outer end of the yoke. The bearing cups for this style are machined to accommodate the snapring.

The Mechanics or Detroit/Saginaw style **(Figure 40–25B)** uses an external snapring that fits into a

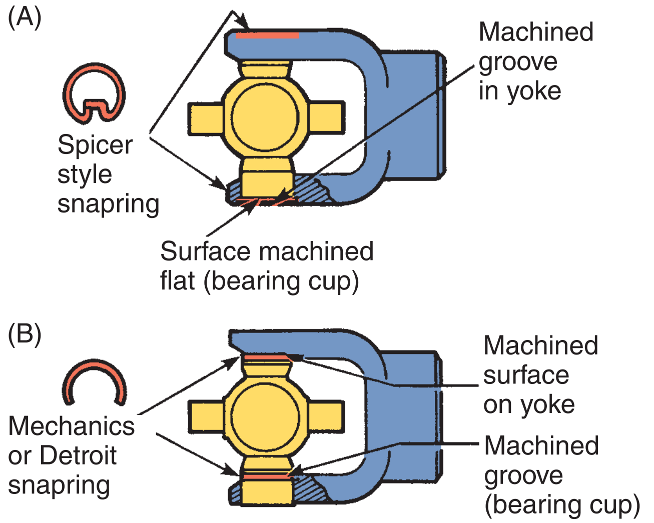


FIGURE 40–25 (A) A Spicer-style U-joint and (B) a Mechanics or Detroit-style U-joint.

groove machined in the bearing cup on the end closest to the grease seal. When installed, the snapring rests against the machined inside portion of the yoke. On some joints, nylon is injected into the machined grooves to retain the U-joint. When these joints are replaced, new retaining rings are included with the joint and the plastic is not reinjected. Make sure that all of the plastic is removed before installing a new joint.

The Cleveland style is an attempt to combine different joint styles to have more applications from one joint. The bearing cups for this U-joint are machined to accommodate either Spicer or Mechanics style snaprings. If a replacement U-joint comes with both style clips, use the clips that pertain to your application.

Double-Cardan Universal Joint

A double-Cardan U-joint is used with split drive shafts and consists of two Cardan U-joints closely connected by a centering ball socket and a center yoke, which functions as a ball and socket. The ball and socket splits the angle of the two shafts between two U-joints **(Figure 40–26)**. Because of the centering socket yoke, the total operating angle is divided equally between the two joints. Since the two joints operate at the same angle, the normal fluctuations that result from the use of a single U-joint are canceled out. The acceleration and deceleration of one joint is canceled by the equal and opposite action of the other. The double-Cardan joint is classified as a CV U-joint.

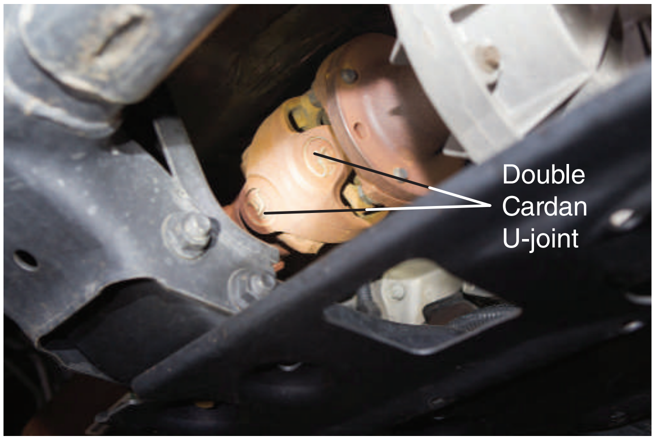


FIGURE 40–26 A double-Cardan joint.

Diagnosis of Drivetrain Problems

Diagnostics of drive shafts, U-joints, drive axles, and final drive units are normally focused on finding the cause of a noise or vibration. The key to locating the problem is clearly defining the symptom or the customer's complaint. This is done by talking with the customer, conducting a thorough road test, and completing a careful inspection.

The final drive assembly is an integral part of the rear drive axle assembly **(Figure 40–27)**. Some driveline noises and vibrations are caused by problems in the differential. Before proceeding to correct

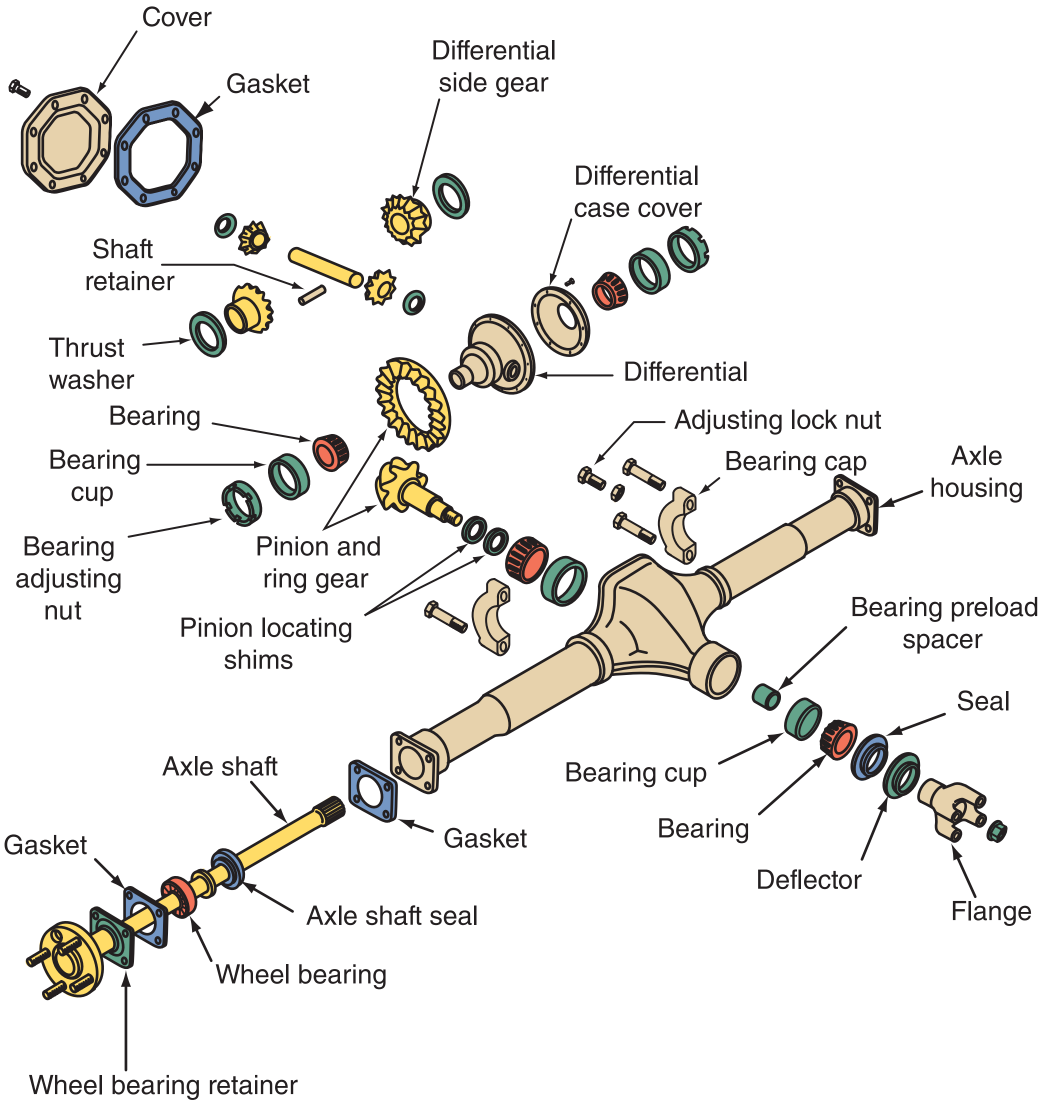


FIGURE 40–27 An exploded view of an integral-carrier axle housing with a hypoid final drive assembly and semifloating axles.

any problem in the driveline, especially with differentials, refer to the appropriate information for the correct procedures.

Talking to the Customer

Diagnosis should begin with gathering as much information as possible from the customer. Ask the customer to carefully describe the problem. If the customer's complaint is based on an abnormal noise or vibration, find out when and where it is felt or heard. This will not only help you pinpoint the cause of the problem, but will also allow you to determine if the problem is in the driveline or if it is caused by other systems. Many noise and vibration problems are caused by damaged or worn suspension, brake, and exhaust parts.

Road Test

A road test can verify the customer's complaint, as well as help you identify its cause. If possible, take the customer along with you on the road test. Attempt to duplicate the complaint by operating the vehicle in the conditions that the problem occurs. Also, pay careful attention to the vehicle during all other operating conditions. Note the engine and vehicle speeds at which the problem is most evident.

Accelerate and decelerate several times during the road test. The car should also be driven at various constant speeds. Note when all noises and vibrations occur.

Normally driveline noises are more noticeable during one or more of these conditions. When the vehicle is firmly accelerated to demand engine torque, the condition is referred to as "drive." The "cruise" condition occurs when a constant speed is maintained by a constant throttle opening. The "coast" condition occurs during deceleration with the throttle closed. "Float" is the condition during which there is controlled deceleration by letting up on the throttle continually to prevent braking or acceleration. While diagnosing driveline noise, it is important to note any changes in noise during each of these conditions.

Visual Inspection

Shift the transmission into N and release the parking brake. Raise and support the vehicle on a hoist or jack stands so that the wheels are free to rotate. The driveshaft should be kept at an angle equal to or close to the curb-weighted position.

Check the entire length of the drive shaft for excess undercoating, dents, missing weights, or other damage that could cause an imbalance and result in a vibration **(Figure 40–28)**. Look at each joint, if the joint has a red dust on it, this could mean it is dry and lacks lubrication. Also check the seating of the joints in their yokes.

FIGURE 40–28 The entire length of the drive shaft should be inspected.

Rotate the driveshaft slowly by hand and feel for binding or looseness at the U-joints and slip splines. Each joint can be further checked by gripping the input and output yokes and attempting to twist them back and forth in opposite directions, then hold one stationary as you try to move the other vertically and side-to-side. Also grip the slip yoke at the rear of the transmission and try to move it vertically and side-to-side. If there is excessive movement, the slip yoke should be replaced.

Inspect the U-joints' grease seals, located at the bottom of the bearing caps, for signs of rust, leakage, or contamination of the lubricant. U-joints can be quickly checked for wear or damage by grasping the yoke and the drive shaft. Carefully watch the two parts as you turn them in opposite directions, there should be no noticeable movement. Then, attempt to move the shaft up and down in the yoke. If any movement is possible, the joint is worn.

Naturally, the amount of movement indicates the amount of wear.

Lastly, if the drive shaft has a center bearing, carefully inspect it. Look for looseness, a broken rubber mounting, and damage due to excessive heat. Then rotate the driveshaft by hand. If the center bearing shows signs of roughness or is noisy, install a new driveshaft assembly.

When a U-joint is damaged or excessively worn, it must be replaced. Photo Sequence 33 covers the typical procedure for removing a U-joint from a drive shaft. After a replacement joint is obtained, it needs to be installed. Photo Sequence 34 covers the reassembly of a common U-joint.

While under the vehicle looking at things, check the fluid in the axle assembly. Poor lubrication in the axle can also be a source of noise, so the lubricant's level and condition should be checked. If the level is low, the axle should be filled with the proper type and amount of lubricant and the car should be road tested again. If the lubricant is contaminated, it should be drained and the axle refilled with the specified lubricant. Low or contaminated lubricant normally indicates a leak somewhere in the assembly. Therefore, the drive axle assembly should be carefully inspected to locate the source of the leak.

Possible Sources of Leaks

To find the exact source of the leak, carefully inspect the driveline for wet spots. Thoroughly clean the area around the leak so the exact source can be found.

If the extension housing seal is leaking, it can be easily replaced. However before replacing the seal, check the extension housing bushing and replace it with the seal if it is worn. That is the most likely reason the seal went bad in the first place. Once the yoke is removed, an internal expanding bearing/bushing puller makes short work of bushing replacement. Before pushing the slip yoke back in after the new seal is installed, make sure the machined surface of the bore is free of scratches, nicks, and grooves that could damage the seal. For that added margin of safety, a little transmission lube or petroleum jelly on the lip of the seal helps the parts slide in easily.

An improperly installed or damaged drive pinion seal will allow the lubricant to leak past the outer edge of the seal **(Figure 40–29)**. Any damage to the seal's bore, such as dings, dents, and gouges, will distort the seal casing and allow leakage. Also, the spring that holds the seal lip against the companion flange may be knocked out and allow leakage past the seal's lip.

FIGURE 40–29 The housing is wet because of a leaking pinion seal.

If a lot of lube is escaping from the pinion shaft seal, the drivetrain noise could be caused by a bad pinion bearing. To confirm the problem, start the engine, put the transmission in gear, and listen at the carrier. If the bearing is noisy, it is necessary to make one of those difficult judgment calls. If the bearing sounds fine but the pinion seal is still leaking, suggest an on-the-car seal replacement.

On some vehicles, seal replacement is a simple procedure that involves removing the pinion flange and replacing the seal. Others are a little more complex because the pinion shaft is retained with a nut that must be removed to gain access to the seal. These units require special tools to loosen and tighten the pinion nut **(Figure 40–30)**, which allows for the removal of the flange. Always refer to the service information for the correct procedure. On many units there is a collapsible spacer behind the pinion nut. Whenever the nut is loosened, a new spacer should be installed before torquing the nut.

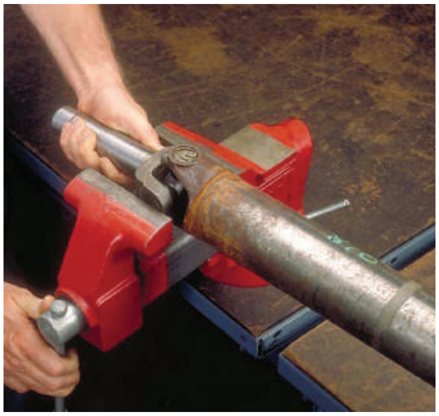
If the seal needs to be replaced, check the runout of the flange. A damaged seal can be caused by excessive runout. To do this, install a dial indicator with its base on the carrier and its plunger on the flange **(Figure 40–31)**. Rotate the wheels while observing the movement of the indicator. Any reading indicates some runout. Compare the reading to specifications. Also inspect the surface of the flange that rides in the seal. During reassembly, make sure the outer surface of the flange is lubricated before pushing it into the seal.

It is also possible for oil to leak past the threads of the drive pinion nut or the pinion retaining bolts. These leaks can be stopped by removing the nut or bolts, applying thread or gasket sealer on the threads, and torquing the nuts or bolts to specifications.

There may be leakage at the retaining nuts for the carrier or cover. One way to correct this problem is to

PHOTO SEQUENCE 33

Disassembling a Single Universal Joint



P33-1 Clamp the slip yoke in a vise and support the outer end of the drive shaft.

P33-2 Remove the lock rings on the tops of the bearing cups. Make index marks in the yoke so that the joint can be assembled with the correct phasing.

P33-3 Select a socket that has an inside diameter large enough for the bearing cup to fit into; usually a 1¼-inch socket works.

P33-4 Select a second socket that can slide into the shaft's bearing cup bore—usually a 9/16-inch socket.

P33-5 Place the large socket against one vise jaw. Position the drive shaft yoke so that the socket is around a bearing cup.

P33-6 Position the other socket to the center of the bearing cup opposite to the one in line with the large socket.

P33-7 Carefully tighten the vise to press the bearing cup out of the yoke and into the large socket.

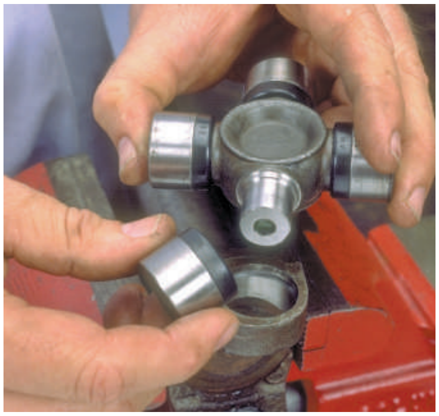
P33-8 Separate the joint by turning the shaft over in the vise and driving the cross and remaining bearing cup down through the yoke with a brass drift and hammer.

P33-9 Use a drift and hammer to drive the joint out of the other yokes.

PHOTO SEQUENCE 34

Reassembling a Single Universal Joint


P34-1 Clean any dirt from the yoke and the retaining ring grooves.

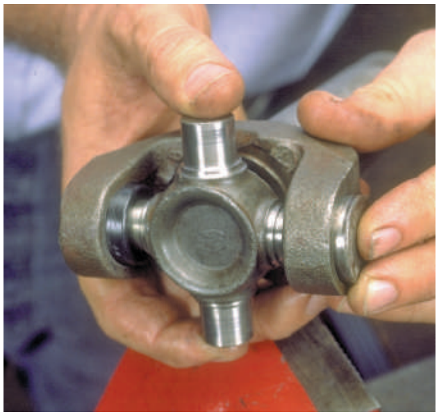

P34-2 Carefully remove the bearing cups from the new U-joint.

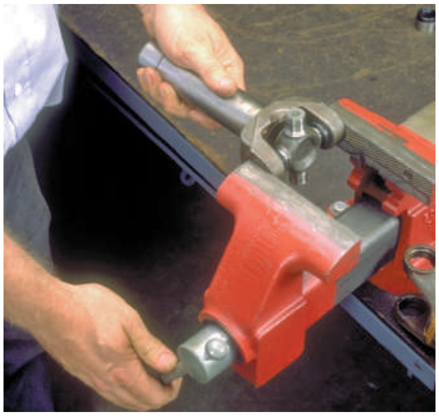

P34-3 Place the new spider inside the yoke and push it to one side.


P34-4 Start one cup into the yoke's ear and over the cross's trunnion.


P34-5 Carefully place the assembly in a vise or U-joint bearing press and press the cup partially through the ear.


P34-6 Remove the shaft from the vise and push the cross toward the other side of the yoke.


P34-7 Start a cup into the yoke's ear and over the trunnion.


P34-8 Place the shaft in the vise and tighten the jaws to press the bearing cup into the ear and over the trunnion. Then install the snaprings. Make sure they are seated in their grooves.


P34-9 Position the joint's cross in the drive shaft yoke and install the two remaining bearing cups.

FIGURE 40–30 The tools required to tighten the flange nut.

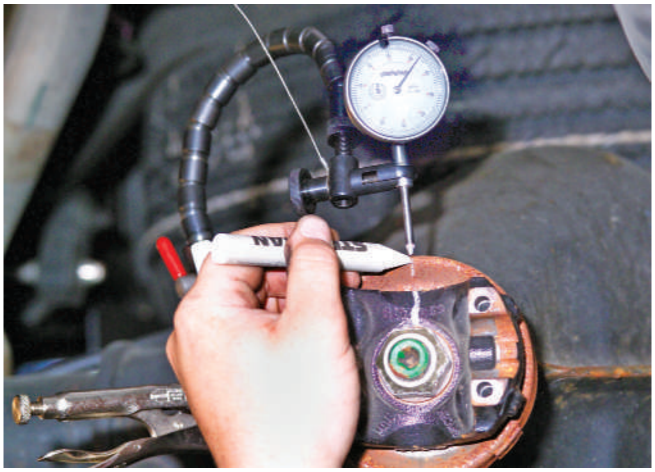


FIGURE 40–31 The setup for checking the runout of a companion flange.

install copper washers under the nuts. This is recommended whenever the carrier is removed, whether or not copper washers were installed originally. If the assembly was originally equipped with steel washers, replace them with copper. Always make sure there is a copper washer under the axle ID tag.

Most gasket leaks result from poor installation, loose retaining bolts, or a damaged mating surface. Most late-model vehicles do not use a gasket on the housing cover; rather silicone sealer is used. The old sealer should be cleaned off before applying a new coat to the surface. If a housing cover is leaking, inspect the surface for imperfections, such as cracks or nicks. File the surface true and install a new gasket. If the surface cannot be trued, apply some gasket sealer to the surface before installing the new gasket. Always follow the correct tightening sequence and torque specifications when tightening an axle housing cover.

At times, lubricant will leak through the pores of the housing. There are two recommended ways to repair these leaks, other than replacing the housing. If the porous area is small, force some metallic body filler into the area. After the filler has set, seal the area with an epoxy-type sealer. If the area is rather large, drill a hole and tap an appropriately sized setscrew into the hole, then cover the area with an epoxy sealer. Minor weld leaks can also be sealed with epoxy sealer. However, if a weld is broken, the housing should be replaced **(Figure 40–32)**.

If the wrong vent was installed in the axle housing or if there is an excessive amount of lubricant or oil turbulence in the axle, lubricant may leak through the axle vent hose. The cause of this type of leakage will only be found by a careful inspection. Check for a crimped or broken vent hose. Replace the hose it is damaged. If the cause of the leakage is an overfilled axle assembly, drain the housing and refill the unit with the specified amount and type of lubricant.

Some differential units are fitted with an ABS sensor. Lubricant can leak from around a damaged O-ring. To correct this problem, remove the sensor and replace the O-ring.

Noise and Vibration Diagnosis

A failed U-joint or damaged drive shaft can exhibit a variety of symptoms. Most often abnormal vibrations are felt or abnormal noises are heard. To help differentiate a potential drivetrain problem from other common sources of noise or vibration, it is important to note the speed and driving conditions at which the problem occurs.

As a general guide, a worn U-joint is noticeable during acceleration or deceleration and is less speed sensitive than an unbalanced tire (occurring in the 30 to 60 mph [50 to 100 km/h] range) or a bad wheel bearing (noticeable at higher speeds).

Before assuming the driveline is the source of a noise or vibration, make sure the tires or exhaust are not the cause. To make sure the noises are not caused by tire tread patterns and/or wear, drive the car on various types of road surfaces (asphalt, concrete, and packed dirt). If the noise changes with the road surfaces, it means the tires are the cause of the noise.

SHOP TALK

When diagnosing driveline noise, if a chirping sound that increases with speed is heard, suspect a dry U-joint. The chirping typically occurs with a frequency two to four times faster than the speed of the wheels.

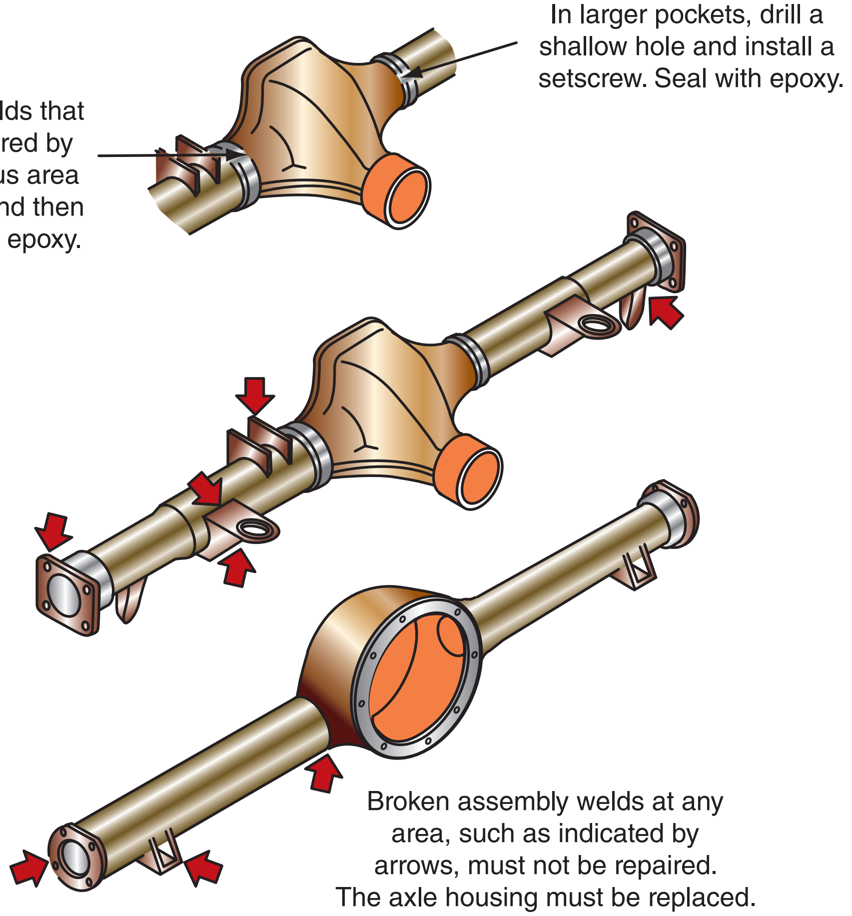


FIGURE 40–32 Basic guidelines for correcting axle housing leaks.

Another way to isolate tire noises is to coast at speeds less than 30 mph (48 km/h). If the noise is still heard, the tires are probably the cause. Drive axle and differential noises are less noticeable at these speeds. Accelerate and compare the sounds to those made while coasting. Drive axle and differential noises change. Tire noise remains constant.

An exhaust component that is contacting the frame can transfer quite a lot of vibration and can be easily missed. At times the exhaust's noise may sound like gear whine or wheel bearing rumble. Tires, especially snow tires, can have a high-pitched tread whine or roar, which is similar to gear noise.

Sometimes it is difficult to distinguish between axle-bearing noises and noises coming from the differential. Differential noises often change with the driving mode, whereas axle-bearing noises are usually constant. The sound of the bearing noise usually increases in speed and loudness as vehicle speed increases.

Often noises and vibration appear to be coming from the axle when they are actually caused by other problems. After the road test, the chassis should be carefully checked on a hoist. Exhaust system components positioned too close to the frame or underbody may be the cause of the noise. Loose or bent wheels, bad tire treads, worn U-joints, and damaged engine mounts all are capable of creating noise and/or vibration that appear to be coming from the axle.

By describing the noise or vibration, you can usually identify the most probable problem areas.

Clunking Perhaps the most noticeable noise to a customer is a clunking noise. Typically this noise is noticed when the vehicle is accelerated from a dead stop or when gears are changed. This sound is caused by harsh metal-to-metal contact and tends to disappear when the load on the driveline is held constant. The most likely causes for this problem are worn or damaged U-joints or excessive backlash somewhere in the driveline. However, excessive clearance between the slip joint and the extension housing bushing, a loose companion flange, and loose upper or lower control bushing bolts can also cause clunking.

Chuckling "Chuckle" sounds much like a stick rubbing against the spokes of a bicycle wheel. It normally can be heard during the coast condition and is usually heard all the way to a stop. The frequency varies with the speed of the car. Chuckle is typically

caused by final drive gear wear or damaged teeth on the pinion and/or ring gears. Often simply cleaning up the gear with a small grinding wheel or file can eliminate the noise. If the damaged area is larger than 1/8 inch or if the damage is on the face of a gear tooth, the gearset is normally replaced.

Knocking "Knocking" sounds very much like chuckling, but it is usually louder and can occur in all driving phases. Damaged gear teeth are a common cause of knocking. The noise can also be caused by ring gear bolts knocking against the inside of the carrier. This problem may simply be due to one or more loose bolts. This problem is corrected by properly tightening the bolts. Casting imperfections can reduce the clearance between the gear and the case, allowing the gear to occasionally hit the case. Removing the carrier and grinding off the interference points can correct this problem.

Chattering "Chatter" is the result of a vibration and it is felt and heard. Chatter is typically evident only when the vehicle is turning. The noise is caused by the entire drive axle vibrating. When this happens on vehicles equipped with a limited-slip axle, the wrong lubricant is the most likely cause. For other axles, excessive preloading can cause partial axle lockup that creates chatter.

To determine if the cause is excessive preload, position the vehicle on a frame-contact lift. Remove the rear wheels, brake drums, and the drive shaft. Install an inch-pound torque wrench on the pinion nut and measure the torque required to turn the pinion. Compare your reading with the specifications. If the required torque is not within specifications, the preload and backlash of the axle assembly must be re-adjusted.

If the vehicle is equipped with a limited-slip axle and the wrong type of lubricant was installed, drain the case and refill with the correct type of lubricant, then drive the car around a parking lot, turning it many times in each direction to allow the new lubricant to work into the clutches. If changing the lubricant doesn't fix the chattering, the bearing preloads are probably incorrect.

Gear Noise "Gear noise" is typically a howling or whining of the ring and pinion gears due to improperly set gears, gear damage, or improper bearing preload. This noise can occur at various speeds and during all driving conditions. It also can be heard continuously.

Bearing Noise Bearing "rumble" sounds like marbles tumbling around in a container. This noise is usually caused by faulty wheel bearings. Since wheel bearings rotate at approximately one-third the speed as other bearings in the driveline, the noise has a much lower tone than other faulty driveline bearings.

Bearing "whine" is a high-pitched sound normally caused by faulty pinion bearings that rotate at drive shaft speed and occur at all speeds. Although they travel at lower speeds, dry or poorly lubricated roller-type wheel bearings may make the same noise. Pinion bearings make a high-pitched, whistling sound. However, if only one pinion bearing is faulty, the noise may change with changes in driving modes.

Drive Shaft Runout

A vibration that occurs during all modes of driving, especially at 35–45 mph, is most often caused by a faulty universal joint, a bent drive pinion shaft, or a damaged pinion flange. All of these will cause the drive shaft to have excessive runout.

The runout of the drive shaft can be checked by putting the transmission in N and releasing the parking brake. Raise and securely support the vehicle on a hoist or jack stands so the wheels can freely rotate. Clean any dirt or rust from around the driveshaft at its center and three inches from each end.

Mount a dial indicator to the vehicle's underbody and position the needle so that it points directly toward the center of the driveshaft **(Figure 40–33)**.

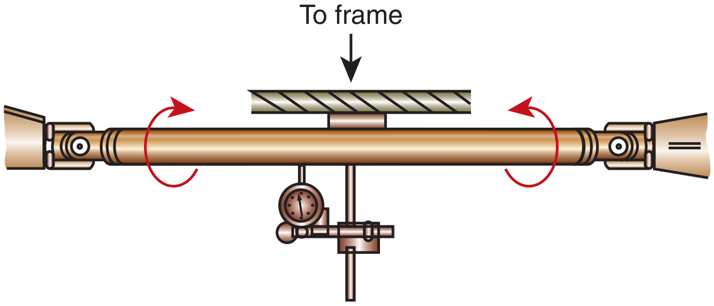


FIGURE 40–33 Checking the runout of a drive shaft.

Rotate the drive shaft until the dial indicator displays its lowest reading; adjust the dial to zero and rotate the driveshaft to the highest reading. Record that reading and the location of the high point, then repeat the procedure at top and bottom of the drive shaft. If the runout is more than 1 mm (0.040 in.), install a new driveshaft.

Drive Shaft Angles

If the runout is fine, check the phasing of the joints and their angle. Angle problems can be caused by worn and sagging rear springs or excessive load on the vehicle or by vehicle modifications, such as installing lift kits or lowering the suspension. If the vehicle is weighted down, the suspension will sag which changes the operating angle of the rear universal joint. This problem can also be caused by worn or defective transmission and/or engine mounts, worn or loose wheel bearings, or unbalanced tire/wheel assemblies.

The angle at which the transmission is mounted to the frame does not change during vehicle operation. However, the angle at which the rear axle pinion is mounted to the frame changes constantly while the suspension is responding to the road's surface.

Normally the drive shaft's operating angle will be correct if the car is at its correct ride height and the rear axle housing and transmission have not moved on their mounts. Typically the maximum allowable drive shaft angle is around 3 degrees from the car's horizontal. Normally, if the angles are wrong, the rear axle has moved in its mounting.

This check is extremely important for vehicles that have lift kits to increase ground clearance. This is a common modification for off-the-road vehicles and those doing the modifications often overlook canceling angles.

Measuring the Angles To check the drive shaft's operating angle, use an inclinometer. This instrument, when attached to the drive shaft, displays the angle of the drive shaft at any point.

Before checking the angles of the U-joints, make sure the vehicle is empty and has a full or near full fuel tank. Raise the car and rotate the drive shaft so that the bearing caps in the rear axle's pinion flange and the transmission's slip yoke are straight up and down. Then, clean the bearing caps of each joint. Install the inclinometer with the magnet on the downward facing bearing cap. Using the adjusting knob on the tool, center the weighted cord on its scale **(Figure 40–34)**.

Remove the inclinometer. Make sure not to bump the adjustment knob. Now, rotate the drive shaft 90 degrees and attach the inclinometer to the bearing cap now facing down, record the reading. Repeat this process until the drive shaft has completed one revolution, then check the angle of the rear joint.

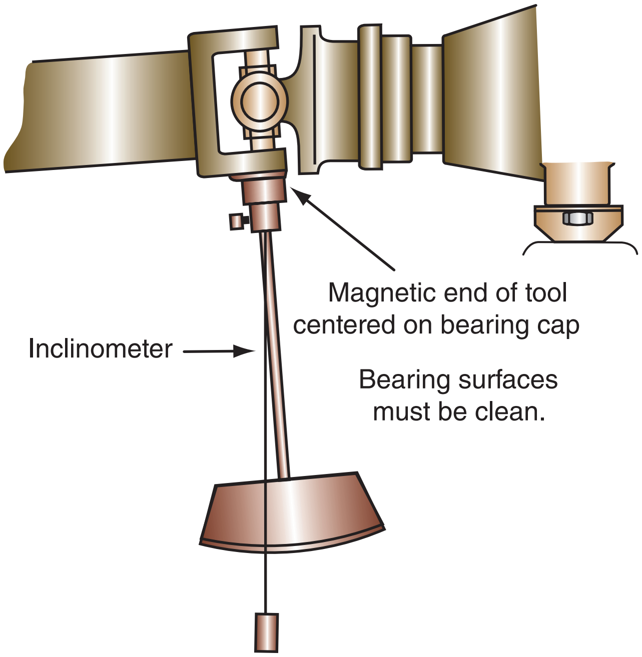


FIGURE 40–34 An inclinometer mounted to a U-joint.

Compare rear and front angle readings. The difference is the operating angle. Your findings from this test should be compared to specifications.

Adjusting the Angles If the operating angles of the two joints are not equal, normally the rear angle is adjusted so that it equals the front angle. On vehicles with leaf springs, the rear angle can be changed by rotating the rear axle assembly on the spring pads or by installing tapered shims between the springs and the spring pads.

If the vehicle has rear coil springs, the joint angle can be changed by inserting wedge-shaped shims between the rear axle assembly and rear control arms, adjusting an eccentric washer at the control arm, or by replacing the control arm with one of a different length.

If it is necessary to change the angle of the front U-joint, shims should be installed between the transmission's extension housing and the transmission mount.

Drive Shaft Balance

Often a driveshaft can be balanced while it is installed in the vehicle. Other times, it is sent out to a specialty shop. There are two ways the shaft can be

balanced while it is in the vehicle, with a driveline balance and NVH analyzer or with hose clamps.

Using an analyzer is the quickest way to balance the drive shaft. It normally relies on an accelerometer mounted near either the transmission or differential end of the driveshaft, reflective tape, and a photo-tachometer sensor.

Following the procedures for the analyzer, test weights are attached to locations on the shaft. Once the shaft is balanced, the recommended weight is secured to the shaft by a metal band and epoxy. Secure the test weight to the driveshaft at the position directed by the analyzer.

Hose Clamp Method Mark the rear of the driveshaft into four approximately equal sectors and number the marks 1 through 4. Install a hose clamp on the driveshaft with its head at position 1 and another at position 2. Check for vibration at road speed.

Recheck with the clamp at each of the other positions to find the position that shows minimum vibration. If two adjacent positions show equal improvement, position the clamp head between them.

If the vibration persists, add another clamp at the same position and recheck for vibration.

If there is no improvement, rotate the clamps in opposite directions at equal distances from the best position determined previously **(Figure 40–35)**. Separate the clamp heads about ½ inch (13 mm) and recheck for vibration at the road speed.

Maintenance

The drive shaft, itself, requires no maintenance except for an occasional cleaning off of any dirt buildup on the shaft. Dirt and any other buildup on the shaft will affect its balance. Factory installed U-joints are normally sealed and also require no periodic lubrication.

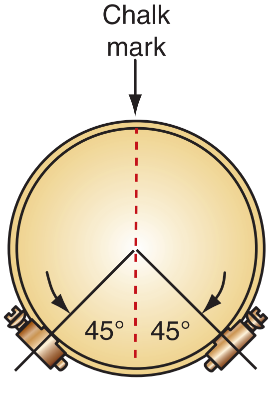


FIGURE 40-35 While balancing the shaft with hose clamps, reposition them in equal amounts.

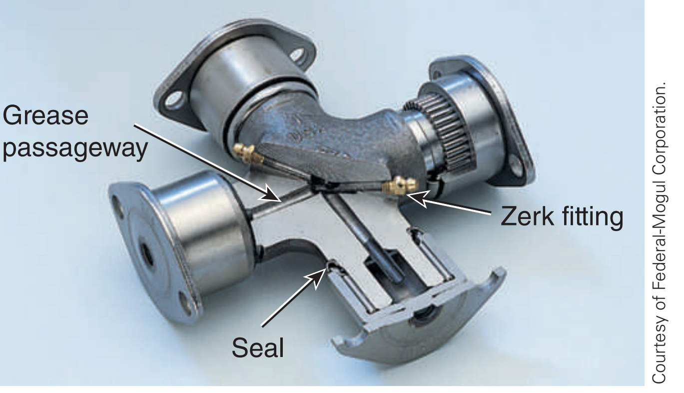


FIGURE 40-36 A zerk fitting is used to lubricate a U-joint.

However, most replacement U-joints are equipped with a **zerk** (grease) **fitting (Figure 40–36)** and should be lubricated on a regular basis.

Final Drives and Drive Axles

The final drive is a geared mechanism located between the driving axles of a vehicle. The differential, a critical part of the final drive unit, rotates the driving axles at different speeds when the vehicle is turning a corner **(Figure 40–37)**. It also allows both

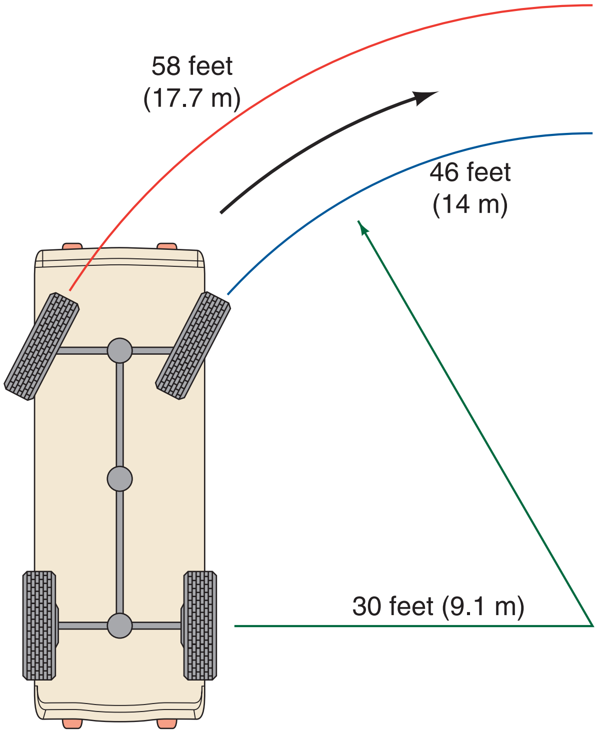


FIGURE 40-37 Travel of wheels when a vehicle is turning a corner.

axles to turn at the same speed when the vehicle is moving in a straight line. The drive axle assembly directs driveline torque to the vehicle's drive wheels. The gear ratio of the drive axle's ring and pinion gears is used to increase torque. The differential serves to establish a state of balance between the forces between the drive wheels and allows the drive wheels to turn at different speeds when the vehicle changes direction.

On a FWD vehicle, the final drive is normally an integral part of the transaxle assembly. Transaxle design and operation depends on whether the engine is mounted transversely or longitudinally. With a transversely mounted engine, the crankshaft centerline and drive axle are on the same plane. With a longitudinally mounted power plant, the differential must change the power flow 90 degrees.

On RWD vehicles, the final drive is located in the rear axle housing or carrier. The drive shaft connects the transmission with the rear axle gearing. Four-wheel drive vehicles have final drive units on both their front and rear axles.

The final drive unit redirects engine torque from the drive shaft to the rear drive axle shafts. The drive shaft turns in a motion perpendicular to the rotation of the drive wheels. The final drive gears redirect the torque so that the drive axle shafts turn in a motion parallel to the rotation of the drive wheels.

The final drive gears in the drive axle assembly are sized to provide a gear reduction, or a torque multiplication. Axles with a low (numerically high) gear ratio allow for fast acceleration and good pulling power. Axles with high gear ratios allow the engine to run slower at any given speed, resulting in better fuel conservation.

Components of Final Drives and Differentials

The components of commonly used final drive units are shown in **Figure 40–38**. There are several other basic design arrangements. However, the one most commonly used design has pinion/ring gears and a pinion shaft. In RWD vehicles the gearset is comprised of hypoid gears, whereas FWD units use a planetary gearset or spiral bevel gears. To create a clear picture of the major components of a differential assembly and their required service, RWD units are the focus of the following discussion.

The pinion shaft is mounted in the front of the carrier and is supported by two or three bearings. An overhung pinion gear is supported by two tapered bearings spaced far enough apart to provide the needed leverage to rotate the ring gear and drive axles **(Figure 40–39)**. A straddle-mounted pinion gear rests on three bearings: Two tapered bearings on the front support the input shaft and one roller bearing is fitted over a short shaft extending from the rear end of the drive **pinion gear**.

The pinion gear meshes with a **ring gear**. The ring gear is made of hardened steel. The ring gear is

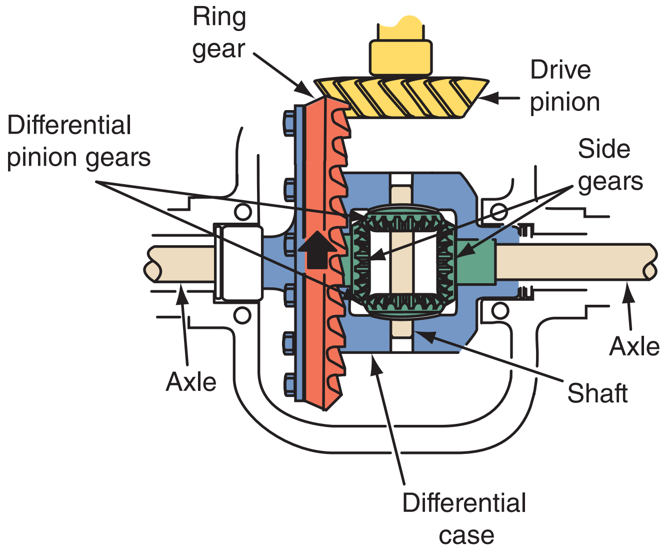


FIGURE 40–38 The components of a typical final drive unit.

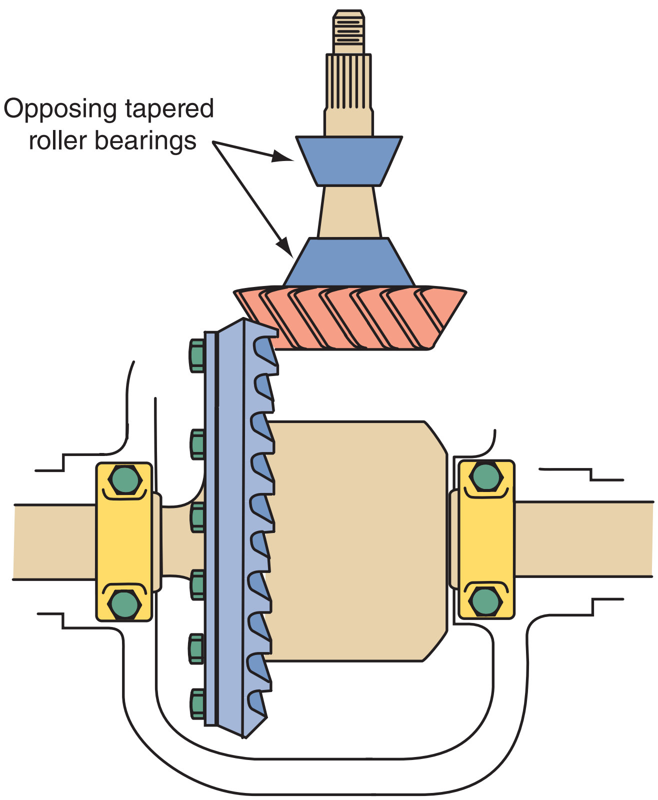


FIGURE 40–39 The pinion drive is supported by bearings.

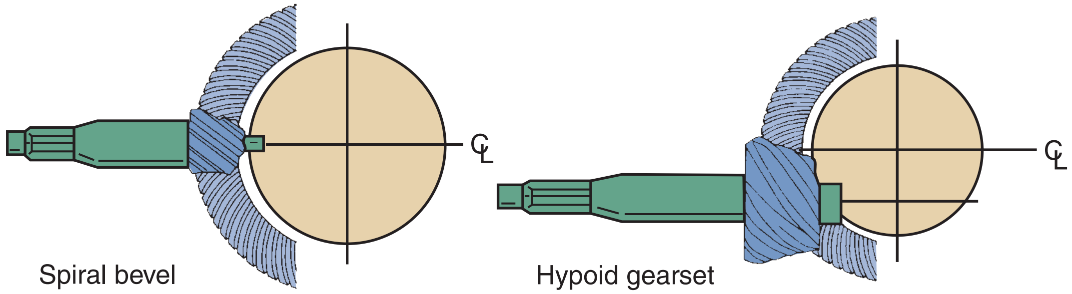


FIGURE 40–40 In a hypoid gearset, the drive pinion meshes with the ring gear at a point below its centerline.

bolted to the differential case. When the pinion gear is rotated by the drive shaft, the ring gear rotates and turns the differential case and axle shafts. Most applications have two pinion gears mounted on a straight shaft in the rear axle case. On heavier trucks, the rear axle contains four pinion gears mounted on a cross-shaped spider in the differential case. The pinion shafts are mounted in holes in the case (or in matching grooves in the case halves) and are secured by a lock bolt or retaining rings.

A final drive assembly also contains two side or axle gears. The inside bore of these gears is splined and mates with splines on the ends of the axles. The differential pinion gears and side gears are in constant mesh. The pinion gears are mounted on a pinion gear shaft, which is mounted in the differential casing. As the case turns with the ring gear, the pinion shaft and gears also turn. The pinion gears deliver torque to the side gears.

Hypoid Gear A **hypoid gear** contacts more than one tooth at a time. The hypoid gear also makes contact with a sliding motion. This sliding action provides smooth and quiet operation. With a hypoid gearset, the pinion gear is placed lower in the differential. The drive pinion meshes with the ring gear at a point below its centerline **(Figure 40–40)**, in contrast to a spiral bevel gearset.

The sliding effect of two hypoid gears meshing tends to wipe lubricant from the face of the gears, resulting in eventual damage. This is why differentials require the use of extreme pressure-type lubricants. The additives in this lubricant allow it to withstand the wiping action of the gear teeth without separating from the gear face.

Types of Final Drive Gearsets

Ring and pinion gearsets are normally classified as hunting, nonhunting, or partial nonhunting gears. These classifications are based on the number of teeth on the pinion and ring gears. Knowing the type of gearset is important when diagnosing and servicing final drive assemblies.

- *Hunting Gearset.* When one drive pinion gear tooth contacts every ring gear tooth after several revolutions, this is called a **hunting gearset**. A typical hunting gearset may have nine drive pinion teeth and thirty-seven ring gear teeth. The rear-axle ratio for this combination would be 4.11:1.
- *Nonhunting Gearset.* When one drive pinion gear tooth contacts only certain ring gear teeth, the gearset is a **nonhunting gearset**. A typical nonhunting gearset may have ten drive pinion teeth and thirty ring gear teeth. The rear-axle ratio for this combination would be 3.00:1. For every revolution of the ring gear, each drive pinion tooth would contact the same three teeth of the ring gear. The drive pinion gear teeth do not hunt out all ring gear teeth. Nonhunting gearsets have timing marks that must be aligned **(Figure 40–41)**. These marks allow the gearset to be placed in the same position as they were when the gears were lapped during the manufacturing process. Returning the gears to this position allows for quiet and durable operation.
- *Partial Nonhunting Gearset.* In a **partial nonhunting gearset** there is a specific number of ring gear

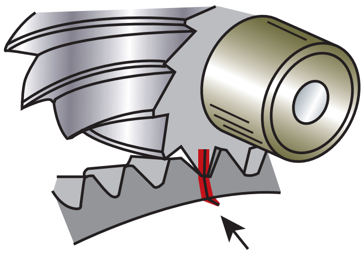


FIGURE 40–41 Index marks on a ring and pinion gearset.

teeth that are contacted. One drive pinion tooth contacts six ring gear teeth instead of three. During the first revolution of the ring gear, one drive pinion tooth contacts three ring gear teeth. During the second revolution of the ring gear, the drive pinion tooth contacts three different ring gear teeth. During every other ring gear revolution, one drive pinion tooth contacts the same ring gear teeth. A typical partial nonhunting gearset may have ten drive pinion teeth and thirty-five ring gear teeth. The rear-axle ratio for this combination would be 3.50:1. These gearsets also have timing marks that must be aligned during service.

Rear Axle Housing and Casing

The differential and final drive gears in a rear-wheel drive vehicle are housed in the rear axle housing, or carrier. The axle housing also contains the two drive axle shafts. There are two basic types of axle housings: the removable carrier and the integral carrier. The removable carrier axle housing is open on the front side. Because it resembles a banjo, it is often called a banjo housing. The backside of the housing is closed to seal out dirt and contaminants and keep in the lubricant. The gears are mounted in a carrier assembly that can be removed as a unit from the axle housing **(Figure 40–42)**. Removable carrier axle housings are most commonly used today on trucks and other heavy-duty vehicles.

The integral housing is most often found on cars and light trucks. A cast-iron carrier forms the center of the axle housing. Steel axle tubes are pressed into both sides of the carrier to form the housing.

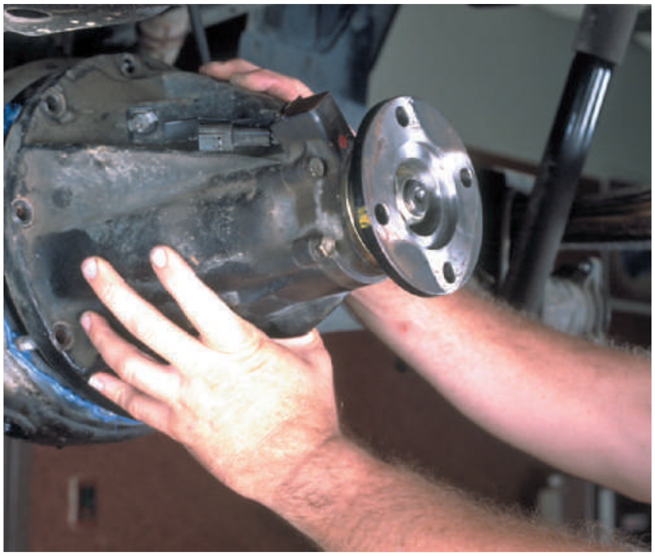


FIGURE 40–42 A typical removable-carrier axle housing.

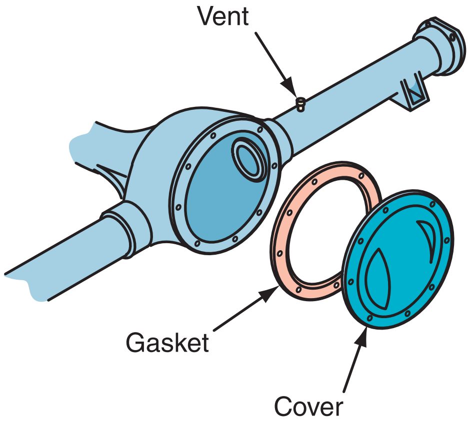


FIGURE 40–43 An integral rear axle housing.

The housing and carrier have a removable rear cover that allows access to the final drive assembly **(Figure 40–43)**. Because the carrier is not removable, the gear assemblies must be removed and serviced separately. For many operations, a case spreader must be used to remove the components. In addition to providing a mounting place for the differential, the axle housing also contains brackets for mounting suspension components such as control arms, leaf springs, and coil springs.

Some vehicles have an ABS speed sensor attached to the carrier housing for rear-wheel lockup prevention during braking.

Open Differential Operation

The amount of power delivered to each driving wheel by the differential is expressed as a percentage. When the vehicle moves straight ahead, each driving wheel rotates at 100 percent of the differential case speed. When the vehicle is turning, the inside wheel might be getting 90 percent of the differential case speed. At the same time, the outside wheel might be getting 110 percent of the differential case speed.

Power flow through the axle begins at the drive pinion yoke, or companion flange **(Figure 40–44)**. The companion flange accepts torque from the rear U-joint. The companion flange is attached to the drive pinion gear, which transfers torque to the ring gear. As the ring gear turns, it turns the differential case and the pinion shaft. The differential pinion gears transfer torque to the side gears to turn the driving axle shafts. The differential pinion gears determine how much torque goes to each driving axle, depending on the resistance an axle shaft or wheel has while turning. The pinion gears can move with the carrier, and they can rotate on the pinion shaft.

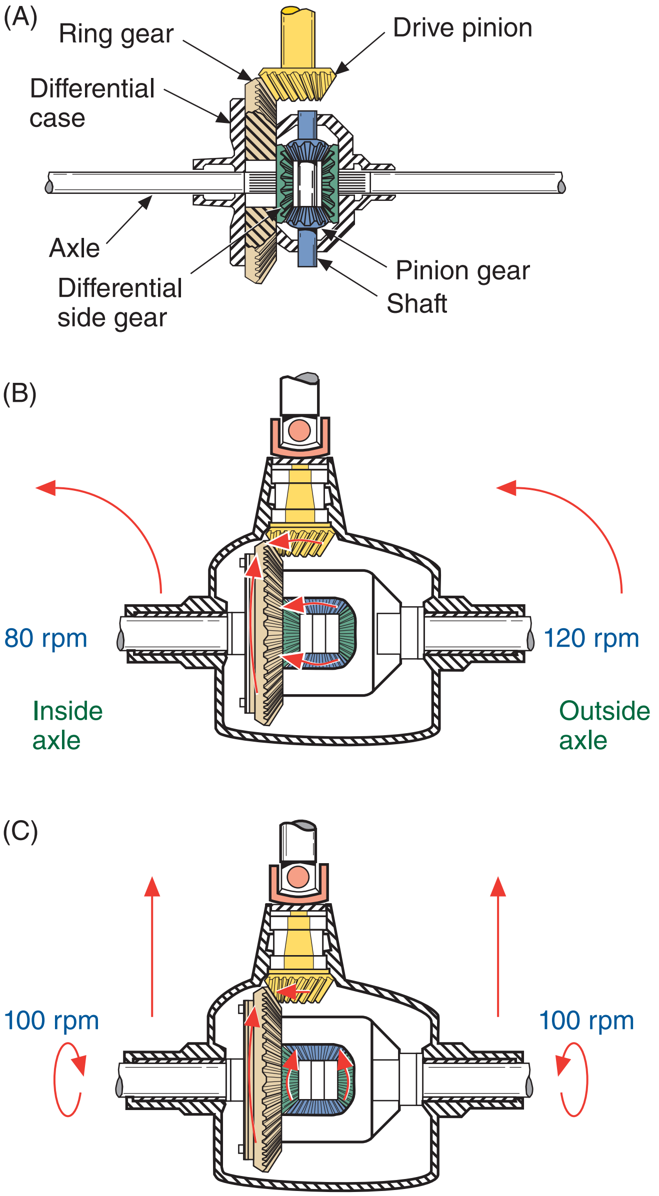


FIGURE 40-44 (A) Basic differential components; (B) differential action while the vehicle is turning left; (C) differential action while the vehicle is moving straight.

When drive shaft torque is applied to the input shaft and drive pinion, the shaft rotates in a direction that is perpendicular to the vehicle's drive axles. When this rotary motion is transferred to the ring gear, the torque flow changes direction and becomes parallel to the axle shafts and wheels. Because the ring gear is bolted to the differential case, the case must rotate with the ring gear. The pinion gear shaft mounted in the differential case must also rotate with the case and the ring gear. The pinions turn end over end. Gears do not rotate on the pinion shaft when both driving wheels are turning at the same speed. They rotate end over end as the differential case rotates. Because the pinions are meshed with both side gears, the side gears rotate and turn the axle shafts. The ring gear, differential gears, and axle shafts turn together without variation in speed as long as the vehicle is moving in a straight line.

When a vehicle turns into a curve or negotiates a turn, the wheels on the outside of the curve must travel a greater distance than the wheels on the inside of the curve. The outer wheels must then rotate faster than the inside wheels. This would be impossible if the axle shafts were locked solidly to the ring gear. However, the differential allows the outer wheels and axle shaft to increase in speed and the inner wheels and axle to slow down, thus preventing the skidding and rapid tire wear that would otherwise occur. The differential action also makes the vehicle much easier to control while turning.

For example, when a car makes a sharp right-hand turn, the left-side wheels, axle shaft, and side gear must rotate faster than the right-side wheels, axle shaft, and side gear. The left side of the axle must speed up and the right side must slow down. This is possible because the pinions to which the side gears are meshed are free to rotate on the pinion shaft. The increased speed of the left-side wheels causes the side gear to rotate faster than the differential case. This causes the pinions to rotate and walk around the slowing down side gear. As the pinions turn to allow the left-side gear to increase speed, a reverse action—known as a reverse walking effect—is produced on the right-side gear. It slows down an amount that is inversely proportional to the increase in the left-side gear.

Limited-Slip Differentials

Driveline torque is evenly divided between the two rear drive axle shafts by the differential. As long as the tires grip the road, providing a resistance to turning, the drivetrain forces the vehicle forward. When one tire encounters a slippery spot on the road, it loses traction, resistance to rotation drops, and the wheel begins to spin. Because resistance has dropped, the torque delivered to both drive wheels changes. The wheel with good traction is no longer driven. If the vehicle is stationary in this situation, only the wheel over the slippery spot rotates. When this is occurring, the differential case is driving the differential pinion gears around the stationary side gear.

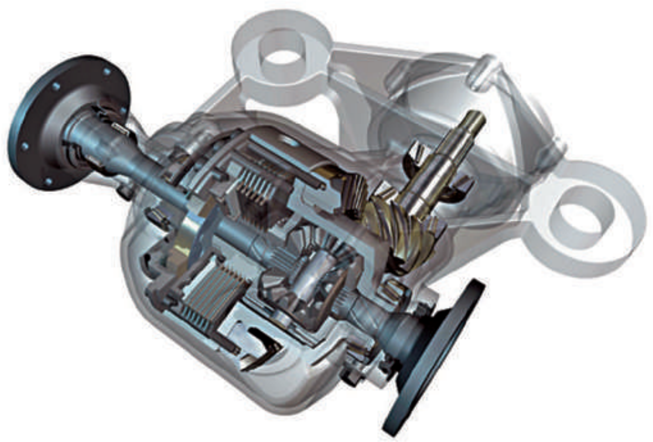
This situation places stress on the differential gears. When the wheel spins because of traction

loss, the speed of some of the differential gears increases greatly, while others remain idle. The amount of heat developed increases rapidly, the lube film breaks down, metal-to-metal contact occurs, and the parts are damaged. If spinout is allowed to continue long enough, the axle could break. The final drive or differential gears can also be damaged from prolonged spinning of one wheel. This is especially true if the spinning wheel suddenly has traction. The shock of the sudden traction can cause severe damage to the drive axle assembly.

To overcome these problems, differential manufacturers have developed the **limited-slip differential (LSD)**. LSDs are manufactured under such names as sure-grip, no-spin, positraction, or equal-lock. Some vehicles use a viscous clutch in their limited-slip drive axles. These units are predominantly used in 4WD vehicles and are discussed in Chapter 44. Also, many late-model vehicles use electronic controls, rather than gearing and clutches, to send torque to the best drive wheel.

Clutch-Based Units

Many LSDs use friction material to transfer the torque applied to a slipping wheel to the one with traction. Those that use a clutch pack **(Figure 40–45)** have two sets (one for each side gear) of clutch plates and friction discs to prevent normal differential action. The friction discs are steel plates with an abrasive coating on both sides. These discs fit over the external splines on the side gears' hub. The clutch plates are also made of steel but have no friction material bonded to them. The plates are placed between the friction discs and fit into internal splines in the differential case. Pressure is kept on the clutch packs by either an S-shaped spring or coil springs.



Courtesy of Dana Corporation.

FIGURE 40–45 A late-model LSD with friction clutches.

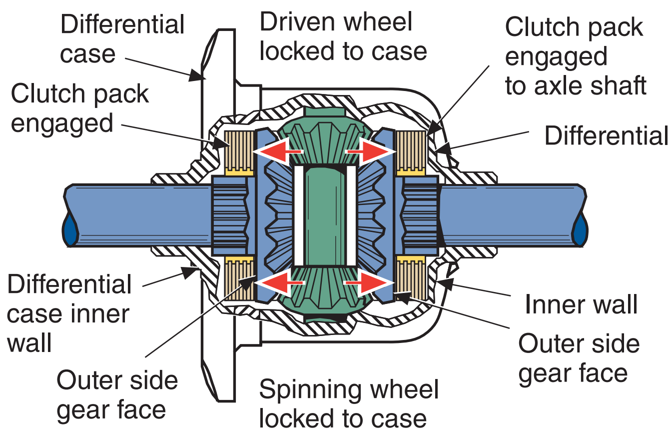


FIGURE 40–46 Action of the clutches in a limited-slip differential.

As long as the friction discs maintain their grip on the steel plates, the differential side gears are locked to the differential case **(Figure 40–46)**, allowing the case and drive axles to rotate at the same speed and preventing one wheel from spinning faster than the other.

A common LSD uses two cone-shaped parts to lock the side gears to the differential case. The cones are located between the side gears and the case and are splined to the side gear hubs. The exterior surface of the cones is coated with a friction material that grabs the inside surface of the case. Four to six coil springs mounted in thrust plates between the side gears maintain a preload on the cones. When the cones are forced against the case, the axles rotate with the differential case.

The clutch plates and cones are designed to slip when a predetermined amount of torque is applied to them, which allows the vehicle to have differential action when it is turning a corner.

Gear-Based Units

Manufacturers are using a wide range of LSD designs other than the typical clutch type. These designs were born out of the need to improve vehicle stability and tire traction. Many are gear-based and are often called torque-bias or torque-sensing (Torsen) units. The basis of these units is a parallel-axis helical gearset **(Figure 40–47)**. The Torsen differential multiplies the torque available from the wheel that is starting to spin or lose traction and sends it to the slower turning wheel with the better traction. This action is initiated by the resistance between the sets of gears in mesh.

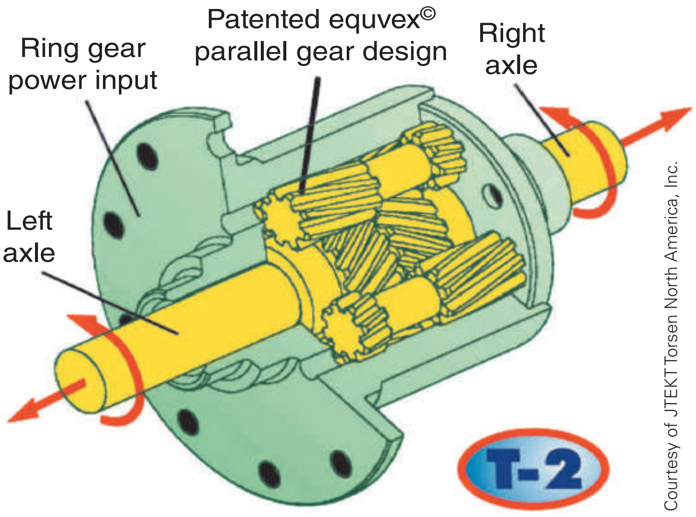


FIGURE 40–47 A Torsen torque-sensitive LSD.

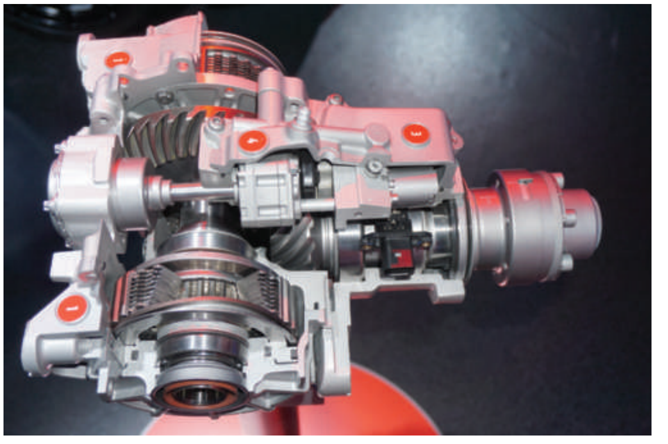


FIGURE 40–48 The Ford Focus torque-vectoring differential.

Helical-geared LSDs respond very quickly to changes in traction. They also do not bind in turns and do not lose their effectiveness with wear as clutch-based units can.

Electronic Torque Vectoring Units

To further increase the capabilities of limited-slip units, several manufacturers, including Ford, BMW, and Porsche, offer electronically controlled differentials. These combine both limited-slip operation and torque vectoring to increase the handling abilities of the car. Torque vectoring means that the amount of torque to each drive wheel can be controlled based on driving conditions. Two types of torque vectoring are currently in use, brake-based and electromechanical systems. Brake-based torque vectoring is discussed in Chapter 53.

Ford's RDU (rear-drive unit) system uses a set of computer controlled clutches that control the torque to each rear axle shaft **(Figure 40–48)**. Based on input from various speed sensors, the computer can vary the amount of clutch application based on driving conditions up to 100 times per second. During cornering, torque is sent to the outer rear wheel to improve turn-in and reduce understeer.

Other systems incorporate a planetary gearset and clutch for each wheel at the rear differential. Power from the differential flows through each clutch pack and into the planetary gearset. Locking the clutch allows the planetary to overdrive the wheel, increasing its speed in relation to the other wheel. This allows for faster corner exits as the rear end pushes the car through the turn more effectively than a standard limited-slip unit.

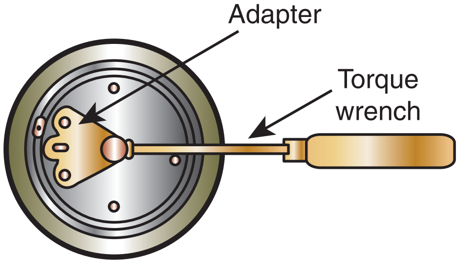


FIGURE 40–49 Checking the breakaway torque of a limited-slip differential.

Limited Slip Differential Diagnostics

A limited-slip differential can be checked for proper operation without removing the unit from the axle housing. Put the transmission in neutral and set one rear wheel on the floor with the other rear wheel raised off the floor. The vehicle's service information will give specifications for the required breakaway torque. Breakaway torque is the amount of torque required to start the rotation of the wheel that is raised off the floor. Breakaway torque is measured with a torque wrench **(Figure 40–49)**.

The initial breakaway torque reading may be higher than the torque required for continuous turning, but this is normal. The axle shaft should turn with even pressure throughout, without slipping or binding. If the torque reading is less than the specified amount, the differential needs to be checked.

Axle Shafts

The purpose of an axle shaft is to transfer driving torque from the differential assembly to the vehicle's driving wheels. There are two types of axles: dead, and live or drive. A **dead axle** does not drive a

vehicle. It merely supports the vehicle load and provides a mounting place for the wheels. The rear axle of a FWD vehicle is a dead axle, as are the axles used on trailers.

A **live axle** is one that drives the vehicle. Drive axles transfer torque from the differential to each driving wheel. Depending on the design, rear axles can also help carry the weight of the vehicle or even act as part of the suspension. Three types of driving axles are commonly used: semifloating, three-quarter floating, and full-floating. Today, three-quarter floating axles are rarely used in automotive or light-truck applications.

All three use axle shafts that are splined to the differential side gears. At the wheel ends, the axles can be attached in any one of a number of ways. This attachment defines the type of axle it is and the manner in which the shafts are supported by bearings.

Semifloating Axle Shafts

Semifloating axles help to support the weight of the vehicle. Most RWD vehicles have semifloating axles. The axles are supported by bearings located in the axle housing **(Figure 40–50)**. An axle shaft bearing supports the vehicle's weight and reduces rotational friction. The inner ends of the axle shafts are splined to the axle side gears. The axle shafts transmit only driving torque and are not acted on by other forces. Therefore, the axle shafts are said to be floating.

The driving wheels are bolted to the outer ends of the axle shafts. The outer axle bearings are located between the axle shaft and axle housing. This type of axle has a bearing pressed into the end of the axle housing. This bearing supports the axle shaft. The axle shaft is held in place with either a bearing retainer belted to a flange on the end of the axle housing or by a C-shaped washer that fits into grooves machined in the splined end of the shaft. A flange on the wheel end of the shaft is used to attach the wheel.

When semifloating axles are used to drive the vehicle, the axle shafts push on the shaft bearings as they rotate. This places a driving force on the axle housing, springs, and vehicle chassis, moving the vehicle forward. The axle shaft faces the bending stresses associated with turning corners and curves, skidding, and bent or wobbling wheels, as well as the weight of the vehicle. In the semifloating axle arrangement with a C-shaped washer-type retainer, if the axle shaft breaks, the driving wheel comes away from or out of the axle housing.

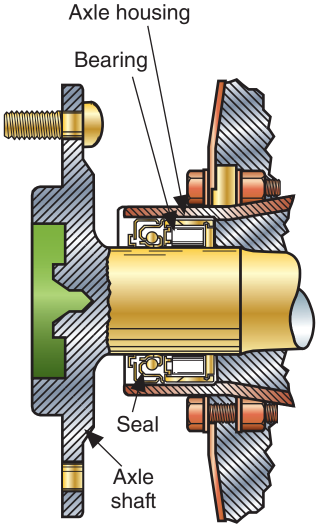


FIGURE 40–50 A semi-floating rear axle.

Full-Floating Axle Shafts

Most medium- and heavy-duty vehicles use a **full-floating axle shaft**. This design uses two bearings to support the wheel hub **(Figure 40–51)**. These are slid over the outside of the axle housing and carry all of the stresses caused by torque loading and turning. The wheel hubs are bolted to flanges on the outer end of each axle shaft.

In operation, the axle shaft transmits only the driving torque. The driving torque from the axle shaft rotates the axle flange, wheel hub, and rear driving wheel. The wheel hub forces its bearings against the axle housing to move the vehicle. The stresses caused by turning, skidding, and bent or wobbling wheels are taken by the axle housing through the wheel bearings. If a full-floating axle shaft should break, it can be removed from the axle housing. Because the rear wheels rotate around the rear axle housing, the disabled vehicle can be towed to a service area for replacement of the axle shaft.

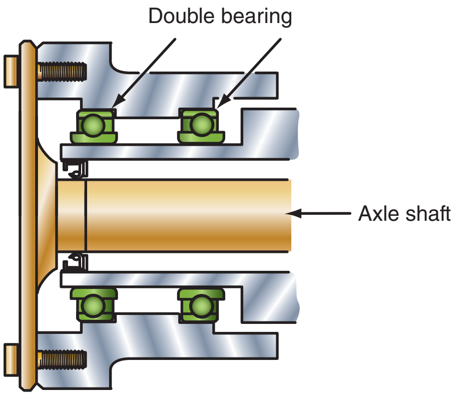


FIGURE 40–51 A full-floating rear axle.

Independently Suspended Axles

In an independently suspended axle system, the driving axles are usually open instead of being enclosed in an axle housing. The two most common suspended rear driving axles are the DeDion axle system and the swing axle system.

The DeDion axle system resembles a normal driveline. The driving axles look like a drive shaft with U-joints at each end of the axles. A slip joint is attached to the innermost U-joint. The outboard U-joint is connected to the wheel hub, which allows the driving axle to move up and down as it rotates.

On vehicles that use a swing axle, the driving axle shafts can be open or enclosed. An axle fits into the differential by way of a ball-and-socket system. The ball-and-socket system allows the axle to pivot up and down. As the axle pivots, the driving wheel swings up and down. This system best describes the drive axles of a FWD vehicle.

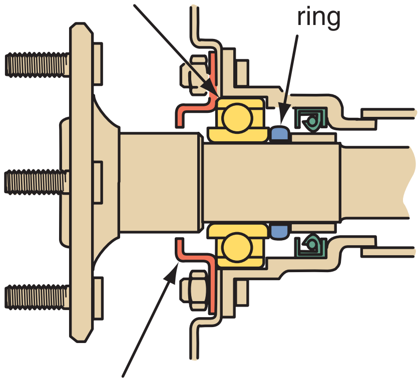


FIGURE 40-52 The location of an axle bearing retainer plate.

Axle Shaft Bearings

The axle shaft bearing supports the vehicle's weight and reduces rotational friction. In an axle mount, radial and thrust loads are always present on the axle shaft bearing when the vehicle is moving. Radial bearing loads act at 90 degrees to the axle shaft's center of axis. **Radial loading** is always present whether or not the vehicle is moving.

Thrust loading acts on the axle bearing parallel with the center of axis. It is present on the driving wheels, axle shafts, and axle bearings when the vehicle turns corners or curves.

There are three designs of axle shaft bearings used in semifloating axles: ball-type bearing, straight roller bearing, and tapered roller bearing.

The bearing load of primary concern is axle shaft end thrust. When a vehicle moves around a corner, centrifugal force acts on the vehicle body, causing it to lean to the outside of the curve. The vehicle's chassis does not lean because of the tires' contact with the road's surface. As the body leans outward, a thrust load is placed on the axle shaft and axle bearing. Each type of axle shaft bearing handles end thrust differently.

Normally, the way the axles are held in the housing is quite obvious after the rear wheels and brake assemblies have been removed. If the axle shaft is held in by a retainer and three or four bolts, it is not necessary to remove the differential cover to remove the axle. Most ball and tapered roller bearing supported axle shafts are retained in this manner **(Figure 40–52)**. To remove the axle, remove the bolts that hold the retainer to the backing plate, then pull the axle out. Normally, the axle shaft slides out without the aid of a puller. Sometimes a puller is required.

A straight-roller bearing supported axle shaft does not use a retainer to secure it. Rather, a C-shaped washer is used to retain the axle shaft **(Figure 40–53)**. This C-shaped washer is located inside the differential, and the differential cover must be removed to gain access to it. To remove this type of axle, first remove the wheel, brake drum, and differential cover. Then remove the differential pinion shaft retaining bolt and differential pinion shaft. Now push the axle shaft

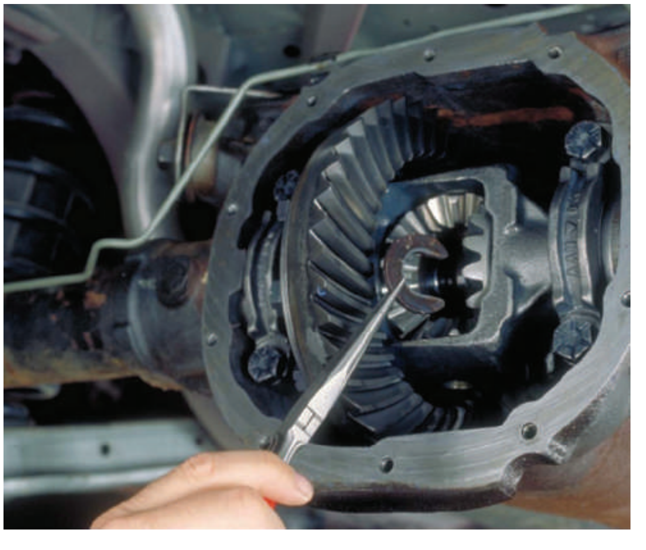


FIGURE 40-53 To remove the axle shafts from the differential in an integral housing, a C-lock must normally be removed.

in and remove the C-shaped washer. The axle can now be pulled out of the housing.

Ball bearings are lubricated with grease packed in the bearing at the factory. An inner seal, designed to keep the gear oil from the bearing, rides on the axle shaft just in front of the retaining ring. This type of bearing also has an outer seal to prevent grease from spraying onto the rear brakes. Ball-type axle bearings are pressed on and off the axle shaft. The retainer ring is made of soft metal and is pressed onto the shaft against the wheel bearing. Never use a torch to remove the ring. Rather, drill into it or notch it in several places with a cold chisel to break the seal **(Figure 40–54)**. The ring can then be slid off the shaft easily. Heat should not be used to remove the ring because it can take the temper out of the shaft and thereby weaken it. Likewise, a torch should never be used to remove a bearing from an axle shaft.

Roller axle bearings are lubricated by the gear oil in the axle housing. Therefore, only a seal to protect the brakes is necessary with these bearings. These bearings are typically pressed into the axle housing and not onto the axle. To remove them, the axle must first be removed and then the bearing pulled out of the housing. With the axle out, inspect the area where it rides on the bearing for pits or scores. If pits or score marks are present, replace the axle.

Tapered-roller axle bearings are not lubricated by gear oil. They are sealed and lubricated with wheel grease. This type of bearing uses two seals and must be pressed on and off the axle shaft using a press. After the bearing is pressed onto the shaft, it must be packed with wheel bearing grease. After packing the bearing, install the axle in the housing. Shaft end play must be checked. Use a dial indicator and adjust the end play to specifications. If the end play is not within specifications, change the size of the bearing shim.

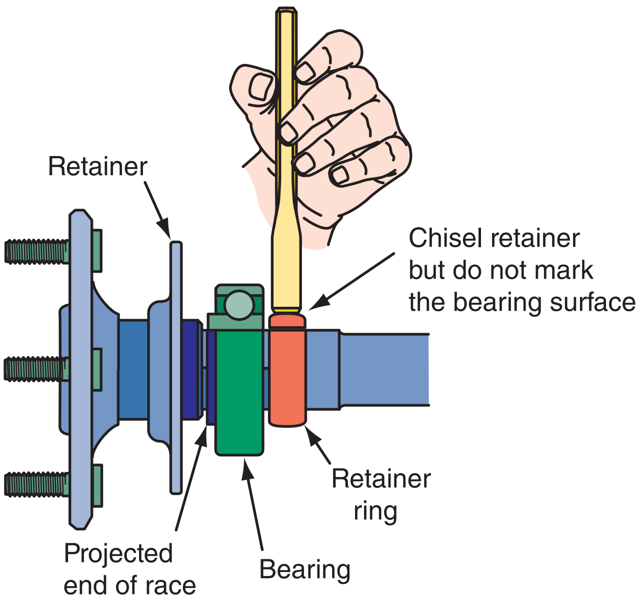


FIGURE 40–54 Freeing the retainer ring from an axle shaft.

USING SERVICE INFORMATION

The driveline can create some especially difficult diagnostic problems. The driveline easily picks up vibrations and noises from other parts of the vehicle. A test drive is the best way to begin diagnosis. Most service information contains a checklist that helps with identifying the cause of a noise or vibration.

The installation of new axle shaft seals is recommended whenever the axle shafts have been removed. Some axle seals are identified as being either right or left side. When installing new seals, make sure to install the correct seal in each side. Check the seals or markings of right or left, or for color coding.

Wheel Studs

Whenever the wheels are removed, the wheel studs should be inspected for damage. If damage is evident, the stud(s) should be replaced. The studs are typically damaged when the wheel lugs are under or over torque or were damaged when the lug nuts cross threaded the stud when they were installed.

To replace a stud, the old one needs to be pressed out of the hub. The new stud must be pressed into the hub. This is easily done with a hydraulic press when the axle shaft has been removed from the housing. However, it can also be done with the axle in place. This is accomplished by placing strong washers over the stud after it has been inserted into its bore. Then the lug nut is attached to the stud, flat side down, and tightened. Tightening the lug nut will pull and seat the stud into its bore. Make sure the head of the stud is fully seated in the flange or hub.

Servicing the Final Drive Assembly

Before removing a final drive unit for service, make sure it needs to be serviced. Typically, problems with the differential and drive axles are first noticed as a leak or noise. As the problem worsens, vibrations or a clunking noise might be felt during certain operating

conditions. Diagnosis of the problem should begin with a road test in which the vehicle is taken through the different modes of operation.

Disassembly

Although FWD axle final drive units are normally an integral part of the transaxle, most of the procedures for servicing RWD units apply to them. To service a final drive assembly in removable carrier housing, the unit must be removed from the housing. Units in integral carriers are serviced in the housing.

A highly important step in the procedure for disassembling any final drive unit is a careful inspection of each part as it is removed. The bearings should be looked at and felt to determine if there are any defects or evidence of damage.

After the ring and pinion gears have been inspected and before they have been removed from the assembly, check the side play. Using a screwdriver, attempt to move the differential case assembly laterally. Any movement is evidence of side play. Side play normally indicates that as the result of loose bearing cones on the differential case hubs, the differential case must be replaced.

Prior to disassembling the assembly, measure the runout of the ring gear. Excessive runout can be caused by a warped gear, worn differential side bearings, warped differential case, or particles trapped between the gear and case. Runout is checked with a dial indicator mounted on the carrier assembly. The plunger on the indicator should be set at a right angle to the gear. With the dial indicator in position and its dial set to zero, rotate the ring gear and note the highest and lowest readings. The difference between these two readings indicates the total runout of the ring gear. Normally, the maximum permissible runout is 0.003 to 0.004 inches (0.0762 to 0.1016 mm).

To determine if the runout is caused by a damaged differential case, remove the ring gear and measure the runout of the ring gear mounting surface on the differential case. Runout should not exceed 0.004 inch (0.1016 mm). If runout is greater than that, the case should be replaced. If the runout was within specifications, the ring gear is probably warped and should be replaced. A ring gear is never replaced without replacing its mating pinion gear.

Some ring gear assemblies have an excitor ring, used in antilock brake systems. This ring is normally pressed onto the ring gear hub and can be removed after the ring gear is removed. If the ring gear assembly is equipped with an excitor ring, carefully inspect it and replace it if it is damaged.

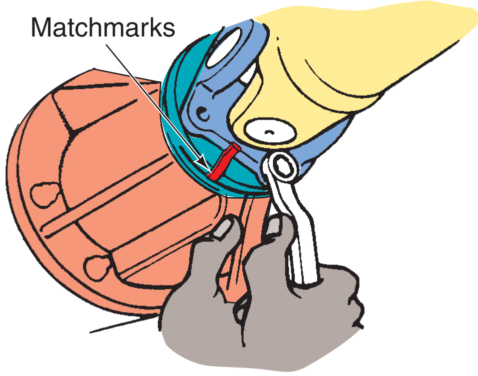


FIGURE 40–55 Make sure to index the rear yoke to the companion flange before removing the drive shaft.

Prior to disassembling the unit, the drive shaft must be removed. Before disconnecting it from the pinion's companion flange, locate the shaft-to-pinion alignment marks. If they are not evident, make new ones **(Figure 40–55)**. This avoids assembling the unit with the wrong index, which can result in driveline vibration.

During disassembly, keep the right and left shims, cups, and caps separated. If any of these parts are reused, they must be installed on the same side as they were originally located.

Assembly

When installing a ring gear onto the differential case, make sure the bolt holes are aligned before pressing the gear in place. While pressing the gear, pressure should be evenly applied to the gear. Likewise, when tightening the bolts, always tighten them in steps and to the specified torque. These steps reduce the chances of distorting the gear.

Examine the gears to locate any timing marks on the gearset that indicate where the gears were lapped by the manufacturer. Normally, one tooth of pinion gear is grooved and painted, while the ring gear has a notch between two painted teeth. If the paint marks are not evident, locate the notches. Proper timing of the gears is set by placing the grooved pinion tooth between the two marked ring gear teeth. Some gearsets have no timing marks. These gears are hunting gears and do not need to be timed. Nonhunting and partial nonhunting gears must be timed.

Whenever the ring and pinion gears or the pinion or differential case bearings are replaced, pinion gear depth, pinion bearing preload, and the ring and pinion gear tooth patterns and backlash must be checked and adjusted. This holds true for all types

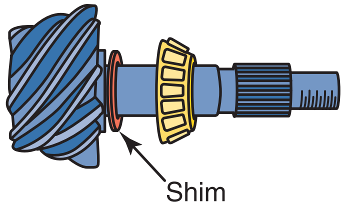


FIGURE 40–56 The typical placement of a pinion gear depth shim.

of differentials except most FWD differentials that use helical-cut gears, and taking tooth patterns is not necessary. Nearly all other final drive units use hypoid gears that must be properly adjusted to ensure a quiet operation.

Pinion gear depth is adjusted with shims placed behind the pinion bearing **(Figure 40–56)** or in the housing. The thickness of the drive pinion rear bearing shim controls the depth of the mesh between the pinion and ring gear. To determine and set pinion depth, a special tool is normally used to select the proper pinion shim **(Figure 40–57)**. Always follow the procedures in the service information when setting up the tool and determining the proper shim.

Pinion bearing **preload** is set by tightening the pinion nut until the desired number of inch-pounds is required to turn the shaft. Tightening the nut crushes the collapsible pinion spacer, which maintains the desired preload. Never overtighten and then loosen the pinion nut to reach the desired torque reading. Tightening and loosening the pinion nut damages the collapsible spacer. It must then be replaced. For the exact procedures and specifications for bearing preload, refer to the service information. Incorrect bearing preload can cause

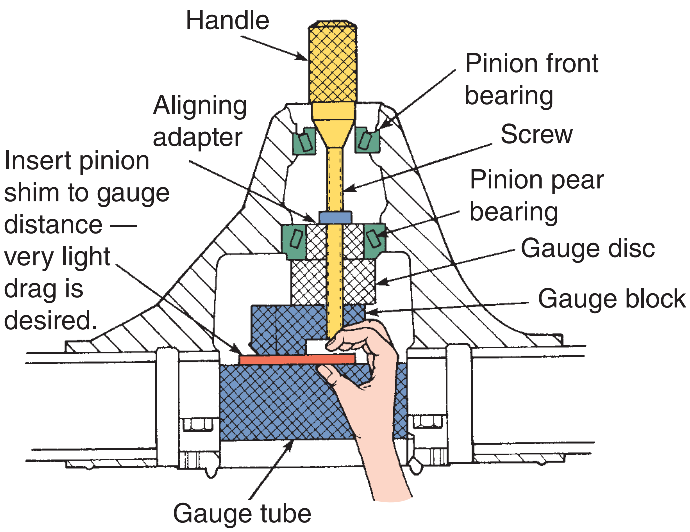


FIGURE 40–57 The special tools used to measure pinion gear depth.

differential noise. Some cases use shims to set pinion bearing preload.

It is recommended that a new pinion seal be installed whenever the pinion shaft is removed from the differential. To install a new seal, thoroughly lubricate it and press it in place with an appropriate seal driver.

Backlash of the gearset is adjusted at the same time as the side-bearing preload. Side-bearing preload limits the amount the differential is able to move laterally in the axle housing. Adjusting backlash sets the depth of the mesh between the ring and pinion gear teeth. Both of these are adjusted by shim thickness or by the adjustments made by the side-bearing adjusting nuts. Photo Sequence 35 goes through the typical procedure for measuring and adjusting backlash and side-bearing preload on a gearset that uses shims for adjustment. Photo Sequence 36 covers the same steps for a unit that has adjusting nuts.

A typical procedure for measuring and adjusting backlash and preload involves rocking the ring gear and measuring its movement with a dial indicator. Compare measured backlash with the specifications. Make the necessary adjustments. Then recheck the backlash at four points equally spaced around the ring gear. Normally, backlash should be less than 0.004 inch (0.1016 mm).

The pattern of gear teeth determines how quietly two meshed gears run. The pattern also describes where on the faces of the teeth the two gears mesh. The pattern should be checked during teardown for gear noise diagnosis, after adjusting backlash and side-bearing preload, or after replacing the drive pinion and setting up the pinion bearing preload. The terms commonly used to describe the possible patterns on a ring gear and the necessary corrections are shown in **Figure 40–58**.

To check the gear tooth pattern, paint several ring gear teeth with nondrying Prussian blue, ferric oxide, or red or white lead marking compound **(Figure 40–59)**. White marking compound is preferred by many technicians because it tends to be more visible than the others are. Use the pinion gear yoke or companion flange to rotate the ring gear. This will preload the ring gear while it is rotating and will simulate vehicle load. Rotate the ring gear so the painted teeth contact the pinion gear. Move it in both directions enough to get a clearly defined pattern. Examine the pattern on the ring gear and make the necessary corrections.

Most new gearsets purchased today come with a pattern pre-rolled on the teeth. This pattern provides the quietest operation for that gearset. Never wipe this pattern off or cover it up. When checking the

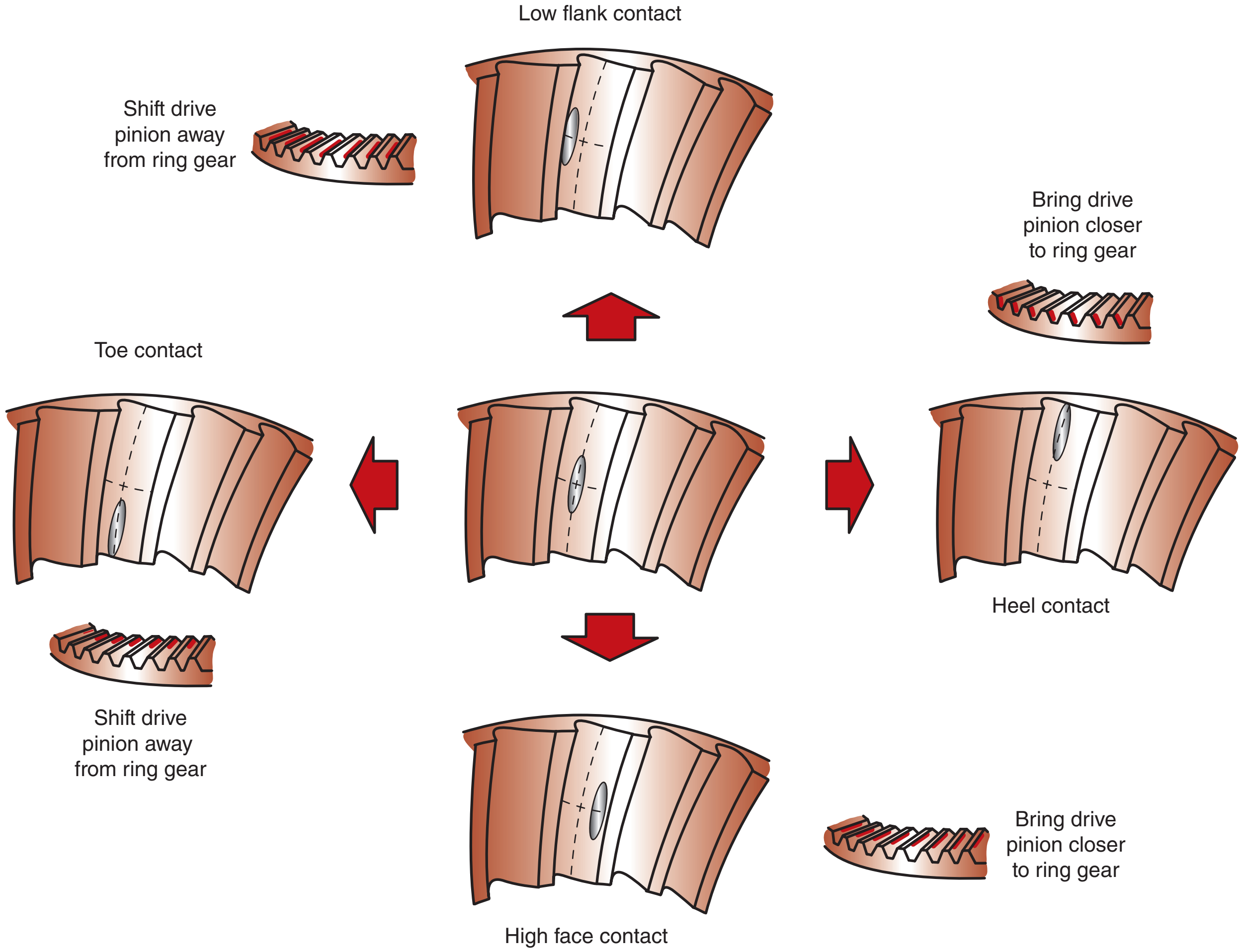


FIGURE 40–58 Commonly used terms for describing the possible patterns on a ring gear with the recommended corrections.

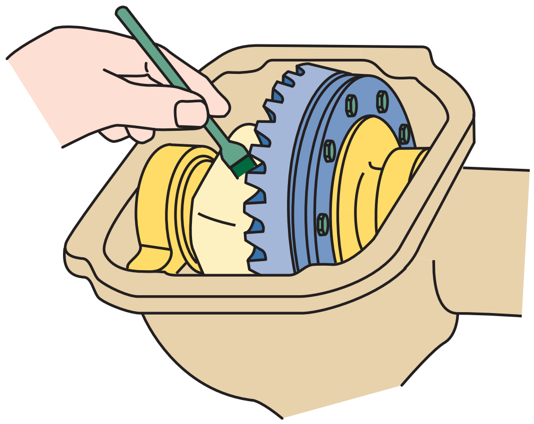


FIGURE 40–59 To check gear tooth patterns, several teeth of the ring gear are coated with a marking compound and the pinion gear is rotated with the ring gear. The resultant pattern shown on the teeth determines how the gearset ought to be adjusted.

pattern on a new gearset, only coat half of the ring gear with the marking compound and compare the pattern with the pre-rolled pattern.

Maintenance

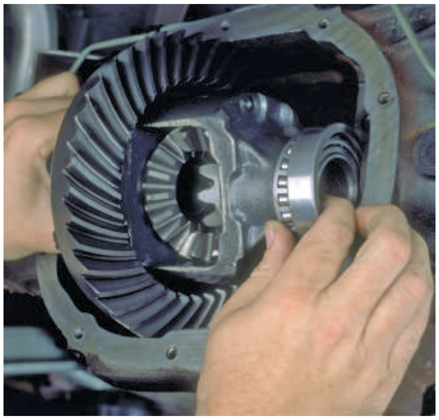
Maintenance includes inspecting the level of and changing the gear lubricant and lubricating the U-joints if they are equipped with zerk or grease fittings. Most modern U-joints are of the extended life design, meaning they are sealed and require no periodic lubrication. However, it is wise to inspect the joints for hidden grease plugs or fittings.

Proper lubrication is necessary for drive axle durability. Different applications require different gear lubes. The American Petroleum Institute (API) has established a rating system for the various gear lubes available. In general, rear axles use either SAE 80- or 90-weight gear oil for lubrication, meeting API GL-4 or GL-5 specifications. With limited-slip axles, it is very important that the proper gear lube be used. Most often, a special friction modifier fluid should be added to the fluid. If the wrong lubricant is used, damage to the clutch packs and grabbing or chattering on turns will result. If this condition exists, try draining the oil and refilling with the proper gear lube before servicing it.

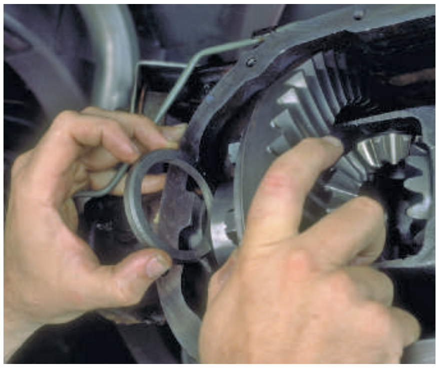
PHOTO SEQUENCE 35

Measuring and Adjusting Backlash and Side-Bearing Preload on a Final Drive Assembly with a Shim Pack

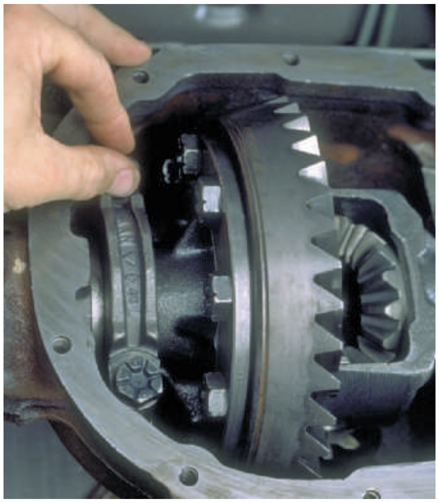
P35-1 Measure the thickness of the original side bearing preload shims.



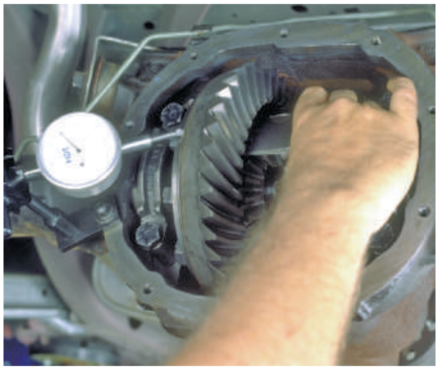
P35-2 Install the differential case into the housing.



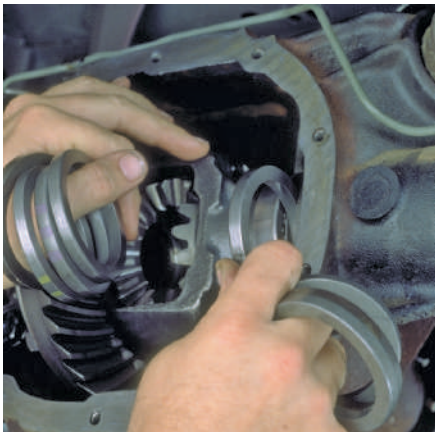
P35-3 Install service spacers that are the same thickness as the original preload shims between each bearing cup and the housing.



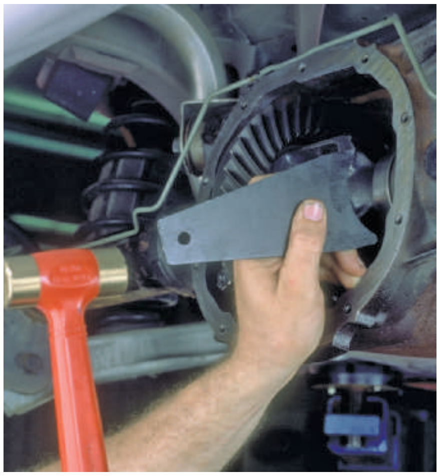
P35-4 Install the bearing caps and finger tighten the bolts.



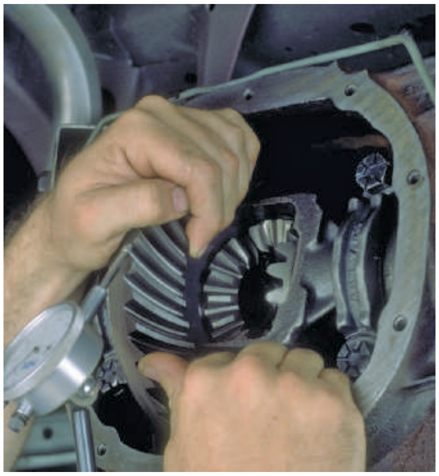
P35-5 Mount a dial indicator to the housing so that the button of the indicator touches the face of the ring gear. Using two screwdrivers, pry between the shims and the housing. Pry to one side and set the dial indicator to zero, then pry to the opposite side and record the reading.



P35-6 Select two shims with a combined thickness to that of the original shims plus the indicator reading, then install them.



P35-7 Using the proper tool, drive the shims into position until they are fully seated.



P35-8 Install and tighten the bearing caps to specifications.

P35-9 Check the backlash and preload of the gearset. Check the backlash by holding the input pinion, rocking the ring gear, and noting the movement on the dial indicator. Adjust the shim pack to allow for the specified backlash. Recheck the backlash at four points equally spaced around the ring gear.

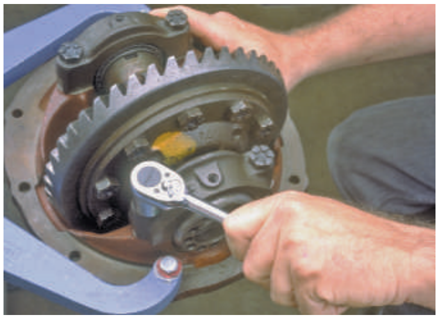
PHOTO SEQUENCE 36

Measuring and Adjusting Backlash and Side-Bearing Preload on a Final Drive Assembly with Adjusting Nuts

P36-1 Lubricate the differential bearings, cups, and adjusters.

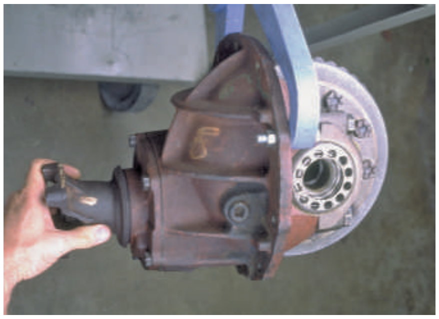
P36-2 Install the differential case into the housing.

P36-3 Install the bearing cups and adjusting nuts onto the differential case.

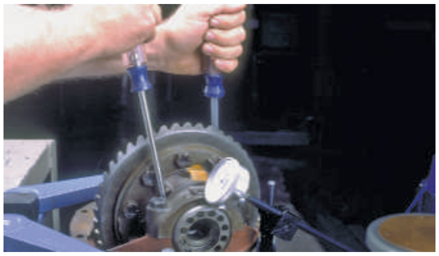


P36-4 Snugly tighten the top bearing cup bolts and finger tighten the lower bolts.

P36-5 Turn each adjuster until bearing free play is eliminated with little or no backlash present between the ring and pinion gears.

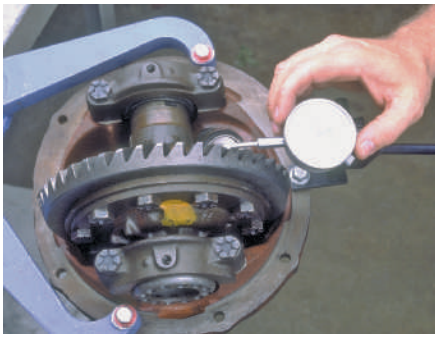


P36-6 Seat the bearings by rotating the pinion several times each time the adjusters are moved.

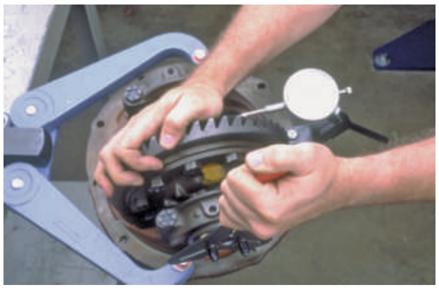


P36-7 Install a dial indicator and position the plunger against the drive side of the ring gear. Set the dial to zero. Using two screwdrivers, pry between the differential case and the housing. Observe the reading.

P36-8 Determine how much the preload needs to be adjusted and set the preload by turning the right adjusting nut.

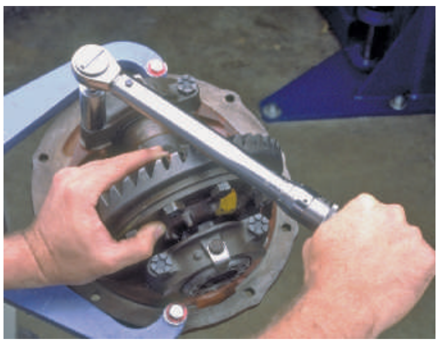


P36-9 Check the backlash by rocking the ring gear and noting the movement on the dial indicator.



P36-10 Adjust the backlash by turning both adjusting nuts in equal amounts so that the preload adjustment remains unchanged.

P36-11 Install the locks on the adjusting nuts.



P36-12 Tighten the bearing cap bolts to the specified torque.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2004	**Make:** Dodge	**Model:** Ram 1500 4WD	**Mileage:** 141,895	**RO:** 15890
Concern:	Customer says loud noises are heard from left front wheel area.			
History:	Left front axle was recently replaced by customer.			
After confirming the complaint, the technician inspects the driveline, wheel bearings, and front drive axles.				
Cause:	Found left front axle detached from differential.			
Correction:	Replaced left front drive axle with correct remanufactured unit. Noise no longer present.			

KEY TERMS

Cross groove joint
Dead axle
Double-offset joint
Fixed joint
Full-floating axle shaft
Hunting gearset
Hypoid gear
Inboard joint
Limited-slip differential (LSD)
Live axle
Nonhunting gearset
Outboard joint
Partial nonhunting gearset
Pinion gear
Plunge joint
Preload
Radial loading
Ring gear
Rzeppa joint
Semifloating axle
Slip yoke
Thrust loading
Tripod-type joint
Zerk fitting

SUMMARY

- FWD axles generally transfer engine torque from the transaxle to the front wheels.
- Constant velocity (CV) joints provide the necessary transfer of uniform torque and a constant speed while operating through a wide range of angles.
- In FWD drivetrains, two CV joints are used on each half shaft. The different types of joints can be referred to by position (inboard or outboard), by function (fixed or plunge), or by design (ball-type or tripod).
- FWD half shafts can be solid or tubular, of equal or unequal length, and with or without damper weights.
- Most problems with FWD systems are noted by noise and vibration.
- Lubricant is the most important key to a long life for the CV joint.
- A U-joint is a flexible coupling located at each end of the drive shaft between the transmission and the pinion flange on the drive axle assembly.
- A U-joint allows two rotating shafts to operate at a slight angle to each other; this is important to RWD vehicles.
- A failed U-joint or damaged drive shaft can exhibit a variety of symptoms. A clunk that is heard when the transmission is shifted into gear is the most obvious. You can also encounter unusual noise, roughness, or vibrations.
- A differential is a geared mechanism located between the driving axle shafts of a vehicle. Its job is to direct power flow to the driving axle shafts. Differentials are used in all types of power trains.
- The differential performs several functions. It allows the drive wheels to rotate at different speeds when negotiating a turn or curve in the road, and the differential drive gears redirect the engine torque from the drive shaft to the rear-drive axles.
- The final drive and differential of a RWD vehicle is housed in the axle housing, or carrier housing.
- The purpose of the axle shaft is to transfer driving torque from the differential and final drive assembly to the vehicle's driving wheels.
- There are two types of driving axle shafts commonly used: semifloating, and full-floating.
- Axle shaft bearings may support the vehicle's weight but always reduce rotational friction.

- Problems with the differential and drive axle shafts are usually first noticed as a leak or noise. As the problem progresses, vibrations or a clunking noise might be felt in various modes of operation.

REVIEW QUESTIONS

Short Answer

1. Name the three ways in which CV joints can be classified.
2. What type of axle housing resembles a banjo?
3. What type of axle merely supports the vehicle load and provides a mounting place for the wheels?
4. What type of floating axle has one wheel bearing per wheel on the outside of the axle housing?
5. How are problems normally first noticed with the differential and drive axles?

Multiple Choice

1. In front-wheel drivetrains, the CV joint nearer the transaxle is the ___.
   a. inner joint
   c. outboard joint
   b. inboard joint
   d. both a and b
2. A CV joint that is capable of in-and-out movement is a ___.
   a. plunge joint
   c. inboard joint
   b. fixed joint
   d. both a and c
3. The double-offset CV joint is typically used in applications that require ___.
   a. higher operating angles and greater plunge depth
   b. lower operating angles and lower plunge depth
   c. higher operating angles and lower plunge depth
   d. lower operating angles and greater plunge depth
4. Which type of joint has a flatter design than any other?
   a. Double-offset
   c. Cross groove
   b. Disc
   d. Fixed tripod
5. Which of these is the best way to determine which CV joint is faulty?
   a. Squeeze test
   b. Runout test
   c. Visual inspection
   d. Road test
6. The single Cardan/Spicer universal joint is also known as the ___.
   a. cross joint
   b. four-point joint
   c. both a and b
   d. neither a nor b
7. The drive shaft component that provides a means of connecting two or more shafts together is the ___.
   a. pinion flange
   b. U-joint
   c. yoke
   d. biscuit
8. Large cars with long drive shafts often use a double-U-joint arrangement called a ___.
   a. Spicer style U-joint
   b. constant velocity U-joint
   c. Cleveland style U-joint
   d. none of the above
9. Which type of driving axle supports the weight of the vehicle?
   a. Semifloating
   b. Three-quarter floating
   c. Full-floating
   d. None of the above
10. Which of the following describes the double-Cardan universal joint?
    a. It is most often installed in front-engine rear-wheel-drive luxury automobiles.
    b. It is classified as a constant velocity U-joint.
    c. A centering ball socket is inside the coupling yoke between the two universal joints.
    d. All of the above.

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that a gear tooth pattern identifies excessive ring gear runout. Technician B says that gear patterns are not accurate if there is excessive ring gear runout. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

2. Technician A says that limited-slip differential clutch packs are designed to slip when the vehicle turns a corner. Technician B says that a special additive is placed in the hypoid gear lubricant to promote clutch pack slippage on corners. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. Technician A says that side-bearing preload limits the amount the differential case is able to move laterally in the axle housing. Technician B says that adjusting backlash sets the depth of the mesh between the ring and pinion gears' teeth. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. Technician A says that a hunting gearset is one in which one drive pinion gear tooth contacts only certain ring gear teeth. Technician B says that a partial nonhunting gearset is one in which one pinion tooth contacts only six ring gear teeth. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. While discussing the possible causes for a clunking noise during acceleration: Technician A says that an outer CV joint could be the cause. Technician B says that runout in the drive axle may be the cause of the problem. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. While diagnosing the cause of a clicking noise that is heard only when the car is turning: Technician A says that the most probable cause is a worn wheel bearing. Technician B says that the most probable cause is a worn outboard CV joint. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. Technician A says that some axle shafts are retained in the housing by a plate and bolts. Technician B says that a C washer or clip retains some axle shafts in the housing. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. Technician A says that when a car is moving straight ahead, all differential gears rotate as a unit. Technician B says that when a car is turning a corner, the inside differential side gear rotates slowly on the pinion, causing the outside side gear to rotate faster. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. While discussing different types of ring and pinion gearsets: Technician A says that with a nonhunting gearset, each tooth of the pinion will return to the same tooth space on the ring gear each time the pinion rotates. Technician B says that when a hunting gearset rotates, any pinion gear tooth is likely to contact each and every tooth on the ring gear. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. While reviewing the procedure for setting backlash: Technician A says that backlash is adjusted along with side-bearing preload by loosening or tightening side-bearing adjusting nuts. Technician B says that normally, to decrease the amount of backlash, a thin shim is installed on one side of the gear and a thick one on the other side. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

SECTION 6

AUTOMATIC TRANSMISSIONS AND TRANSAXLES

CHAPTER 41

AUTOMATIC TRANSMISSIONS AND TRANSAXLES

Many rear-wheel drive (RWD) and four-wheel drive vehicles are equipped with automatic transmissions **(Figure 41–1)**. Automatic transaxles, which combine an automatic transmission and final drive assembly in a single unit, are used on front-wheel drive (FWD), all-wheel drive, and some RWD vehicles **(Figure 41–2)**.

An automatic transmission or transaxle selects gear ratios according to engine speed, powertrain load, vehicle speed, and other operating factors. Little effort is needed on the part of the driver, because both upshifts and downshifts occur automatically. A driver-operated clutch is not needed to change gears, and the vehicle can be brought to a stop without shifting to neutral. This is a great convenience, particularly in stop-and-go traffic. The driver can also manually select a lower forward gear, reverse, neutral, or park. Depending on the forward range selected,

OBJECTIVES

- Explain the basic design and operation of standard and lockup torque converters.
- Describe the design and operation of a simple planetary gearset.
- Name the major types of planetary gear controls and explain their basic operating principles.
- Describe the construction and operation of common Simpson geartrain-based transmissions and transaxles.
- Describe the construction and operation of common Ravigneaux geartrain-based transmissions.
- Describe the construction and operation of transaxles that use planetary gearsets in tandem.
- Describe the construction and operation of transmissions that use the Lepelletier system.
- Describe the construction and operation of automatic transmissions that use helical gears in constant mesh.
- Describe the construction and operation of CVTs.
- Identify the various pressures in the transmission, state their purpose, and tell how they influence the operation of the transmission.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2014	**Make:** Toyota	**Model:** Sienna	**Mileage:** 94,633	**RO:** 17045
Concern:	Customer states the transmission doesn't feel as if it is shifting properly.			
History:	Van was serviced two months ago and no problems were noted. Vehicle was used for a family vacation last month.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

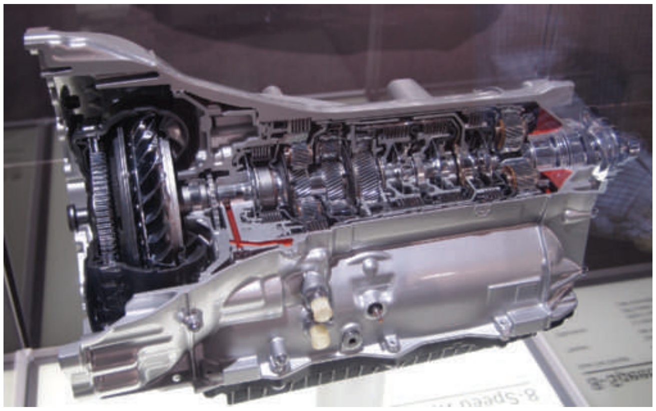


FIGURE 41–1 An eight-speed automatic transmission.

FIGURE 41–2 A transaxle mounted to the rear of an engine.

the transmission can provide engine braking during deceleration.

The number of available forward gears in current vehicles varies. Some have zero fixed ratios and use a constantly variable design, where the ratio changes according to conditions. Some automatic transmissions are fitted with a transfer case that sends torque to additional drive axles to allow for four-wheel or all-wheel drive **(Figure 41–3)**.

Until recently, all automatic transmissions were controlled by hydraulics that mainly responded to the operating conditions of the engine. However, modern systems now feature computer-controlled operation of the torque converter and transmission. Based on input data supplied by electronic sensors and switches, the computer sets the torque

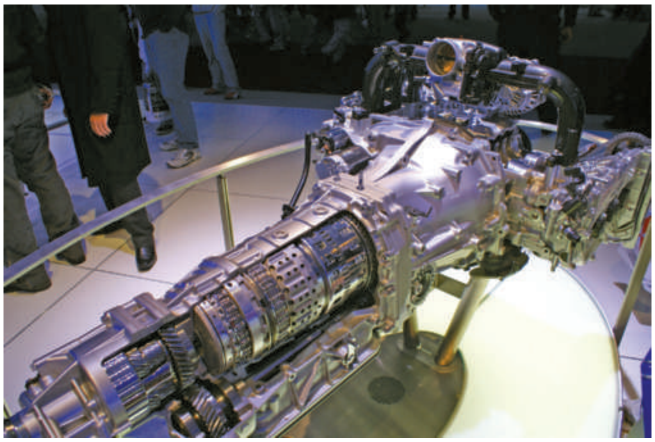


FIGURE 41–3 An automatic transmission fitted with a transfer case for all-wheel drive.

converter's operating mode and controls the transmission's hydraulic system.

The most widely used automatic transmissions and transaxles are six- to ten-speed units. Many older cars had three to five speeds. Six-speed units are common but are quickly being phased out with newer designs. Today's transmissions have at least one overdrive gear to reduce fuel consumption, lower emission levels, and reduce noise while the vehicle is cruising. The transmissions have a lockup torque converter that eliminates loss of power through the torque converter.

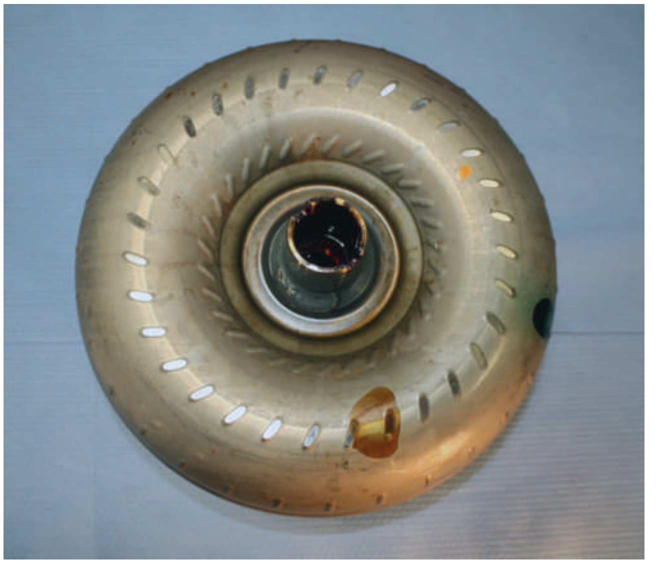


FIGURE 41–4 A torque converter.

Torque Converter

Automatic transmissions use a fluid clutch known as a torque converter to transfer engine torque from the engine to the transmission. In addition, the torque converter also acts as a damper and flywheel, helping to smooth out power fluctuations from the engine.

The torque converter operates through hydraulic force provided by automatic transmission fluid, often called transmission oil. The torque converter changes or multiplies the twisting motion of the engine crankshaft and directs it through the transmission.

The torque converter automatically engages and disengages power from the engine to the transmission in relation to engine rpm. With the engine running at the correct idle speed, there is not enough fluid flow for much power transfer through the torque converter. As engine speed is increased, the added fluid flow creates sufficient force to transmit engine power through the torque converter assembly to the transmission.

FIGURE 41–5 A cutaway of a late-model torque converter with a lock-up clutch.

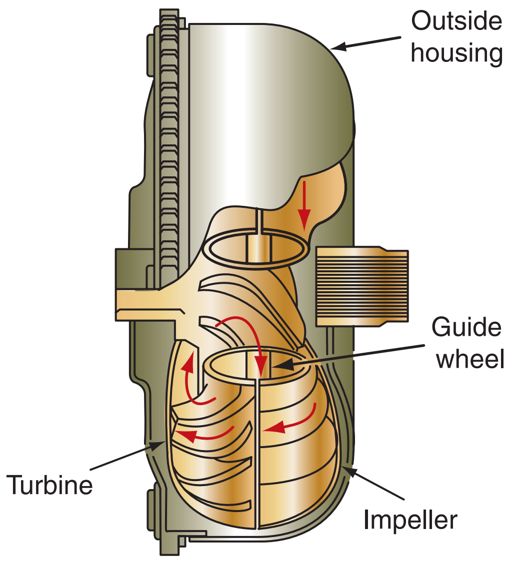
Design

Nearly all torque converters, or T/Cs, are one-piece, welded units that can only be repaired by specialty shops. They are located between the engine and transmission and are sealed, doughnut-shaped units **(Figure 41–4)** that are always filled with automatic transmission fluid. All of the vital parts of a torque converter are housed within its shell **(Figure 41–5)**.

A flexplate or driveplate is used to mount the torque converter to the crankshaft. The flexplate transfers the rotation of the crankshaft to the shell of the torque converter. The flexplate is designed to flex in response to the slight change in torque converter size as pressure builds in it. It is bolted to a flange on the rear of the crankshaft and to mounting pads on the front of the torque converter shell. A heavy flywheel is not needed because the mass of the torque converter and flexplate work like a flywheel to smooth out the intermittent power strokes of the engine. The flexplate or torque converter is surrounded by the ring gear for the starting motor.

Components

A standard torque converter consists of three elements **(Figure 41–6)**: the pump assembly, often called an impeller, the stator assembly, and the turbine.



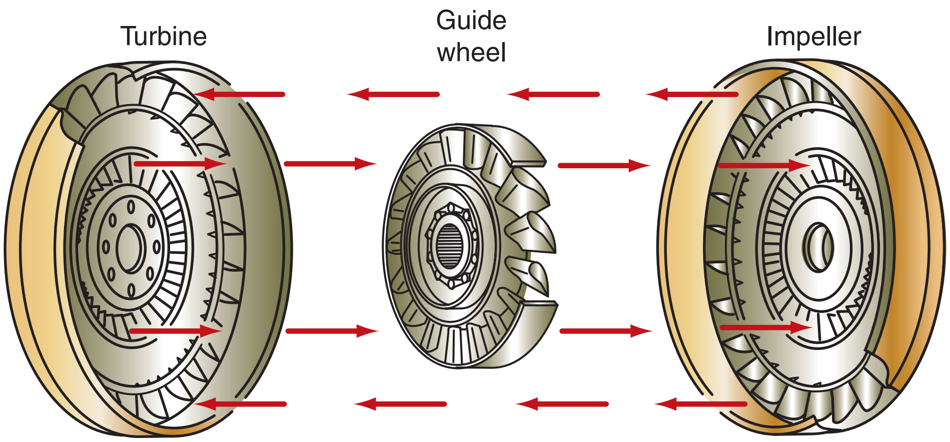


FIGURE 41–6 A torque converter's major internal parts are its impeller, turbine, and stator (guide wheel).

The **impeller** assembly is the input (drive) member and is attached to the inside of the shell. It receives power from the engine and begins to move fluid as soon as the engine begins to spin. The **turbine** is the output (driven) member. It is splined to the transmission's input shaft and has no direct connection to the impeller or shell. The **stator** assembly (also called a guide wheel) is the reaction member or torque multiplier and is used to direct fluid flow based on the operating conditions of the transmission. The stator is supported on a one-way clutch, which operates as an overrunning clutch and permits the stator to rotate freely in one direction and lock up in the opposite direction.

The exterior of the torque converter shell is shaped like two bowls standing on end facing each other. To support the weight of the torque converter, a short stubby shaft projects forward from the front of the torque converter shell and fits into a pocket at the rear of the crankshaft. At the rear of many torque converter shells is a hollow hub with notches or flats at one end, ground 180 degrees apart. This hub is called the pump drive hub. The notches or flats drive the transmission oil pump assembly. At the front of the transmission within the pump housing is a pump bushing that supports the pump drive hub and provides rear support for the torque converter assembly. Some other transaxles have a separate shaft to drive the pump.

The impeller forms one internal section of the torque converter shell and has numerous curved blades that rotate as a unit with the shell. It turns at engine speed, acting like a pump to start the transmission oil circulating within the torque converter shell.

While the impeller is positioned with its back facing the transmission housing, the turbine is positioned with its back to the engine. The curved blades of the turbine face the impeller assembly.

The turbine blades have a greater curve than the impeller blades, which helps eliminate oil turbulence between the turbine and impeller blades that would slow impeller speed and reduce the converter's efficiency.

The stator is located between the impeller and turbine. It redirects the oil flow from the turbine back into the impeller in the direction of impeller rotation with minimal loss of speed or force. The side of the stator blade with the inward curve is the concave side. The side with an outward curve is the convex side.

Basic Operation

Transmission oil is used as the medium to transfer energy in the T/C. **Figure 41–7A** illustrates the T/C impeller or pump at rest. **Figure 41–7B** shows it being driven. As the pump impeller rotates, centrifugal force throws the oil outward and upward due to the curved shape of the impeller housing.

The faster the impeller rotates, the greater the centrifugal force becomes. In **Figure 41–7B**, the oil is simply flying out of the housing and is not producing any work. To harness some of this energy, the turbine assembly is mounted on top of the impeller **(Figure 41–7C)**. Now the oil thrown outward and upward from the impeller strikes the curved vanes of the turbine, causing the turbine to rotate. (There is no direct mechanical link between the impeller and turbine.) The operation of the torque converter can be visualized by two fans facing each other **(Figure 41–8A)**. The fan on the left is blowing air across the blades of the fan on the right. This causes the blades of the second fan to turn, although at a slower speed than that of the first fan. Inside the torque converter, the fluid moved by the impeller flows across the turbine blades, causing them to move in the same direction **(Figure 41–8B)**. Just as with the fans, the turbine does not rotate with as much speed as the impeller. This loss, about 5 to 10 percent of the efficiency, is inherent to the torque converter. To correct for this loss, a lockup clutch is used. It is discussed in the next section.

An oil pump driven by the converter shell and the engine continually delivers oil under pressure into the T/C through a hollow shaft at the center axis of the rotating torque converter assembly. A seal prevents the loss of fluid from the system.

The turbine shaft is located within this shaft **(Figure 41–9)**. As mentioned earlier, the turbine shaft is splined to the turbine and transfers power from the torque converter to the transmission's main

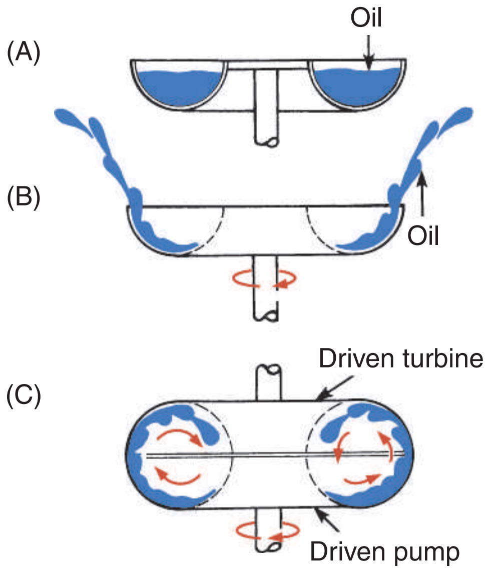


FIGURE 41–7 Fluid travel inside the torque converter: (A) Fluid at rest in the impeller/pump; (B) fluid thrown up and outward by the spinning pump; and (C) fluid flow harnessed by the turbine and redirected back into the pump.

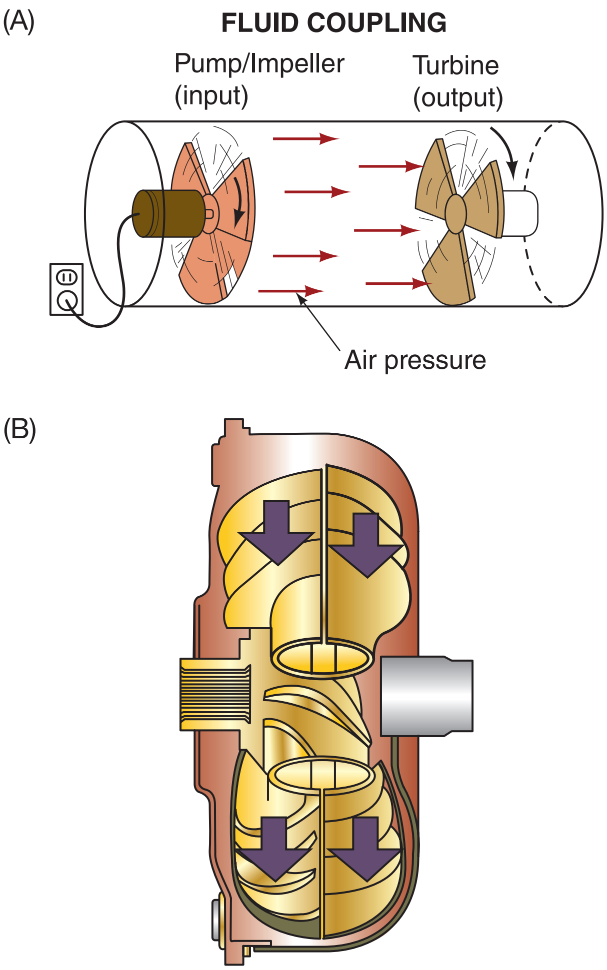


FIGURE 41–8 (A) The fluid flow from impeller generates movement of the turbine. (B) The turbine spins in the same direction as the impeller.

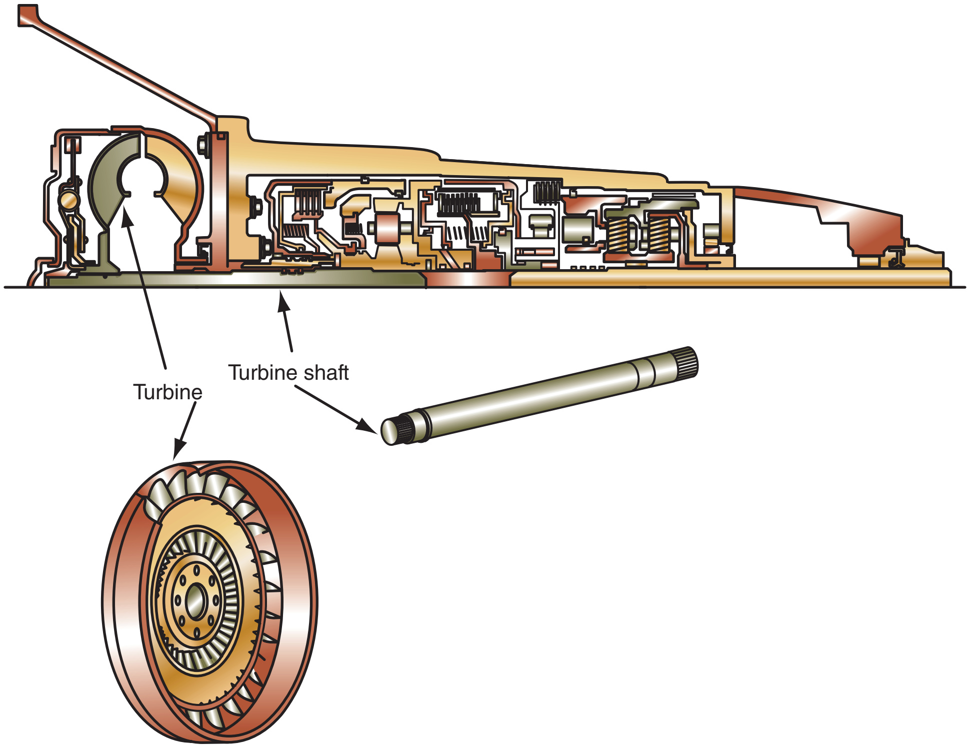


FIGURE 41–9 The turbine drives the input shaft.

drive shaft. Oil leaving the turbine is directed out of the torque converter to an external oil cooler and then to the transmission's oil sump or pan.

With the transmission in gear and the engine at idle, the vehicle can be held stationary by applying the brakes. At idle, engine speed is slow. Since the impeller is driven by engine speed, it turns slowly, creating little fluid flow or centrifugal force against the turbine blades. Therefore, little or no power is transferred to the transmission.

When the throttle is opened, engine speed, impeller speed, and the amount of centrifugal force generated in the torque converter increase dramatically. However, the turbine is not moving when the vehicle is stopped. To increase the power flow once the vehicle starts to move, the stator overrunning clutch locks, holding the stator in place. As the fluid leaves the turbine, it is going opposite of flow out of the pump. This collision of fluid would work against the pump, reducing efficiency and power. To correct this condition, the stator vanes redirect oil from the turbine back to the impeller **(Figure 41–10)**. This redirection takes place when there is a significant difference between impeller and turbine speed and is called torque multiplication. Torque multiplication only occurs when the turbine is spinning much more slowly than the impeller. The increase in fluid flow can allow engine torque to be increased by two times or more.

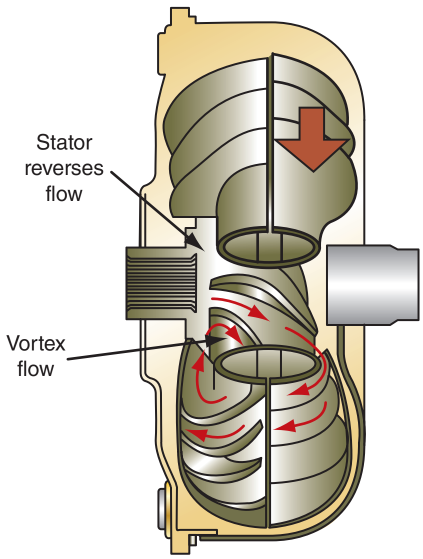


FIGURE 41–10 The stator redirects fluid flow to increase efficiency.

Types of Oil Flow

Two types of oil flow take place inside the torque converter: rotary and vortex flow **(Figure 41–11). Rotary oil flow** is the oil flow around the circumference of the torque converter caused by the rotation of the torque converter on its axis. **Vortex oil flow** is the oil flow occurring from the impeller to the turbine and back to the impeller, at a 90-degree angle from engine rotation.

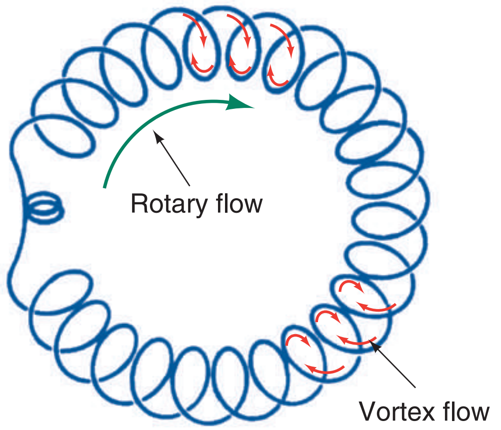


FIGURE 41–11 The difference between rotary and vortex flow. Note that vortex flow spirals its way around the converter.

Figure 41–12A also shows the oil flow pattern as the speed of the turbine approaches the speed of the impeller. This is known as the **coupling** (stage or) **point (Figure 41–12B)**. The turbine and the impeller are running at essentially the same speed. They cannot run at exactly the same speed due to slippage between them. The only way they can turn at exactly the same speed is by using a lockup clutch to mechanically tie them together.

The stator mounts through its splined center hub to a mating stator shaft. The stator freewheels when the impeller and turbine reach the coupling stage.

The stator redirects the oil leaving the turbine back to the impeller, which helps the impeller rotate more efficiently **(Figure 41–13)**. Torque converter

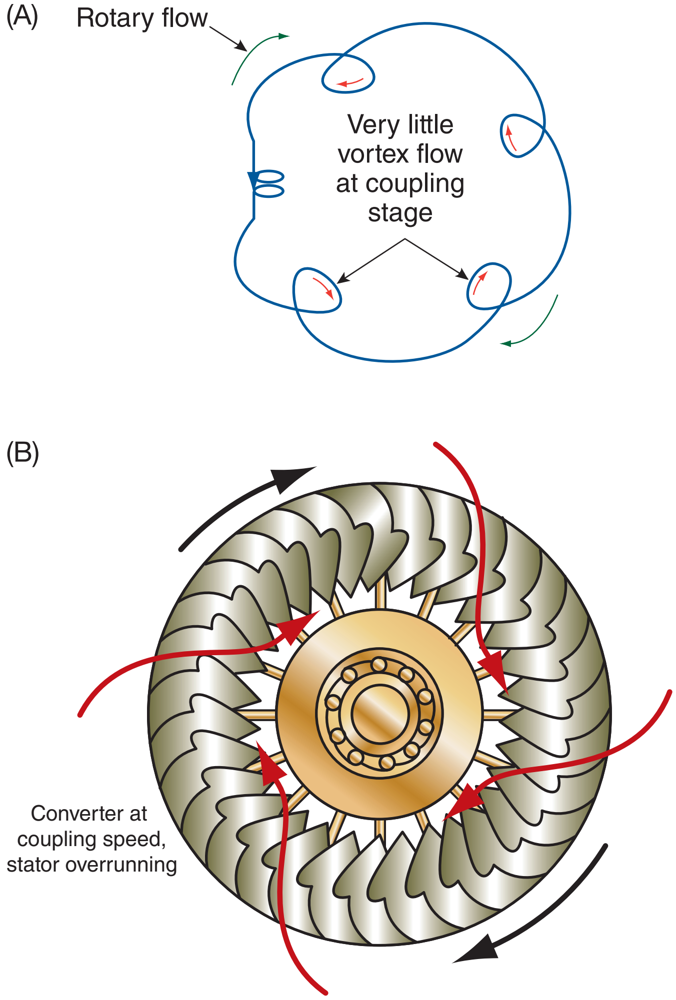


FIGURE 41–12 (A) Rotary flow is at its greatest at the coupling stage. (B) Fluid flow during the coupling stage.

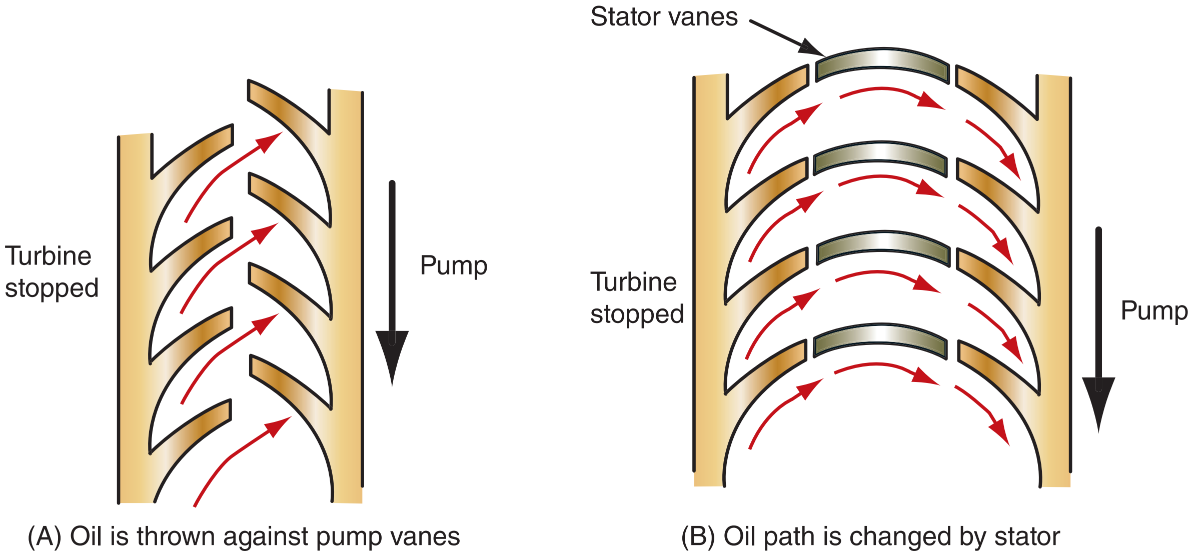


FIGURE 41–13 (A) Without a stator, fluid leaving the turbine works against the direction in which the impeller or pump is rotating. (B) With a stator in its locked (noncoupling) mode, fluid is directed to help push the impeller in its rotating direction.

multiplication can only occur when the impeller is rotating faster than the turbine.

A stator is either a rotating or fixed type. Rotating stators are more efficient at higher speeds because there is less slippage when the impeller and turbine reach the coupling stage.

Overrunning Clutch

An **overrunning clutch** keeps the stator assembly from rotating when driven in one direction and permits overrunning (rotation) when turned in the opposite direction. Rotating stators generally use a roller-type overrunning clutch that allows the stator to freewheel (rotate) when the speed of the turbine and impeller reach the coupling point.

The roller clutch **(Figure 41–14)** is designed with a splined inner race, rollers, accordion (apply) springs, and movable outer race. Around the inside diameter of the outer race are several cam-shaped pockets. The rollers and accordion springs are located in these pockets.

As the vehicle begins to move, the stator stays in its stationary or locked position because of the force of the fluid flow against the stator vanes and the difference between the impeller and turbine speeds. The accordion springs force the rollers up the ramps of the cam pockets into a wedging contact with the inner and outer races. With the stator locked, fluid flow from the turbine is redirected by the stator vanes back to the impeller and in the same direction as the impeller. The flow increases the force against the impeller, adding to the power supplied by the engine.

As vehicle road speed increases, turbine speed increases until it approaches impeller speed. Oil exiting the turbine vanes strikes the back face of the stator, causing the stator to rotate in the same direction as the turbine and impeller **(Figure 41–15)**. At this higher speed, clearance exists between the inner stator race and hub. The rollers at each slot of the stator are pulled around the stator hub. The stator freewheels or turns as a unit.

If the vehicle slows, engine speed also slows along with turbine speed. This decrease in turbine speed allows the oil flow to change direction. It now strikes the front face of the stator vanes, halting the turning stator and attempting to rotate it in the opposite direction.

As this happens, the rollers jam between the inner race and hub, locking the stator in position. In a stationary position, the stator now redirects the oil exiting the turbine so torque is again multiplied.

Lockup Torque Converter

A lockup torque converter eliminates the 5–10 percent slip that takes place between the impeller and turbine at the coupling stage. The engagement of a clutch between the impeller and the turbine assembly greatly improves fuel economy and reduces operational heat and engine speed. The assembly of a lockup torque converter is typically called a **torque converter clutch (TCC)**.

Through the years, many different types of TCC systems have been used. The most common design is the electronically controlled lockup piston clutch. Clutch lockup systems can also be fully mechanical, centrifugally controlled, or dependent on a viscous coupling.

Lockup Piston Clutch

The lockup piston clutch has a piston-type clutch located between the front of the turbine and the

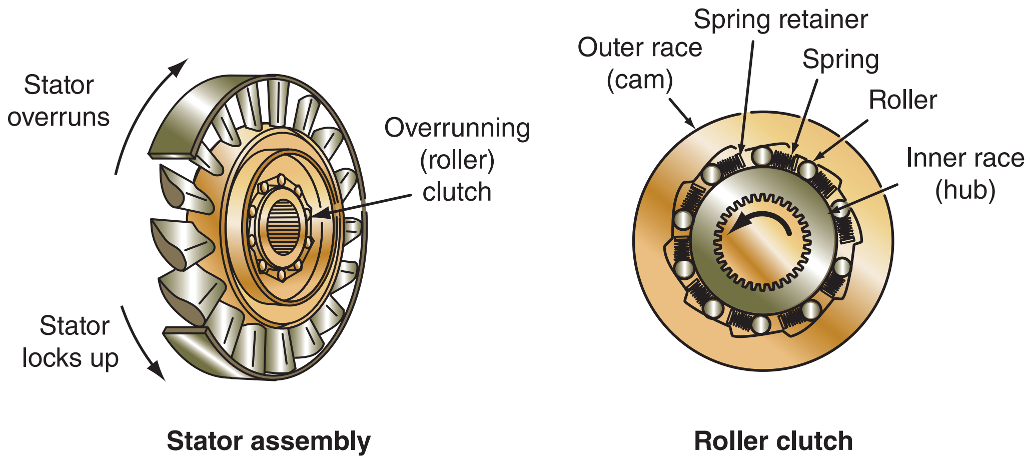


FIGURE 41–14 The roller clutch in a stator assembly.

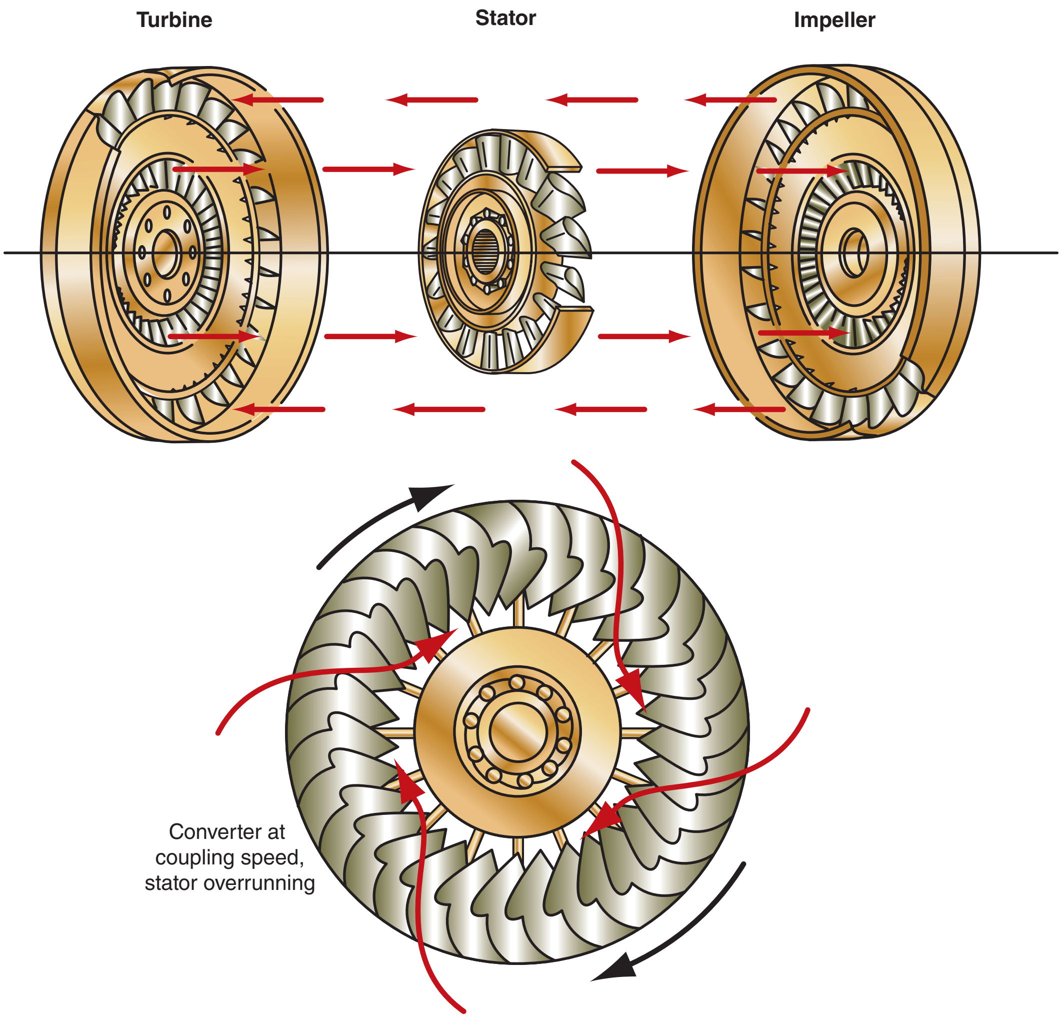


FIGURE 41–15 Fluid flow through the converter at coupling speed.

interior front face of the shell **(Figure 41–16)**. Its main components are a piston plate and damper assembly and a clutch friction plate **(Figure 41–17)**.

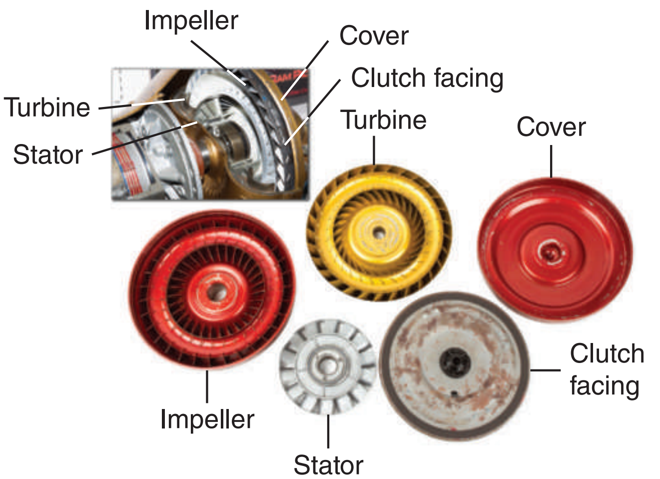


FIGURE 41–16 When oil pressure in applied to the torque converter friction plate, the plate moves tightly against the friction surface on the housing to lock the torque converter.

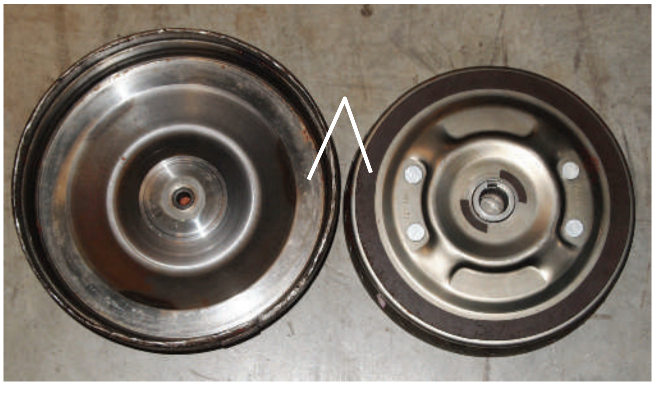


FIGURE 41–17 The friction surfaces of a torque converter clutch.

The damper assembly is made of several coil springs and is designed to transmit driving torque and absorb shock.

The clutch is controlled by hydraulic valves, which are controlled by the PCM **(Figure 41–18)**. The PCM monitors operating conditions and controls lockup according to those conditions.

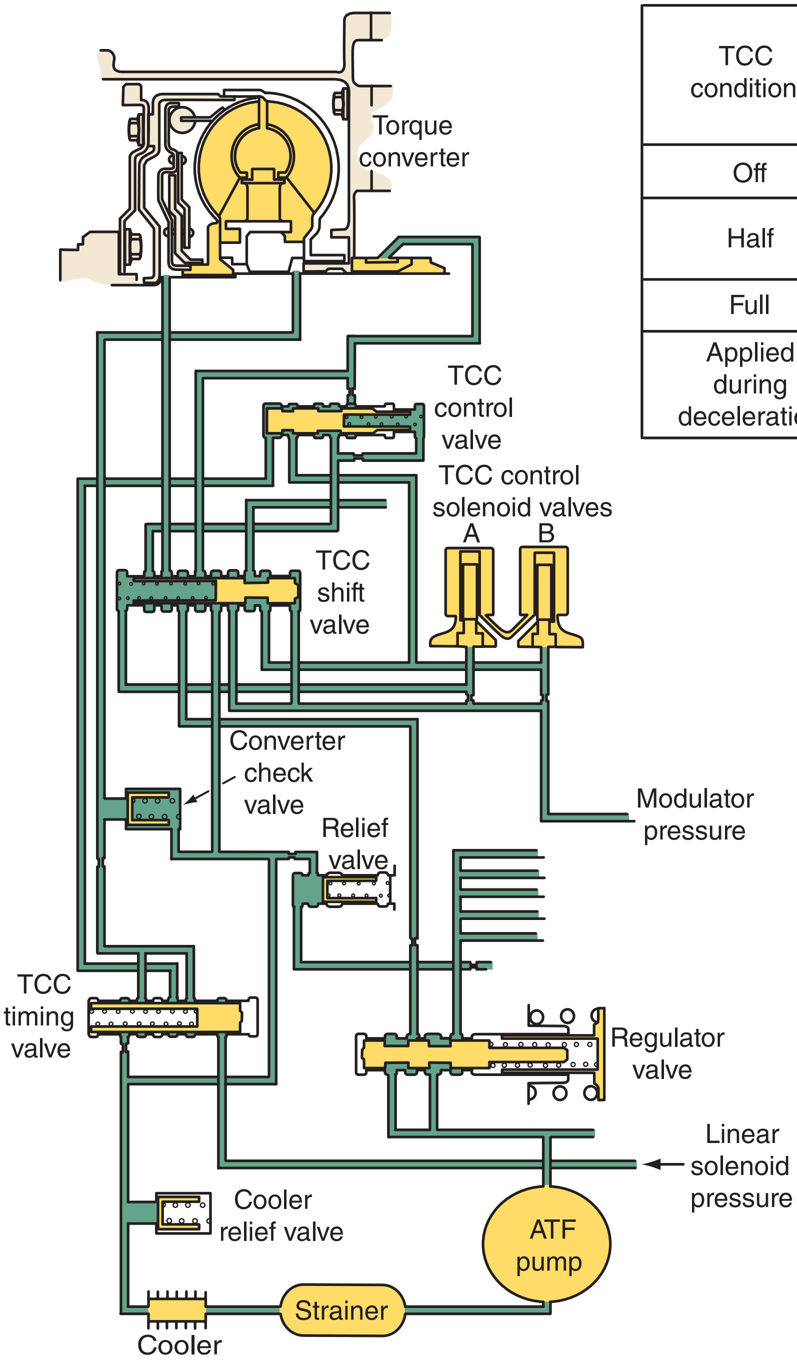


FIGURE 41–18 A typical circuit for activating the TCC.

TCC conditions	TCC control solenoid valve		Linear solenoid pressure
	A	B	
Off	Off	Off	High
Half	On	Duty operation Off ↔ On	Low
Full	On	On	High
Applied during deceleration	On	Duty operation Off ↔ On	Low

To understand how this system works, consider this example: To provide for clutch control, Chrysler adds a three-valve module to its standard transmission valve body. The three valves are the lockup valve, fail-safe valve, and switch valve. The lockup valve actually controls the clutch. The fail-safe valve prevents lockup until the transmission is in third gear. The switch valve directs fluid through the turbine shaft to fill the torque converter.

When the converter is not locked, fluid enters the converter and moves to the front side of the piston, keeping it away from the shell or cover. Fluid flow continues around the piston to the rear side and exits between the neck of the torque converter and the stator support gearsets **(Figure 41–19)**.

During the lockup mode, the switch valve moves and reverses the fluid path. This causes the fluid to move to the rear of the piston, pushing it forward to apply the clutch to the shell and allowing for lockup. Fluid from the front side of the piston exits through the turbine shaft that is now vented at the switch valve.

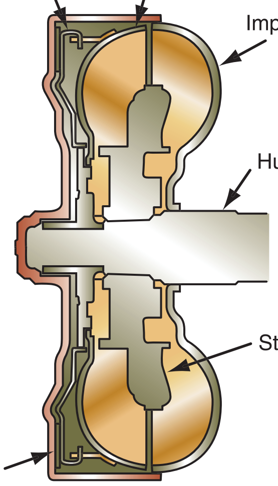


FIGURE 41–19 The lockup clutch.

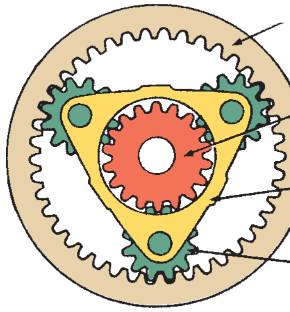


FIGURE 41–21 Planetary gear configuration is similar to the solar system, with the sun gear surrounded by the planetary pinion gears. The ring gear surrounds the complete gearset.

During acceleration, system fluid pressure increases. If the converter is in its lockup mode, the higher pressure moves the fail-safe valve to block fluid pressure to the lockup valve. Spring tension moves the switch valve, directing fluid pressure to the front side of the piston. The torque converter then returns to its nonlockup mode.

Planetary Gears

Nearly all automatic transmissions rely on planetary gearsets **(Figure 41–20)** to transfer power and multiply engine torque to the drive axle. Compound gearsets combine two simple planetary gearsets so load can be spread over a greater number of teeth for strength and also to obtain the largest number of gear ratios possible in a compact area.

A simple planetary gearset consists of three parts: a sun gear, a carrier with planetary pinions mounted to it, and an internally toothed ring gear or **annulus**. The **sun gear** is located in the center of the assembly **(Figure 41–21)**. It can be either a spur or helical gear design. It meshes with the teeth of the planetary pinion gears. Planetary pinion gears are small gears fitted into a framework called the **planetary carrier**. The planetary carrier can be made of cast iron, aluminum, or steel plate and is designed with a shaft for each of the planetary pinion gears. (For simplicity, planetary pinion gears are called **planetary pinions**.)

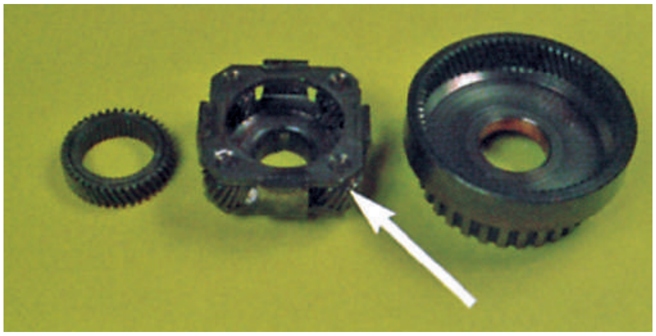


FIGURE 41–20 A single planetary gearset.

Planetary pinions rotate on needle bearings positioned between the planetary carrier shaft and the planetary pinions. The carrier and pinions are considered one unit—the midsize gear member.

The planetary pinions surround the sun gear's center axis and they are surrounded by the annulus or ring gear, which is the largest part of the simple gearset. The ring gear acts like a band to hold the entire gearset together and provide great strength to the unit. To help remember the design of a simple planetary gearset, use the solar system as an example. The sun is the center of the solar system with the planets rotating around it; hence, the name planetary gearset.

How Planetary Gears Work

Each member of a planetary gearset can spin (revolve) or be held at rest. Power transfer through a planetary gearset is only possible when one of the members is held at rest, or if two of the members are locked together.

Any one of the three members can be used as the driving or input member. At the same time, another member might be kept from rotating and thus becomes the reaction, held, or stationary member. The third member then becomes the driven or output member. Depending on which member is the driver, which is held, and which is driven, either a torque increase (underdrive) or a speed increase

(overdrive) is produced by the planetary gearset. Output direction can also be reversed through various combinations.

Table 41–1 summarizes the basic laws of simple planetary gears. It indicates the resultant speed, torque, and direction of the various combinations available. Also, remember that when an external-to-external gear tooth set is in mesh, there is a change in the direction of rotation at the output. When an external gear tooth is in mesh with an internal gear, the output rotation for both gears is the same.

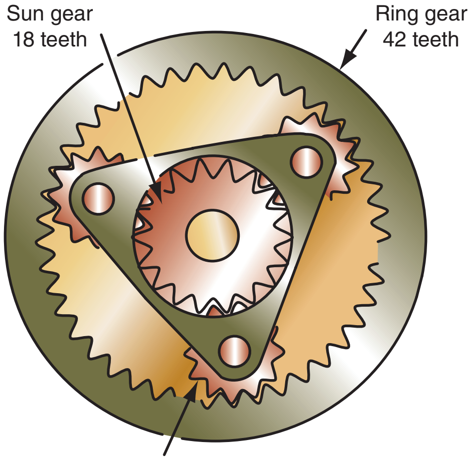


FIGURE 41–22 A simple planetary gearset.

Planetary Gear Ratios

The gear ratios available from a planetary gearset depend on the number of teeth on the driven and the driving gears, just as with any set of gears. However, since there are three members in the planetary set instead of two, we have to calculate the ratios a little differently. For this example, our planetary set has 18 teeth on the sun gear and 42 teeth on the ring gear **(Figure 41–22)**. The number of teeth on the planetary pinions is equal to the sum of the teeth of both the sun and ring gears, or 60. If the ring gear is held and the sun gear is the input, then the carrier is the output. The gear ratio would be found by adding 18 and 42 and dividing by 18, for a 3.33:1 gear ratio.

Maximum Forward Reduction With the ring gear held and the sun gear (the input) turning clockwise, the sun gear rotates the planetary pinions counterclockwise on their shafts. The small sun gear (driving) rotates several times, driving the midsize planetary carrier (the output) one complete revolution, resulting in the most gear reduction or the maximum torque multiplication that can be achieved in one planetary gearset. Input speed is high, but output speed is low.

The gear ratio based on our sample gearset is 3.33:1 found by dividing 60 by 18.

Minimum Forward Reduction In this combination, the sun gear is held and the ring gear (input) rotates clockwise. The ring gear drives the planetary pinions clockwise and walks around the stationary sun gear (held). The planetary pinions drive the planetary carrier (output) in the same direction as the ring gear—forward. This results in more than one turn of the input as compared to one complete revolution of the output. The result is torque multiplication. The planetary gearset is operating in a forward reduction with the large ring gear driving the small planetary carrier. Therefore, the combination produces minimum forward reduction. The gear ratio is 1.43:1 based on 60/42.

Maximum Overdrive With the ring gear held and the planetary carrier (input) rotating clockwise, the

TABLE 41–1 LAWS OF SIMPLE PLANETARY GEAR OPERATION

Sun Gear	Carrier	Ring Gear	Speed	Torque	Direction
1. Input	Output	Held	Maximum reduction	Increase	Same as input
2. Held	Output	Input	Minimum reduction	Increase	Same as input
3. Output	Input	Held	Maximum increase	Reduction	Same as input
4. Held	Input	Output	Minimum increase	Reduction	Same as input
5. Input	Held	Output	Reduction	Increase	Reverse of input
6. Output	Held	Input	Increase	Reduction	Reverse of input
7. When any two members are held together, speed and direction are the same as input. Direct 1:1 drive occurs.					
8. When no member is held or locked together, output cannot occur. The result is a neutral condition.					

three planetary pinion shafts push against the inside diameter of the planetary pinions. The pinions are forced to walk around the inside of the ring gear, driving the sun gear (output) clockwise. In this combination, the midsize planetary carrier is rotating less than one turn and driving the smaller sun gear at a speed greater than the input speed. The result is overdrive with maximum speed increase. This provides a gear ratio of 0.3:1 from 18/60.

Slow Overdrive In this combination, the sun gear is held and the carrier rotates (input) clockwise. As the carrier rotates, the pinion shafts push against the inside diameter of the pinions and they are forced to walk around the held sun gear. This drives the ring gear (output) faster and the speed increases. The carrier turning less than one turn causes the pinions to drive the ring gear one complete revolution in the same direction as the planetary carrier and a slow overdrive occurs. This results in a more usable 0.8:1 overdrive gear ratio based on 42/60.

Slow Reverse Here the sun gear (input) is driving the ring gear (output) with the planetary carrier held stationary. The planetary pinions, driven by the sun gear, rotate counterclockwise on their shafts. While the sun gear is driving, the planetary pinions are used as idler gears to drive the ring gear counterclockwise. This means the input and output shafts are operating in the opposite or reverse direction to provide a reverse power flow. Since the driving sun gear is small and the driven ring gear is large, the result is slow reverse with a gear ratio of 2.33:1 based on 42/18.

Fast Reverse For fast reverse, the carrier is held, but the sun gear and ring gear reverse roles, with the ring gear (input) now being the driving member and the sun gear (output) driven. As the ring gear rotates counterclockwise, the pinions rotate counterclockwise as well, while the sun gear turns clockwise. In this combination, the input ring gear uses the planetary pinions to drive the output sun gear. The sun gear rotates in reverse to the input ring gear, providing fast reverse. This provides a gear ratio of 0.43:1 based on 18/42.

Direct Drive In the direct drive combination, both the ring gear and the sun gear are input members. They turn clockwise at the same speed. The internal teeth of the clockwise turning ring gear try to rotate the planetary pinions clockwise as well. But the sun gear, which rotates clockwise, tries to drive the planetary pinions counterclockwise. These opposing forces lock the planetary pinions against rotation so the entire planetary gearset rotates as one complete unit, providing direct drive. Whenever two members of the gearset are locked together, direct drive results. Direct drive, if using only the simple planetary gearset, is a 1:1 ratio. For every crankshaft revolution the transmission output shaft will also spin once.

Neutral Operation When no member is held or locked, a neutral condition exists.

SHOP TALK

The following are some tips for remembering the basic operation of a simple planetary gearset:

- **When the planetary carrier is the drive (input) member, the gearset provides an overdrive condition. Speed increases, torque decreases.**
- **When the planetary carrier is the driven (output) member, the gearset provides a forward reduction direction. Speed decreases, torque increases.**
- **When the planetary carrier is stationary (held), the gearset provides a reverse gear.**

Compound Planetary Gearsets

A limited number of gear ratios are available from a single planetary gearset. Gearsets can be combined to increase the number of available gear ratios. A typical automatic transmission has two usable forward gears per planetary gear set. This means a four-speed transmission has at least two planetary gearsets **(Figure 41–23)** connected together to provide the various gear ratios needed to efficiently move a vehicle. There are two common designs of compound gearsets: the Simpson gearset, in which two planetary gearsets share a common sun gear, and the Ravigneaux gearset, which has two sun gears, two sets of planet gears, and a common ring gear.

Many transmissions are fitted with additional single planetary gearsets connected in tandem to

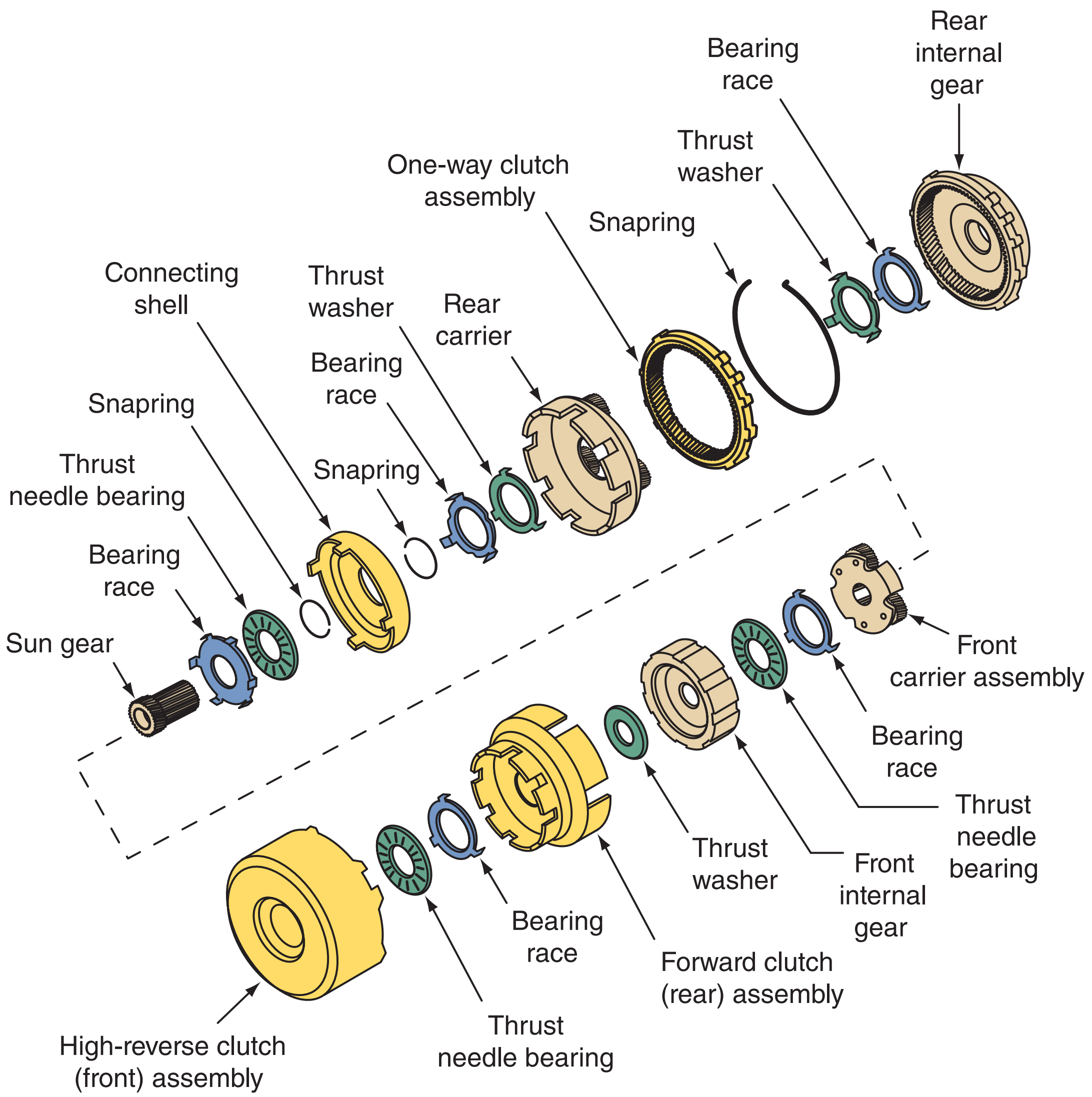


FIGURE 41–23 A Simpson planetary gearset.

provide additional forward speed ratios. Some, such as GMs 8L90 and the new 10-speed transmissions combine simple planetary gearsets. Both the 8- and 10-speed transmissions use four simple planetaries. These four gearsets, along with four rotating and two brake clutches, produce the 10-speed unit. Increasing the number of gears allows for a wide overall gear range, which is used to keep the engine operating at peak efficiency.

Simpson Geartrain

The **Simpson geartrain** is an arrangement of two separate planetary gearsets with a common sun gear, two ring gears, and two planetary pinion carriers. A Simpson geartrain is the most commonly used compound planetary gearset and is used to provide three forward gears. One half of the compound set or one planetary unit is referred to as the front planetary and the other planetary unit is the rear planetary **(Figure 41–24)**. The two planetary units do not need to be the same size or have the same number of teeth on their gears. The size and number of gear teeth determine the actual gear ratios obtained by the compound planetary gear assembly.

Gear ratios and direction of rotation are the result of applying torque to one member of either planetary unit, holding at least one member of the gearset, and using another member as the output. For the most part, each automobile manufacturer uses different parts of the planetary assemblies as inputs, outputs, and reaction members. The role of the planetary members also varies with the different transmission models from the same manufacturer. There are also many different apply devices used in the various transmission designs.

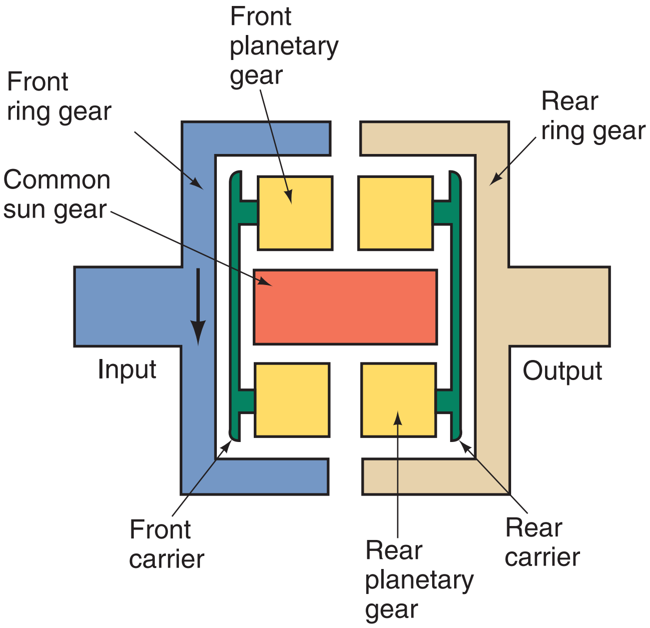


FIGURE 41–24 Components of a Simpson gearset.

A Simpson gearset can provide the following gear ranges: neutral, first reduction gear, second reduction gear, direct drive, and reverse. The typical power flow through a Simpson geartrain when it is in neutral has engine torque being delivered to the transmission's input shaft by the torque converter's turbine. No planetary gearset member is locked to the shaft; therefore, engine torque enters the transmission but goes nowhere else.

When the transmission is shifted into first gear **(Figure 41–25)**, engine torque is again delivered into the transmission by the input shaft. The input shaft is now locked to the front planetary ring gear that turns clockwise with the shaft. The front ring gear drives the front planet gears, also in a clockwise direction. The front planet gears drive the sun gear in a counterclockwise direction. The rear planet carrier is locked; therefore, the sun gear spins the rear planet gears in a clockwise direction. These planet gears drive the rear ring gear, which is locked to the output shaft, in a clockwise direction. The result of this power flow is a forward gear reduction.

When the transmission is operating in second gear **(Figure 41–26)**, engine torque is again delivered into the transmission by the input shaft. The input shaft is locked to the front planetary ring gear that turns clockwise with the shaft. The front ring gear drives the front planet gears, also in a clockwise direction. The front planet gears walk around the sun gear because it is held. The walking of the planets forces the planet carrier to turn clockwise. Since the carrier is locked to the output shaft, it causes the shaft to rotate in a forward direction with some gear reduction.

When operating in third gear **(Figure 41–27)**, the input is received by the front ring gear, as in the other forward positions. However, the input is also received by the sun gear. Since the sun and ring gear are rotating at the same speed and in the same direction, the front planet carrier is locked between the two and is forced to move with them. Since the front carrier is locked to the output shaft, direct drive results.

To obtain a suitable reverse gear in a Simpson geartrain, there must be a gear reduction, but in the

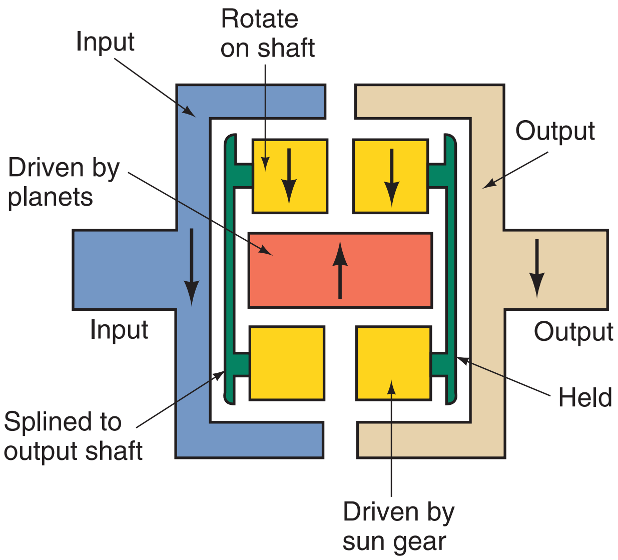


FIGURE 41–25 Power flow through a Simpson gearset while operating in first gear.

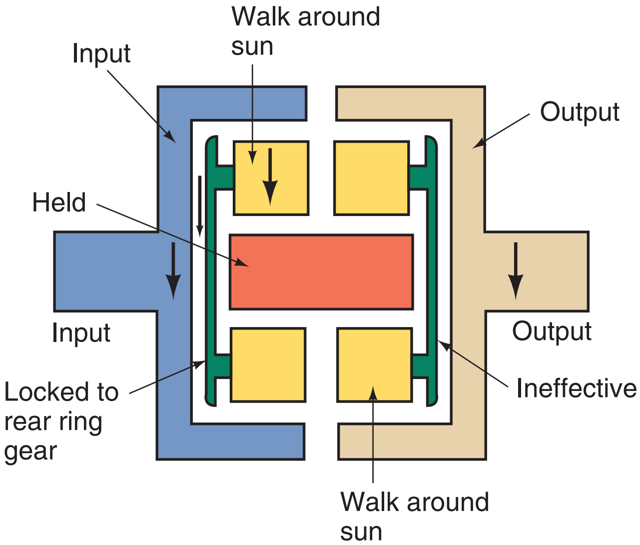


FIGURE 41–26 Power flow through a Simpson gearset while operating in second gear.

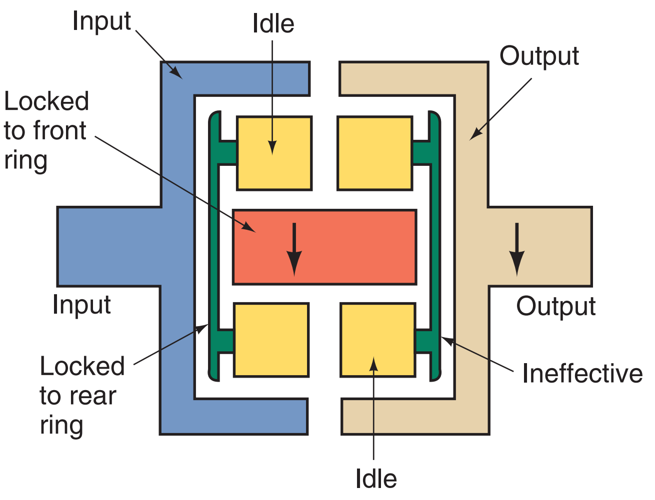


FIGURE 41–27 Power flow through a Simpson gearset while operating in direct drive.

opposite direction as the input torque **(Figure 41–28)**. The input is received by the sun gear, as in the third gear position, and rotates in a clockwise direction. The sun gear then drives the rear planet gears in a clockwise direction. The rear planet carrier is held; therefore, the planet gears drive the rear ring gear in a counterclockwise direction. The ring gear is locked to the output shaft that turns at the same speed and direction as the rear ring gear. The result is a reverse gear.

Typically, when the transmission is in neutral or park, no apply devices are engaged, allowing only the input shaft and the transmission's oil pump to turn with the engine. In park, a pawl is mechanically engaged to a parking gear that is splined to the transmission's output shaft, locking the drive wheels to the transmission's case.

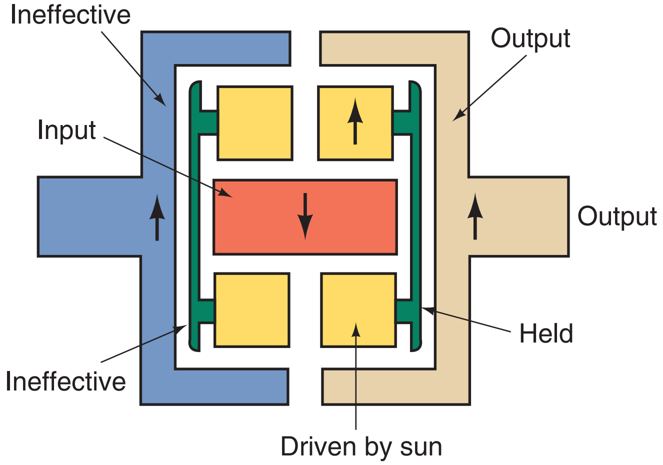


FIGURE 41–28 Power flow through a Simpson gearset while operating in reverse.

Ravigneaux Geartrain

The **Ravigneaux geartrain**, like the Simpson geartrain, provides forward gears with a reduction, direct drive, overdrive, and a reverse operating range. The Ravigneaux offers some advantages over a Simpson geartrain. It is very compact. It can carry large amounts of torque because of the great amount of tooth contact. It can also have three different output members. However, it has a disadvantage because it is more complex and, therefore, its actions are more difficult to understand.

The Ravigneaux geartrain is designed to use two sun gears: one small and one large **(Figure 41–29)**. They also have two sets of planetary pinion gears: three long pinions and three short pinions. The planetary pinion gears rotate on their own shafts that are fastened to a common planetary carrier. A single ring gear surrounds the complete assembly.

The small sun gear is meshed with the short planetary pinion gears. These short pinions act as idler gears to drive the long planetary pinion gears. The long planetary pinion gears mesh with the large sun gear and the ring gear.

Typically, when the gear selector is in neutral position, engine torque, through the converter turbine shaft, drives the small (forward) sun gear. The sun gear is not locked to another gear, so it freewheels on the pinion gears and the power is not transmitted through the geartrain. There is no power output.

When the transmission is operating in first gear **(Figure 41–30)**, engine torque drives the small sun gear clockwise. The planetary carrier is prevented from rotating counterclockwise; therefore, the sun gear drives the short planet gears counterclockwise. The direction of rotation is reversed as the short planet gears drive the long planet gears, which drive the ring gear and output shaft in a clockwise direction but at a lower speed than the input.

In second gear **(Figure 41–31)** operation, the small sun gear is rotating clockwise and causes the short planet gears to rotate counterclockwise.

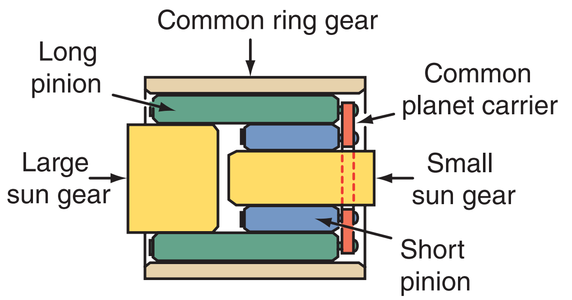


FIGURE 41–29 The parts of a Ravigneaux gearset.

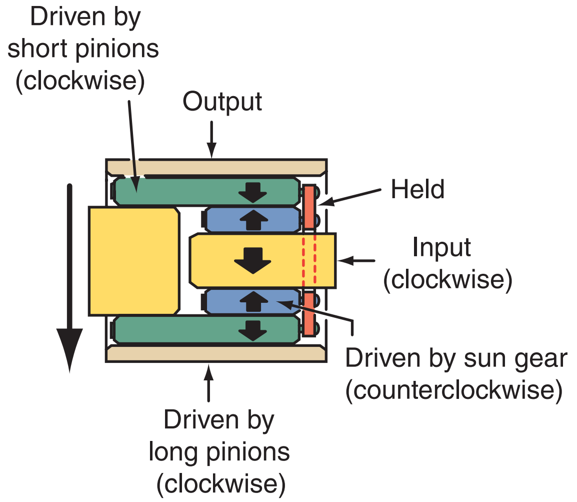


FIGURE 41–30 Power flow through a Ravigneaux gearset while operating in first gear.

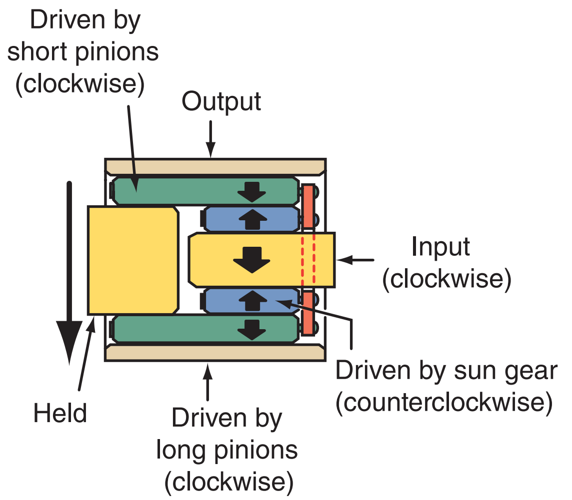


FIGURE 41–31 Power flow through a Ravigneaux gearset while operating in second gear.

The direction of rotation is reversed as the short planet gears drive the long planet gears, which walk around the stationary large or reverse sun gear. This walking drives the ring gear and output shaft in a clockwise direction and at a torque reduction.

During third gear **(Figure 41–32)** operation, there are two inputs into the planetary geartrain. As in other forward gears, the turbine shaft of the torque converter drives the small sun gear in a clockwise direction. Input is also received by the planetary gear carrier. Because two members of the geartrain are being driven at the same time, the planetary gear carrier and the forward sun gear rotate as a unit. The long planet gears transfer the torque in a clockwise direction through the gearset to the ring gear and output shaft. This results in direct drive.

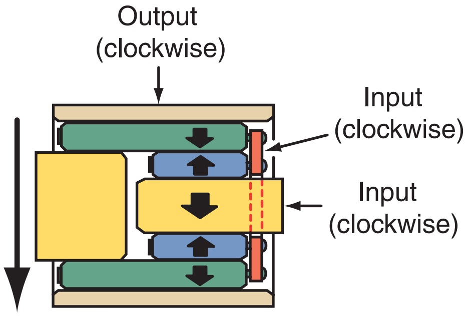


FIGURE 41–32 Power flow through a Ravigneaux gearset while operating in direct drive.

To operate in overdrive or fourth gear, input is received only at the planetary carrier in a clockwise direction. The long planet gears walk around the stationary reverse sun gear in a clockwise direction and drive the ring gear and output shaft. This results in an overdrive condition.

During reverse gear operation, input is received at the reverse sun gear. The planetary gear carrier is held. The clockwise rotation of the reverse sun gear drives the long planet gears in a counterclockwise direction. The long planets then drive the ring gear and output shaft in a counterclockwise direction with a speed reduction.

Planetary Gearsets in Tandem

Rather than relying on the use of a compound gearset, some automatic transmissions use two simple planetary units in series **(Figure 41–33)**. In this type of arrangement, gearset members are not shared; instead, the holding devices are used to lock different members of the planetary units together.

Although the geartrain is based on two simple planetary gearsets operating in tandem, the combination of the two planetary units does function much like a compound unit. The two tandem units do not share a common member; rather, certain members are locked together or are integral with each other. The front planetary carrier is locked to the rear ring gear and the front ring gear is locked to the rear planetary carrier.

A transaxle may have additional planetary gearsets, including one that is used as the final drive gearset.

Lepelletier System

Some late-model six-, seven-, eight-, and nine-speed transmissions use the Lepelletier system. The Lepelletier system connects a simple planetary gearset to a Ravigneaux gearset. This design has

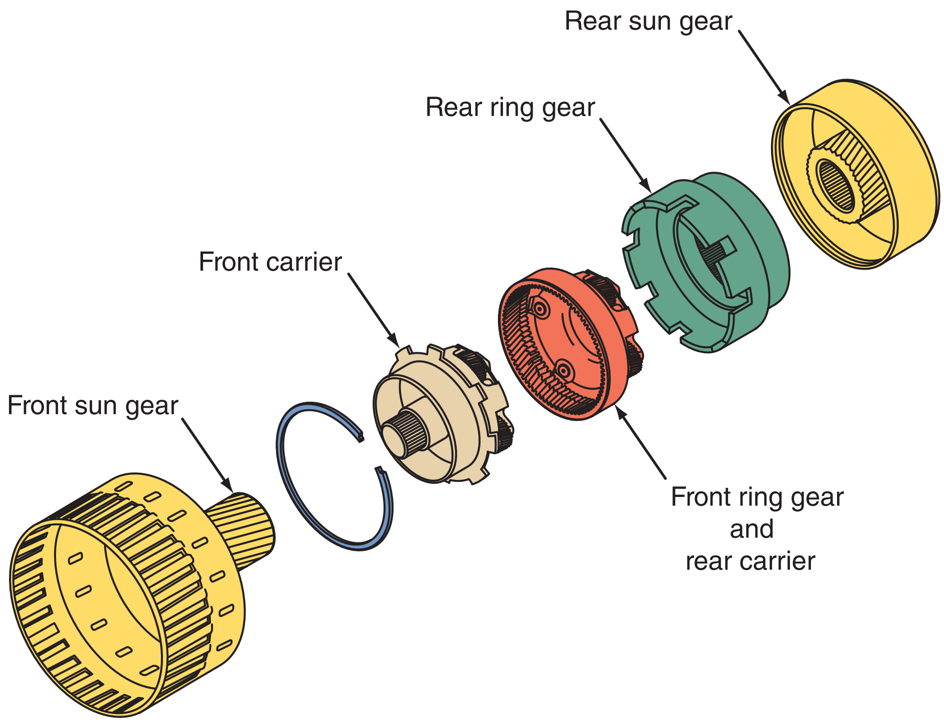


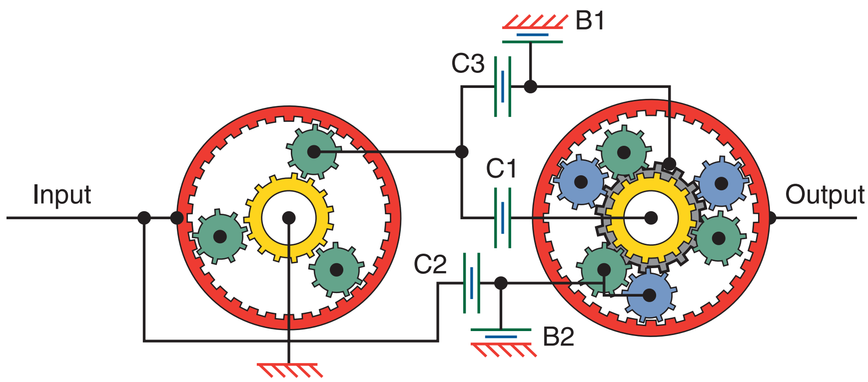
FIGURE 41–33 Two planetary units with the ring gear of one gearset connected to the planet carrier of the other.

been around for many years but was difficult to control. Today's electronic technologies have made it practical. With this design, transmissions can be made with additional forward speeds without an increase in size and weight. In fact, most six-speed transmissions are more compact and are lighter than nearly all four- or five-speed transmissions.

In this arrangement, the ring gear of the simple gearset serves as the input to the gearsets, and the input can be connected to the carrier of the Ravigneaux gear at the same time **(Figure 41–34)**. As engine torque passes through different input gears, it drives a variety of combinations of gears in the simple and the Ravigneaux gearsets. These combinations result in the various forward speed ratios. The ring gear of the Ravigneaux gearset is the output member for the transmission.

In some models, the input shaft is always connected to the ring of the simple planetary gear and, in addition, can be connected to the carrier and large sun gear of the Ravigneaux gear. This allows for additional gear combinations. The ring gear of the Ravigneaux gearset still serves as the output.

Power Flow The power flow through a Lepelletier gearset is based on splitting the input into two ratios: the ratio of the single set and the ratio of the second. The overall ratio is the combination of the two. Here



Range	C1	C2	C3	B1	B2
1	X				
Manual 1	X				X
2	X			X	
3	X		X		
4	X	X			
5		X	X		
6		X		X	
Reverse			X		X

FIGURE 41–34 A six-speed Lepelletier transmission based on a planetary gear and a Ravigneaux gearset.

is an example of the power flow for a typical six-speed unit.

- **Drive: First Gear—**For first gear, the rear carrier is held. This transfers torque from the sun gear in the rear planetary assembly to the ring gear **(Figure 41–35)**. The transmission is now in first gear.
- **Drive: Second Gear—**When shifting into second gear, the large sun gear of the rear planet is held. The sun gear now transfers torque through the short and long planetary pinions to the ring gear, which is the output.
- **Drive: Third Gear—**Third gear is achieved by locking the input shaft and both of the sun gears in the compound gearset together. This forces both of the rear planetary assemblies to lock and drive the output ring gear.
- **Drive: Fourth Gear—**For fourth gear, the input is transferred from the single gearset's carrier to the large sun gear and the planetary carriers in the compound gearset **(Figure 41–36)**. The ring gear is then driven with a slight reduction.
- **Drive: Fifth Gear—**In fifth gear, the input moves from the single planetary unit's carrier to the small sun gear and the planetary carrier in the compound gearset. The ring gear is then driven at an overdrive.

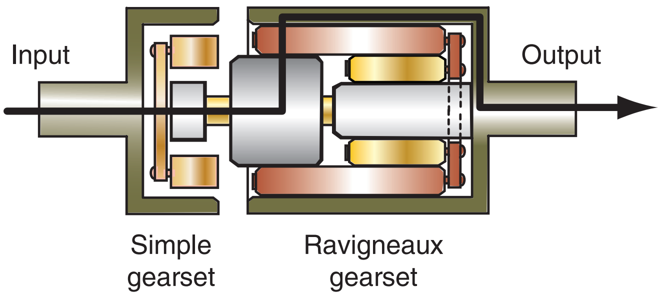


FIGURE 41–35 Power flow in first gear for a typical Lepelletier gearset.

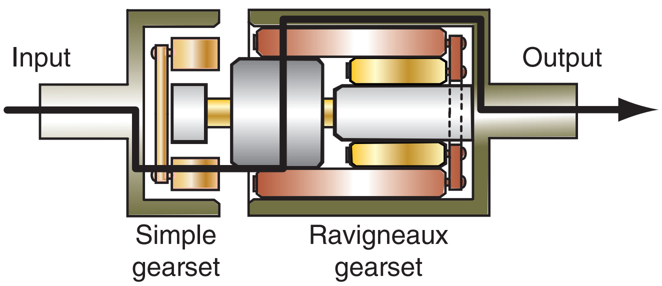


FIGURE 41–36 Power flow in fourth gear for a typical Lepelletier gearset.

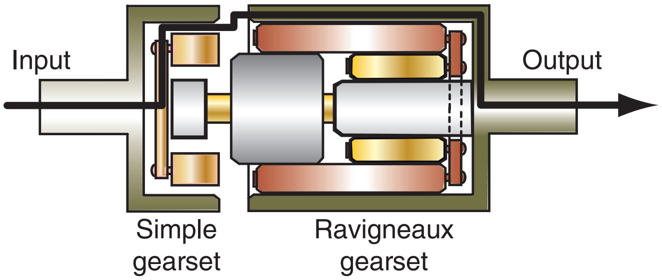


FIGURE 41–37 Power flow in sixth gear for a typical Lepelletier gearset.

- **Drive: Sixth Gear—**Sixth speed is made by holding the front sun gear in the compound gearset. The input shaft is locked to the carrier of the compound gear. The carrier then drives the ring gear to provide for an overdrive output **(Figure 41–37)**.
- **Reverse—**For reverse, the ring and planet gears of the simple planetary rotate together. The single sun gear is held and rotates the carrier and the sun gear of the compound planetary gear (rear) assembly. The rear planet carrier is also held. The long planets in the compound gear rotate with the rear sun gear. This causes the ring gear to rotate backward and drives the output shaft in reverse.

Honda's Nonplanetary-Based Transmission

The Honda nonplanetary-based transaxles are used in many Honda and Acura cars. Saturn automatic transaxles were also based on this design. These transmissions are unique in that they use constant-mesh helical and square-cut gears in a manner similar to that of a manual transmission.

These transaxles have a mainshaft and countershaft on which the gears ride. To provide the four forward and one reverse gear, different pairs of gears are locked to the shafts by hydraulically controlled clutches **(Figure 41–38)**. Reverse gear is obtained through the use of a shift fork that slides the reverse gear into position. The power flow through these transaxles is also similar to that of a manual transaxle.

The action of the clutches is much the same as the action of the synchronizer assemblies in a manual transaxle. Honda uses four multiple-disc clutches, a sliding reverse gear, and a one-way clutch to control the gears.

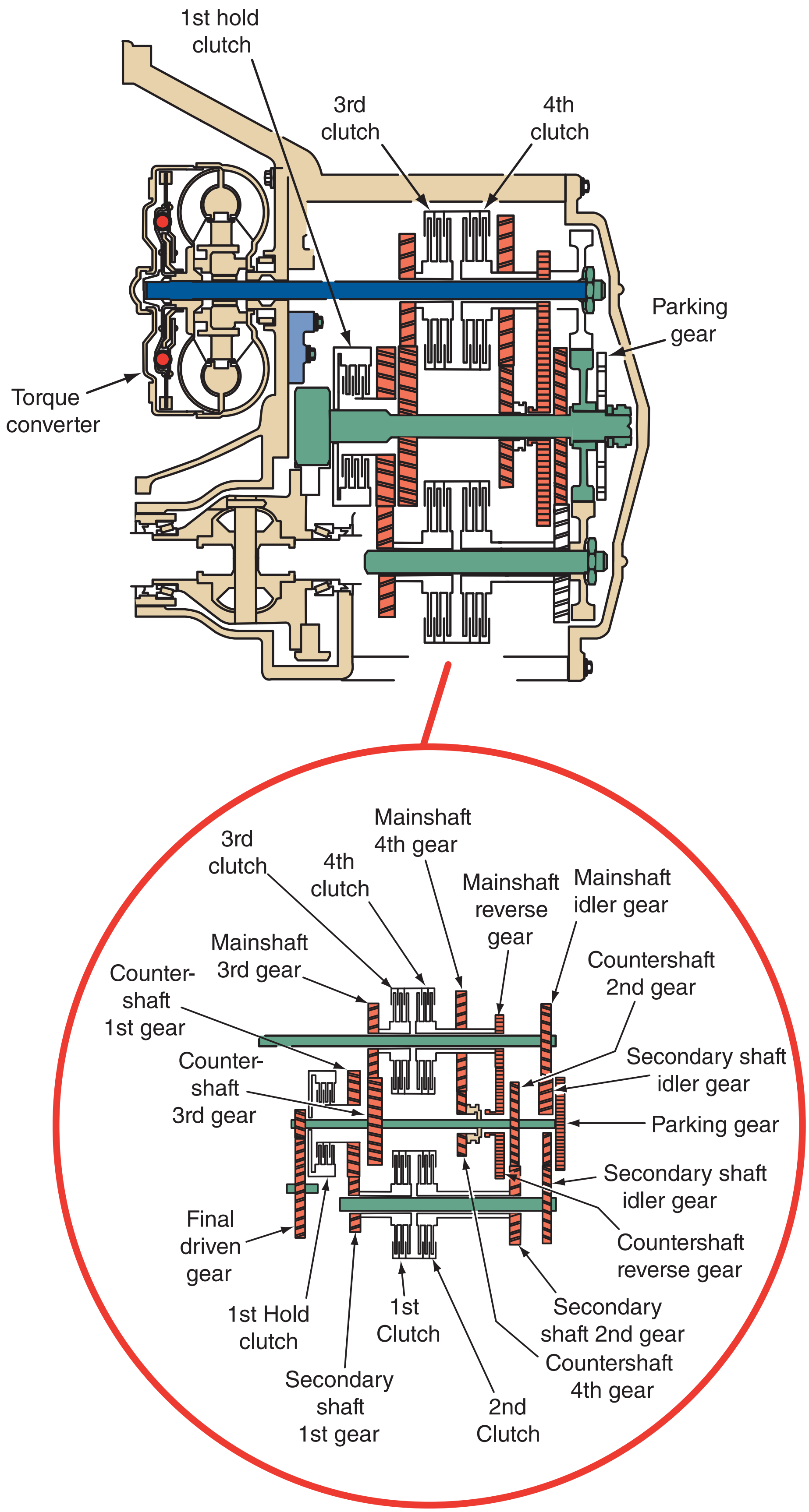


FIGURE 41–38 Arrangement of gears and reaction devices in a typical nonplanetary gearset transaxle.

Continuously Variable Transmissions (CVT)

Another unconventional transmission design, the **continuously variable transmission (CVT)**, is a transmission with no fixed forward speeds. The gear ratio varies with engine speed and temperature. These transmissions are, however, fitted with a one-speed reverse gear. Some CVT transaxles do not have a torque converter; rather, they use a manual-transmission-type flywheel with a start clutch. The start clutch is designed to slip just enough to get the car moving without stalling or straining the engine. The start clutch can be electrically or hydraulically controlled.

Instead of relying on planetary or helical gearsets to provide drive ratios, a CVT uses belts and pulleys **(Figure 41–39)**. One pulley is the driven member and the other is the drive. Each pulley has a movable face and a fixed face. When the movable face moves, the effective diameter of the pulley changes. The change in effective diameter changes the effective pulley (gear) ratio. A steel belt links the driven and drive pulleys **(Figure 41–40)**.

A CVT can automatically select any desired drive ratio within its operating range. It automatically and continuously selects the best overall ratio for the operating conditions. During drive ratio changes, there is no perceptible shift. The controls of this type of transmission attempt to keep the engine operating at its most efficient speed. This decreases fuel consumption and exhaust emissions. During maximum acceleration, the drive ratio is adjusted to maintain peak engine horsepower. At a constant vehicle speed, the drive ratio is set to obtain maximum fuel mileage while maintaining good driveability.

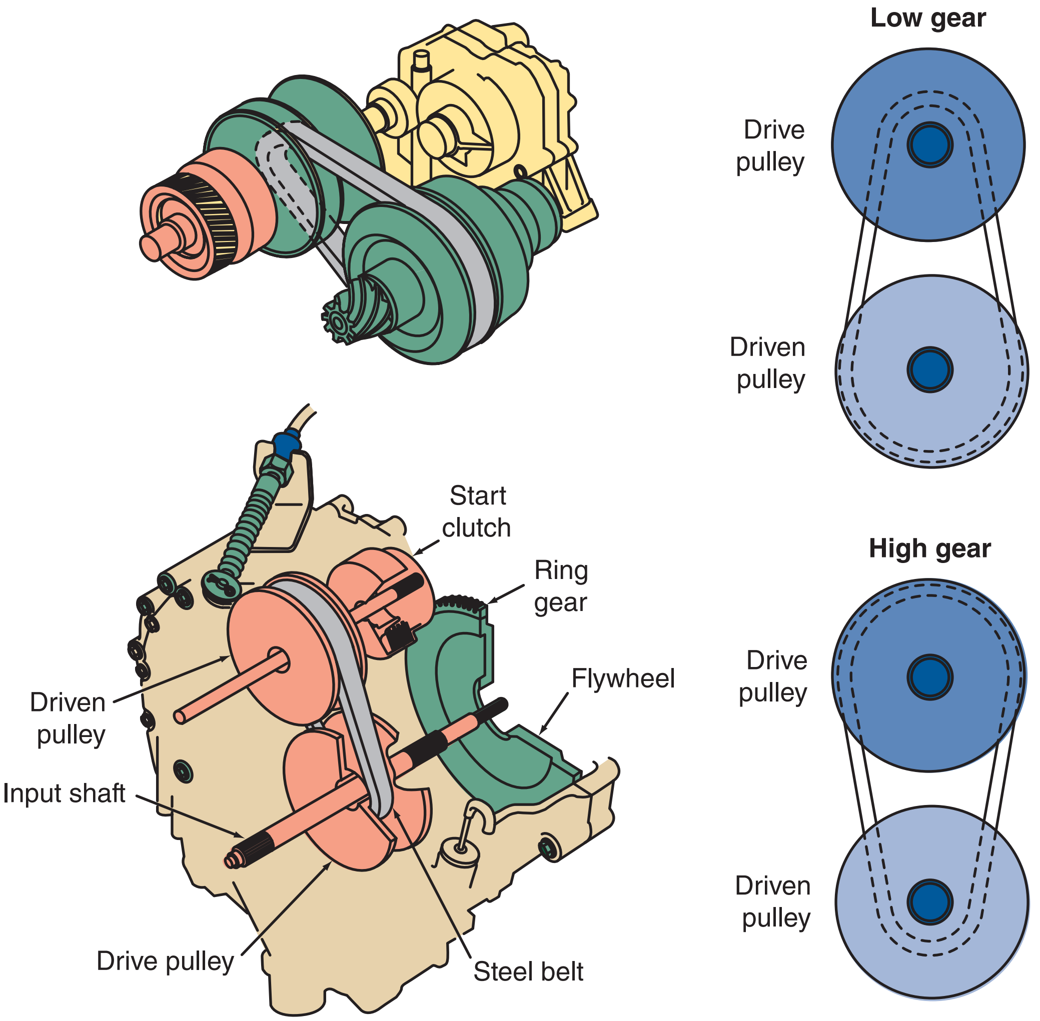


FIGURE 41–39 Honda's CVT.

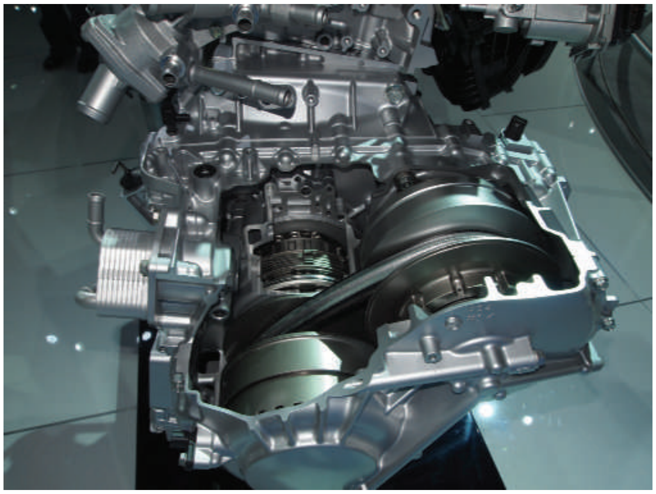


FIGURE 41–40 CVTs use pulleys that change size and are connected by a belt.

To achieve a low pulley ratio, high hydraulic pressure works on the movable face of the driven pulley to make it larger. In response to this high pressure, the pressure on the drive pulley is reduced. Since the belt links the two pulleys and proper belt tension is critical, the drive pulley reduces just enough to keep the proper tension on the belt. The increase of pressure at the driven pulley is proportional to the decrease of pressure at the drive pulley. The opposite is true for high pulley ratios. Low pressure causes the driven pulley to decrease in size, whereas high pressure increases the size of the drive pulley.

Different speed ratios are available any time the vehicle is moving. Because the size of the drive and driven pulleys can vary greatly, vehicle loads and speeds can be changed without changing the engine's speed. With this type of transmission, attempts are made to keep the engine operating at its most efficient speed, thus increasing fuel economy and decreasing emissions.

Many late-model CVTs are equipped with a feature that simulates the activity of a manual shifting automatic transmission. These transmissions have five or six predetermined areas that the pulleys stop in, thereby giving the feel and shift effect of distinct shifts.

CVT Controls

The control system for a typical CVT consists of a TCM, various sensors, linear solenoids, and an inhibitor solenoid. Input from the various sensors determines which drive ratio will command **(Figure 41–41)**. Activating the shift control solenoid changes the shift control valve pressure, causing the shift valve to move. This changes the pressures applied to the driven and drive pulleys, which changes the effective pulley ratio.

Planetary Gear-Based CVTs

Hybrid vehicles from Toyota and Ford rely on a planetary gearset to provide for a CVT. The transaxle contains two electric motor/generators, a differential, and a simple planetary gearset. The engine and the motor/generators are connected directly to the planetary gear unit **(Figure 41–42)**. The planetary gearset is called the power split device because it can transfer power between the engine, motor/generators, drive wheels, and nearly any combination of these. The power split device splits power from the engine to different paths: to drive one of the motor/generators or to drive the car's wheels, or both. The other motor/generator can drive the wheels, assist the engine in driving the wheels, or be driven by the wheels. The speed ratios change in response to the torque applied to the various members of the gearset. In this arrangement, there are basically two sources of torque: the engine and an electric traction motor. Both rotate in the same direction but not at the same speed. Therefore, one can assist the rotation of the other, slow down the rotation of the other, or work together.

Toroidal CVT

Another version of the CVT, the toroidal CVT, uses discs and power rollers instead of pulleys and belts. Nissan calls their version of this style CVT an "Extroid toroidal CVT."- Toroidal CVTs provide the same gains and results as other CVTs, however the gear changes are much less abrupt and their reliability is better. The unit is comprised of two separate discs, one connected to the engine (the input disc or driving disc) and the other connected to the drive shaft (the output or driven disc). Each of the discs have a concave shape from the outside and inside of the discs, placed next to each other they form an hour glass shape.

Filling the concave portion of the discs are hydraulically controlled power rollers or wheels, these wheels transmit power from one disc to the other. The angle of the wheels as they ride between the input and output discs determine the effective drive gear ratio. When the rollers contact the driving disc near its center, they also contact the driven disc near its outside edge. This results in a speed reduction and torque increases when the rollers contact near the edge of the driving disc. They also contact the driven disc near the center, resulting in decrease in torque but an

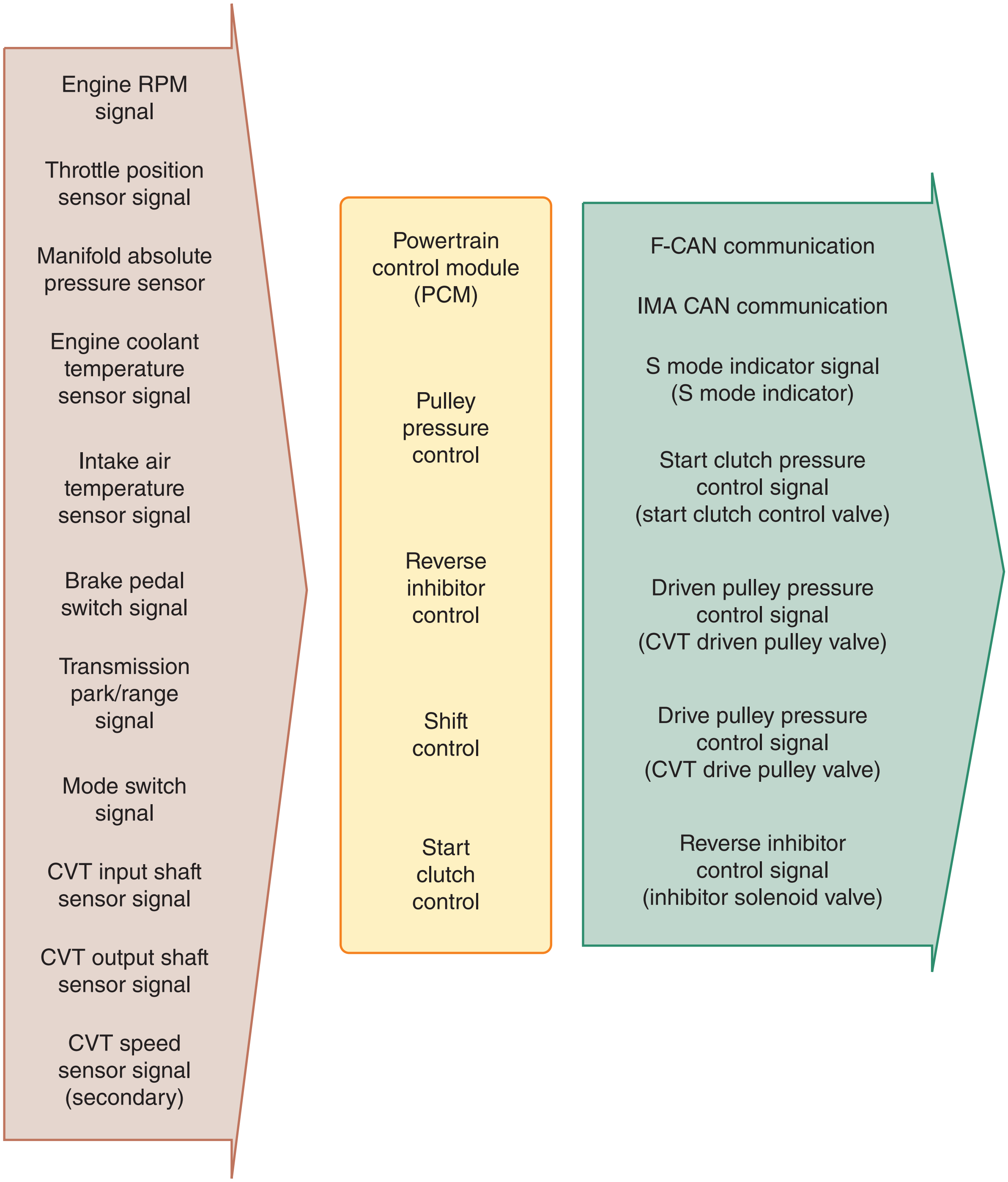


FIGURE 41–41 The input, processing, and control systems for the electronic control of a Honda CVT.

increase in speed. Therefore the tilt of the rollers will incrementally change the effective drive ratio for what seems to be a truly stepless gear changes.

Two-Mode Hybrid System

GM, BMW, and Chrysler together developed a two-mode full hybrid system. The **two-mode hybrid system** is another planetary gear-based CVT. The system fits into a standard transmission housing and is basically two planetary gearsets coupled to two electric motors, which are electronically controlled. This combination results in a CVT with motor/generators for hybrid operation. The system has two distinct modes of operation. It operates in the first mode during low speed and low load conditions and in the second mode while cruising at highway speeds.

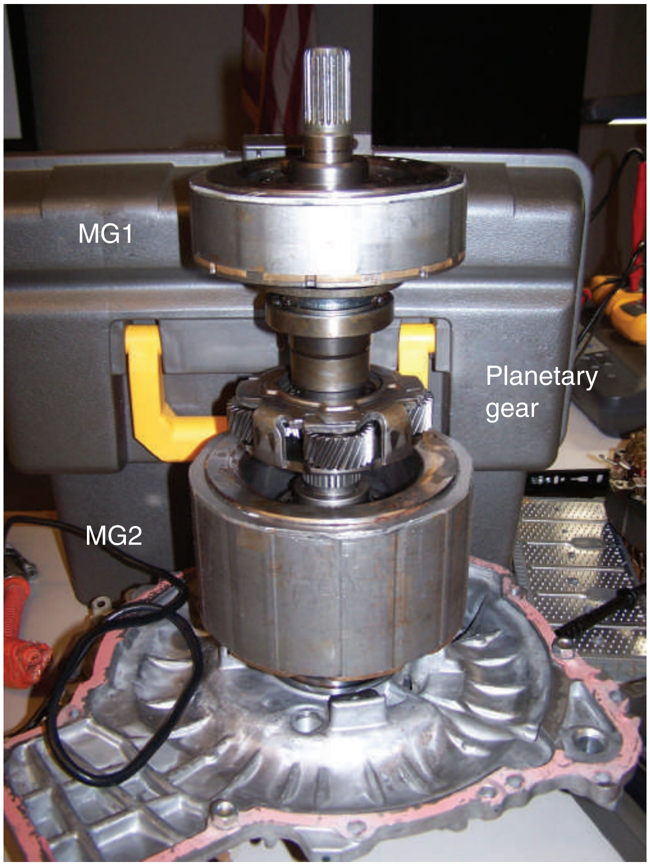


FIGURE 41–42 In this hybrid CVT, the planetary gearset is located between two electric motors.

The two-mode hybrid system can operate solely on electric or engine power, or a combination of the two. Electronic controls are used to control the output of the motors and the engine.

Two compact electric motors are connected to the transmission's gearsets. The gears work to increase the torque output of the motors. Typically, when one or both of the motors are not providing propulsion power, they work as generators driven by the engine or by the drive wheels for regenerative braking.

Planetary Gear Controls

Certain parts of the planetary geartrain must be held, while others must be driven to provide the needed torque multiplication and direction for vehicle operation. Apply or control devices are used to set the power flow through the gearset. A control device is activated hydraulically or by the direction of gear rotation. There are two basic classifications of control devices: driving or reaction. A driving member connects the engine's torque to a member of the gearset and a reaction device prevents a gearset member from rotating or limits the amount of rotation. Control devices are transmission bands and hydraulic or mechanical clutches.

Transmission Bands

A **band** is a braking assembly positioned around a stationary or rotating drum or carrier. The band brings a drum to a stop by wrapping itself around the drum and holding it. The band is hydraulically applied by a servo assembly. Connected to the drum is a member of the planetary geartrain. The purpose of a band is to hold a member of the planetary gearset by holding the drum and connecting planetary gear member stationary. Bands provide excellent holding characteristics and require a minimum amount of space within the transmission housing.

When a band closes around a rotating drum, a wedging action takes place to stop the drum from rotating. The wedging action is known as self-energizing action. A typical band is designed to be larger in diameter than the drum it surrounds. This design promotes the self-disengagement of the band from the drum when the servo apply force is decreased to less than the servo release spring tension. A friction material is bonded to the inside diameter of the band.

Typically, if the band will be holding a low-speed drum, the lining material of a band is a semimetallic compound. If the band is designed to hold a high-speed drum, it will have a paper-based lining.

Band lugs are either spot welded or cast as a part of the band assembly. The purpose of the lugs is to connect the band with the servo through the actuating (apply) linkage and the band anchor (reaction) at the opposite end. The band's steel strap is designed with slots or holes to release fluid trapped between the drum and the applying band.

The bands used in automatic transmissions are rigid, flexible, single wrap, or double wrap types. Steel single wrap bands **(Figure 41–43A)** are used to hold geartrain components driven by high-output engines. Self-energizing action is low because of the rigidity of the band's design. Thinner steel bands are not able to provide a high degree of holding power, but because of the flexibility of design, self-energizing action is stronger and provides more apply force.

SHOP TALK

A holding planetary control unit is also called a brake or reaction unit because it holds a geartrain member stationary, reacting to rotation.

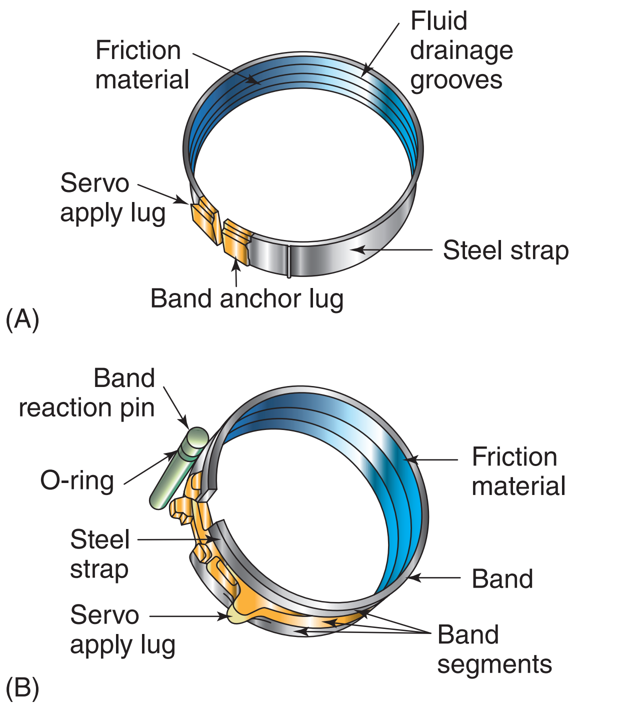


FIGURE 41–43 (A) Typical single wrap and (B) double wrap transmission band designs.

The double wrap band is a circular external contracting band normally designed with two or three segments **(Figure 41–43B)**. As the band closes, the segments align themselves around the drum and provide a cushion. The steel body of the double wrap band may be thin or thick steel strapping material. Modern automatic transmissions use thin single or double wrap bands for increased efficiency. Double wrap bands made with heavy thick steel strapping are required for high output engines.

Transmission Servos

The **servo** assembly converts hydraulic pressure into a mechanical force that applies a band to hold a drum stationary. Simple and compound servos are used to engage bands in modern transmissions.

Simple Servo In a simple servo **(Figure 41–44)**, the servo piston fits into the servo cylinder and is held in the released position by a coil spring. The piston is sealed with a rubber ring, which keeps fluid pressure confined to the apply side of the servo piston.

To apply a band, fluid pressure is directed to the apply side of the servo piston. The servo piston moves against the return coil spring and develops servo apply force. This force is applied to the band lug through the apply lever and strut. At the opposite end of the band is the anchor strut or end pin and adjustment screw. These hold that end of the band stationary as the band tightens around the rotating drum. The rotating drum comes to a stop and is held stationary by the band.

When servo apply force is released, the return spring forces the servo piston to move in the cylinder.

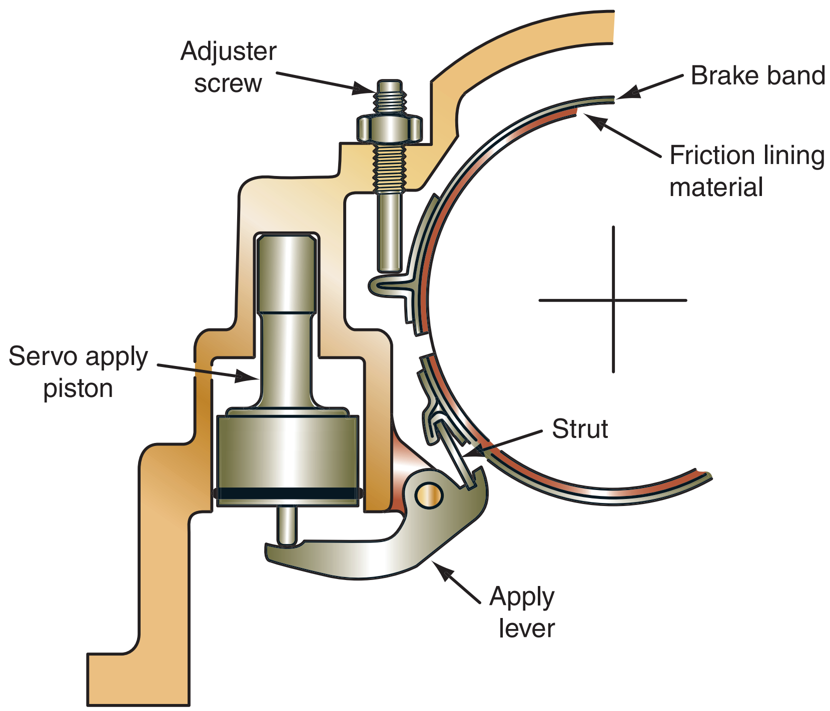


FIGURE 41–44 A typical band and servo assembly.

With the servo apply force removed, the band springs free and permits drum rotation. Remember, in most automatic transmissions, hydraulic pressure applies the band and spring pressure releases it.

Compound Servo A compound servo **(Figure 41–45)** has a cylinder that is cast as part of the transmission housing. If the servo is located near the front of the transmission, it uses seal rings capable of withstanding the heat generated by the torque converter and engine.

When the compound servo is applied, fluid pressure flows through the hollow piston pushrod to the apply side of the servo piston. The piston compresses the servo coil spring and forces the pushrod to move one end of the band toward the adjusting screw and anchor. The band tightens around the rotating drum and brings it to a stop. The apply of the compound servo piston is much like the simple servo, but there the similarity ends.

Fluid pressure is applied to the release side of the servo piston when the band is to be released. This provides equal pressure on both sides of the piston and allows the tension of the servo spring to push the piston back up its bore. This action releases the band.

In some transmissions, the servo piston has a larger area on the release side, which causes a more positive release. This design is used to ensure that a band is released before another reaction member is applied.

Transmission Clutches

In contrast to a band, which can only hold a planetary gear member, transmission clutches are capable of both holding and driving members.

One-Way Clutches

In an automatic transmission, both sprag and roller one-way or overrunning clutches are used to hold drive members of the planetary gearset. These clutches operate mechanically and apply and release quickly in response to their rotational direction; this allows for smooth gear changes.

In a roller type **(Figure 41–46)**, roller bearings are held in place by springs to separate the inner and outer races of the clutch assembly. One of the races is normally held by the transmission case and is unable to rotate. Around the inside of the outer race are several cam-shaped indentations. The rollers and springs are located in these pockets. Rotation of one race in one direction locks the rollers between the two races, preventing the race from moving. When the race is rotated in the opposite direction, the roller bearings move into the pockets and are not locked and the race is free to rotate.

A one-way sprag clutch **(Figure 41–47)** consists of a hub and drum separated by figure-eight-shaped metal pieces called sprags. The sprags are shaped so that they lock between the races when a race is

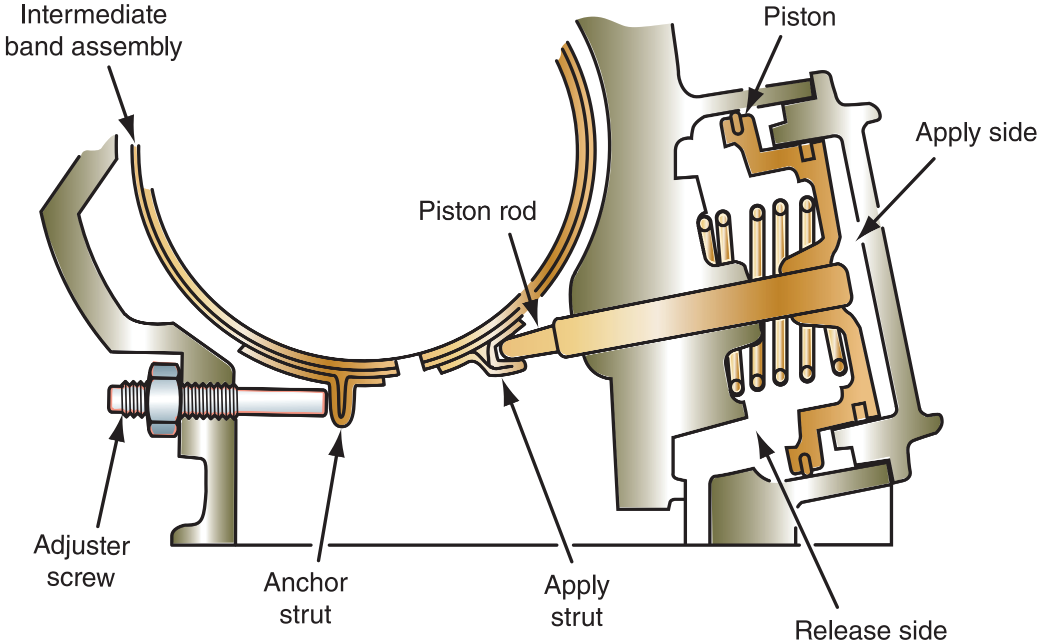


FIGURE 41–45 A typical compound servo design.

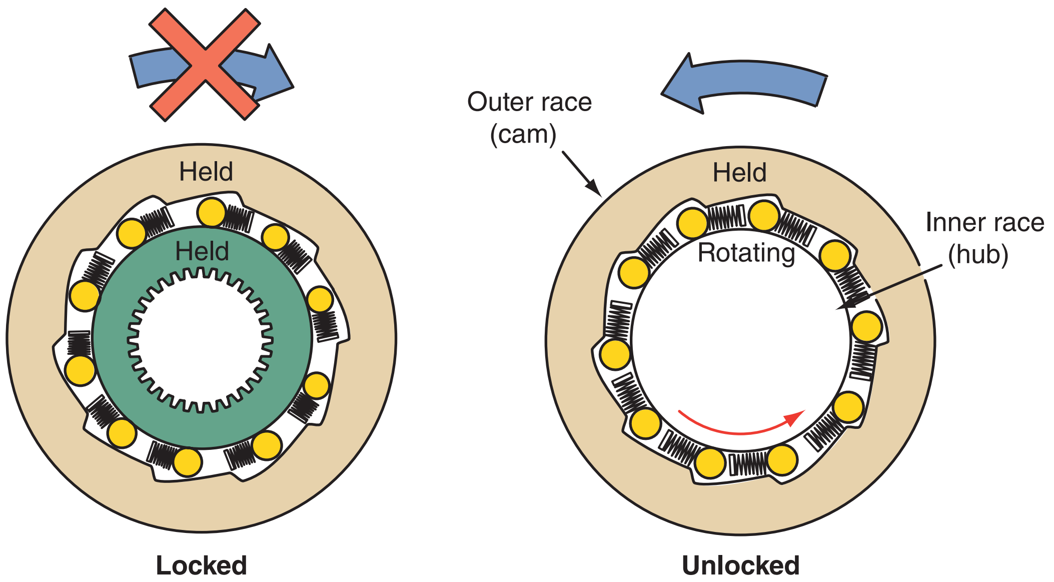


FIGURE 41–46 The action of a one-way roller clutch.

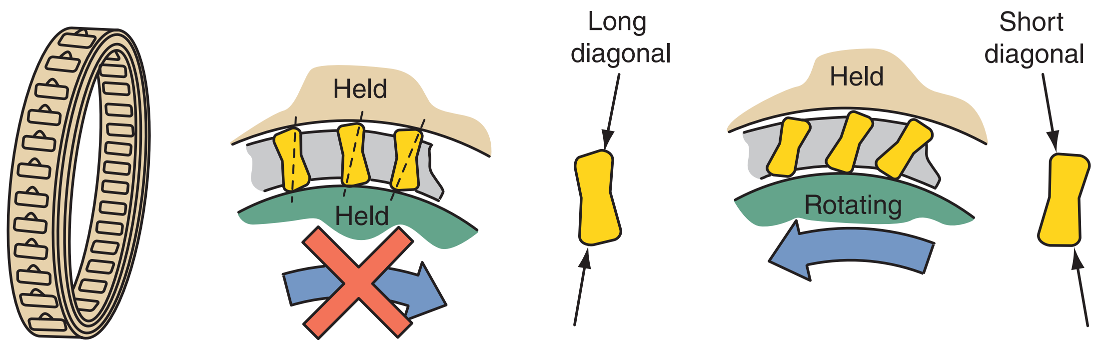


FIGURE 41–47 The action of a sprag-type one-way clutch.

turned in one direction only. The sprags are longer than the distance between the two races. Springs hold the sprags at the correct angle and maintain the sprags' contact with the races, thereby allowing for instantaneous engagement. When a race rotates in one direction, the sprags lift and allow the races to move independently. When a race is moved in the opposite direction, the sprags straighten and lock the two races together.

Sprag and roller clutches can be used to hold a member of the gearset by locking the inner race to the outer race, which is held by the transmission housing **(Figure 41–48)**. Both types also are effective as long as the engine powers the transmission. When the transmission is in a low gear and is coasting, the drive wheels rotate the transmission's output shaft with more power than is present on the input shaft. This allows the sprags or rollers to unwedge and begin freewheeling. This means they rotate without affecting the input or output of the gearset. When one-way clutches are freewheeling, they are off or ineffective. Freewheeling normally takes place when the clutch is rotating in a counterclockwise direction.

Selectable One-Way Clutch

Found in the new 10-speed automatic developed jointly by GM and Ford, is a selectable one-way clutch (SOWC). In addition to operating as a standard one-way clutch, the SOWC can allow locking in both directions or freewheeling in both directions based on the demand. There are two methods for locking and unlocking the clutch, a tangential and an axial selector plate. In the tangential style, a sliding selector plate moves to the side to allow struts to pop up and lock a second plate. As the selector plate moves back over the struts, they recess back down and unlock the plates. The axial design uses an actuator plate that pushes the struts upward and through openings in the second plate. Pulling the actuator plate back releases the struts.

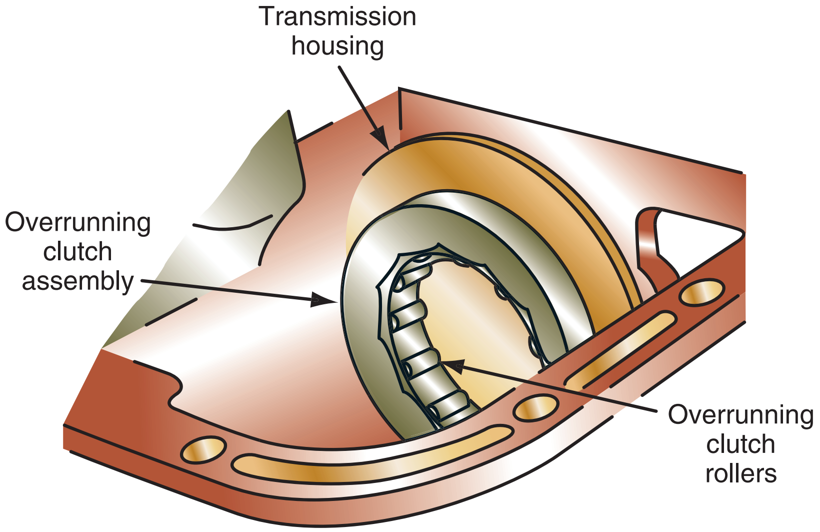


FIGURE 41–48 A one-way clutch secured in a transmission housing.

Multiple-Friction Disc Clutch and Brake Assemblies

The **multiple-disc assembly (Figure 41–49)** can be used to drive or hold a member of the planetary gearset. The assemblies can serve as a brake by locking a gearset member to the transmission housing to prevent it from rotating. They can also be used to lock one race of a one-way clutch. As a brake, a multiple disc pack serves the same purpose as a band; however, because there is much more surface area on the friction discs, it has greater holding capabilities. The multiple-friction disc pack can also be used to connect and hold two planetary members together. Multiple-disc assemblies are often referred to as clutch packs.

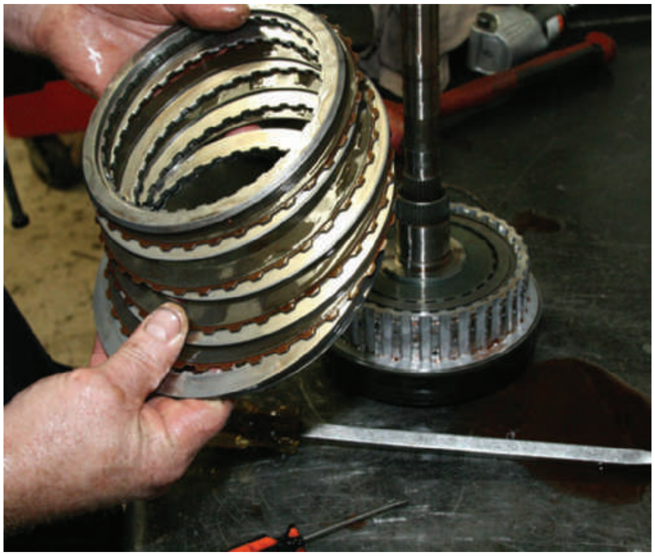


FIGURE 41–49 In a multiple-disc clutch assembly, friction plates are positioned between steel plates.

The multiple-disc assembly used in automatic transmissions is a "wet clutch." When it is used as a clutch to connect and hold two members together, it **(Figure 41–50)** typically has friction discs, steel plates, clutch drum and hub, apply piston, and return spring(s). When it is used as a brake, it has the same basic parts but uses the transmission housing instead of a clutch drum.

The clutch pack has several plates lined with friction material and steel separator discs that are placed alternately inside a clutch drum. The friction plates are lined with rough frictional material on their faces, whereas the steel discs have smooth faces without friction material. A friction plate has friction material bonded to both sides of a steel plate **(Figure 41–51)**. Paper cellulose is the most commonly used friction material because it offers good holding power without the high frictional wear of metallic materials. The friction plates often have grooves cut in them to help keep them cool, thereby increasing their effectiveness and durability. Friction discs are always mounted between two steel plates.

The steel plates provide a smooth surface for the friction discs to engage. Plates can be installed steel-to-steel to create a specific clearance for the clutch pack. The set of friction or steel plates has splines on its inner edges, while the other set is splined on its outer edges. The splines of each set fit into matching splines on a shaft, drum, member of the gearset, or the transmission case.

The discs are mounted in the clutch drum or in the housing of the transmission. The drum or housing also contains the apply piston, seals, and return springs. Hydraulic pressure moves the apply piston against

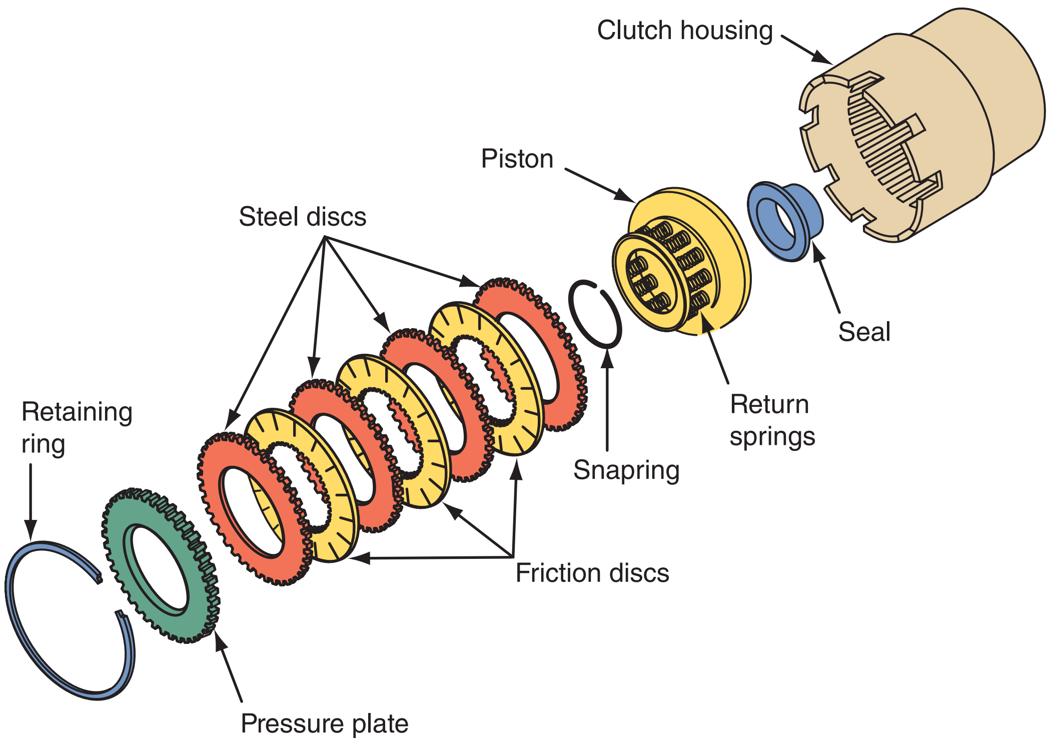


FIGURE 41–50 A multiple-disc clutch assembly.

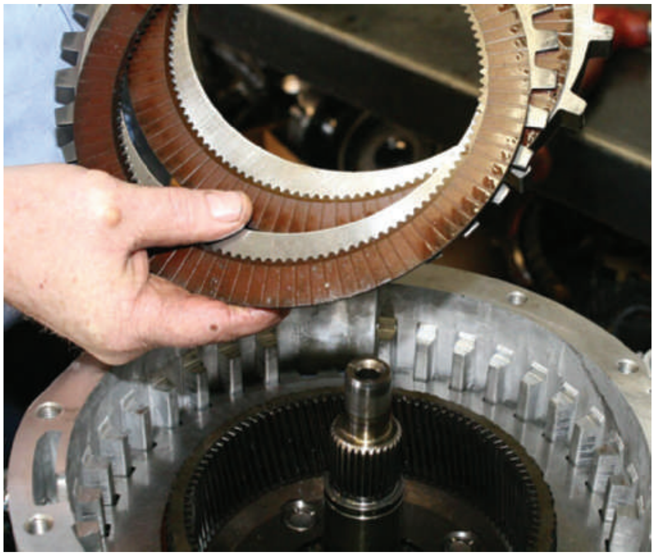


FIGURE 41–51 The friction plates have friction material bonded to both sides.

return spring pressure and clamps the plates against the pressure plate. The friction between the plates locks them together, causing them to turn as a unit.

The pressure plate is a heavy metal plate that provides the clamping surface for the plates and is installed at one, or both, ends of the pack. The seals hold in the hydraulic pressure when the clutch pack is applied. In a typical pack, the apply piston is held in place by the return springs and a spring retainer secured by a snapring.

The apply piston is retracted by one large coil spring, several small springs **(Figure 41–52)**, or a single Belleville spring. The type and number of return springs used in the pack is determined by the pressure needed to release the piston quickly enough to prevent dragging. However, the amount

FIGURE 41–52 The apply piston can be retracted by several small springs.

of spring tension is limited to minimize the resistance to moving the piston.

A Belleville spring acts to improve the clamping force of the assembly, and as a piston return spring. The spring is locked into a groove inside the drum by a snapring. As the piston moves to apply the pack, it moves the inner ends of the Belleville spring fingers into contact with the pressure plate to apply the assembly. The spring's fingers act as levers against the pressure plate and increase the application force of the pack. When hydraulic pressure to the piston is stopped, the spring relaxes and returns to its original shape. The piston is forced back and the pack is released.

Some clutch drums or pistons have a check ball and vent port. The vent port and check ball are used to relieve any residual pressure when the pack is released. The check ball is forced against its seat when full hydraulic pressure is applied to the pack. This holds the pressure inside the drum. When the pressure is stopped, only residual pressure remains on the check ball. Centrifugal force pulls the ball from its seat and allows the fluid to escape from the drum through the open vent port. When a multiple disc pack is used as a brake, there is no need for the check ball. Since the unit does not rotate, centrifugal force will have no affect on the fluid behind the piston.

Newer transmissions do not have a vent port or a check ball. Rather they have a centrifugal fluid pressure canceling system. This system has opposing fluid chambers that apply equal amounts of centrifugal force to both sides of the piston. As the clutch drum rotates, fluid in the canceling pressure chamber counters the pressure built up inside the drum pressure chamber. This cancels out the effects of centrifugal force on piston movement and leads to smoother shifts.

Multiple-disc packs can function as holding or driving devices, depending on what they are splined to. When a pack locks two members of a planetary gearset together, it is a driving device **(Figure 41–53)**. To apply the clutch, hydraulic pressure is routed to the side of the piston opposite the return springs. When the pressure overcomes the tension of the return spring(s), the springs compress and the piston squeezes the friction discs and steel plates tightly together so they rotate as a unit.

A multiple-disc pack may also be used to hold one member of the planetary gearset. The friction discs are splined on their inner edges and are fit into matching splines on the outside of a drum. The steel discs are splined on their outer edges and fit into matching splines machined into the transmission case **(Figure 41–54)**. When the pack is applied, the gearset member cannot rotate as it is locked to the transmission case.

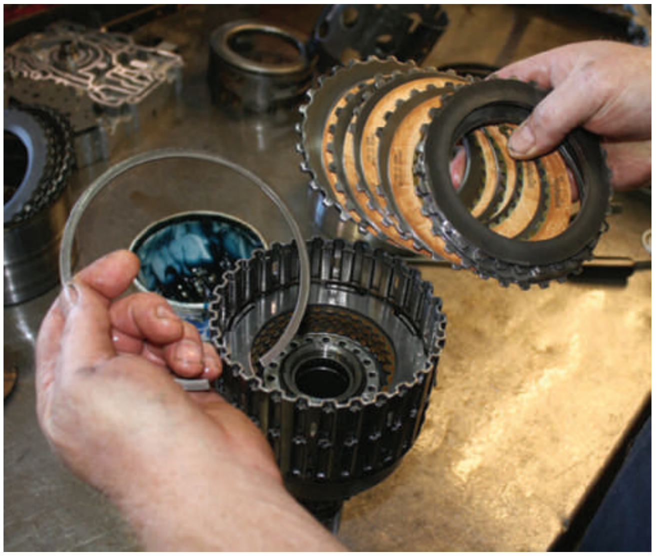


FIGURE 41–53 These discs fit into the clutch drum.

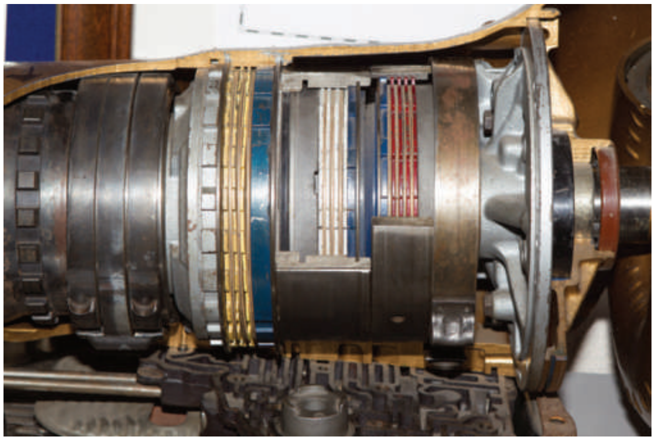


FIGURE 41–54 These discs are fitted into the case and a clutch drum.

Several factors contribute to the effectiveness of a clutch pack:

- The type of frictional material used on the friction discs.
- The composition of the steel plates and their surface finish.
- Sufficient fluid flow to cool the clutch pack.
- Condition and type of transmission fluid.
- Proper grooving of the lining on the friction plates to aid in the cooling process.
- Proper clutch plate clearances.
- The force used to apply the clutch.

Bearings, Bushings, and Thrust Washers

When a component slides over or rotates around another part, the surfaces that contact each other are called bearing surfaces. A gear rotating on a fixed shaft can have more than one bearing surface; it is supported and held in place by the shaft in a radial direction. Also, the gear tends to move along the shaft in an axial direction as it rotates and is therefore held in place by some other components. The surfaces between the sides of the gear and the other parts are bearing surfaces.

A bearing is a device placed between two bearing surfaces to reduce friction and wear. Most bearings have surfaces that either slide or roll against each other. In automatic transmissions, sliding bearings are used where one or more of the following conditions prevail: low rotating speeds, very large bearing surfaces compared to the surfaces present, and low-use applications. Rolling bearings are used in high-speed applications, high load with relatively small bearing surfaces, and high use.

Transmissions use sliding bearings composed of a relatively soft bronze alloy. Many are made from steel with the bearing surface bonded or fused to the steel. Those that take radial loads are called bushings and those that take axial loads are called thrust washers **(Figure 41–55)**. The bearing's surface usually runs against a harder surface such as steel to produce minimum friction and heat wear characteristics.

Bushings are cylindrically shaped and usually held in place by press fit. Since bushings are typically made of a soft metal, they act like a bearing and support many of the transmission's rotating parts **(Figure 41–56)**. They are also used to precisely guide the movement of various valves in the transmission's valve body. Bushings can also be used to control fluid flow; some restrict the flow from one part to another, while others are made to direct fluid flow to a particular point or part in the transmission.

Often serving both as a bearing and a spacer, thrust washers are made in various thicknesses. They may have one or more tangs or slots on the inside or outside circumference that mate with the shaft bore to keep them from turning. Some thrust washers are made of nylon or Teflon, which are used when the load is low. Others are fitted with rollers to reduce friction and wear.

Thrust washers normally control free axial movement or end play. Since some end play is necessary in all transmissions because of heat expansion, proper end play is often accomplished through selective thrust washers. These thrust washers are inserted between various parts of the transmission. Whenever end play is set, it must be set to manufacturer's specifications. Thrust washers work by filling the gap between two objects and become the primary wear item because they are made of softer materials than the parts they protect. Normally, thrust washers are made of copper babbit-faced soft steel, bronze, nylon, or plastic.

Torrington bearings (Figure 41–57) are thrust washers fitted with roller bearings. These thrust bearings are primarily used to limit end play but also to reduce the friction between two rotating parts. Most often, Torrington bearings are used in combination with flat thrust washers to control end play of a shaft or the gap between a gear and its drum.

The bearing surface is greatly reduced through the use of roller bearings. The simplest roller bearing design leaves enough clearance between the bearing surfaces of two sliding or rotating parts to accept some rollers. Each roller's two points of contact between the bearing surfaces are so small that friction is greatly reduced. The bearing surface is more like a line than an area.

If the roller length-to-diameter is about 5:1 or more, the roller is called a needle and such a bearing is called a needle bearing. Sometimes the needles are loose or they can be held in place by a steel cylinder or by rings at each end. Often the latter are drilled to accept pins at the ends of each needle that act as axles. These small assemblies help save the agony of losing one or more loose needles and the delay caused by searching for them.

Many other roller bearings are designed as assemblies. The assemblies consist of an inner and outer race, the rollers, and a cage. There are roller bearings designed for radial loads and others designed for axial loads.

A tapered roller bearing is designed to accept both radial and axial loads. Its rollers turn on an angle to the bearing assembly's axis rather than parallel to it. The rollers are also slightly tapered to fit the angle of the inner and outer races. The bearing assembly consists of an inner race, the rollers, the cage, and the outer race. Tapered roller bearings are normally used in pairs and are rarely used in automatic transmissions. They are commonly used in final drive units.

The heaviest radial loads in automatic transmissions are carried by either roller or ball bearings. Ball bearings are constructed similarly to roller bearings, except that the races are grooved to accept the balls. The groove radius is slightly larger than the ball radius, which reduces the bearing surface area more than the roller bearing does. A ball bearing can also

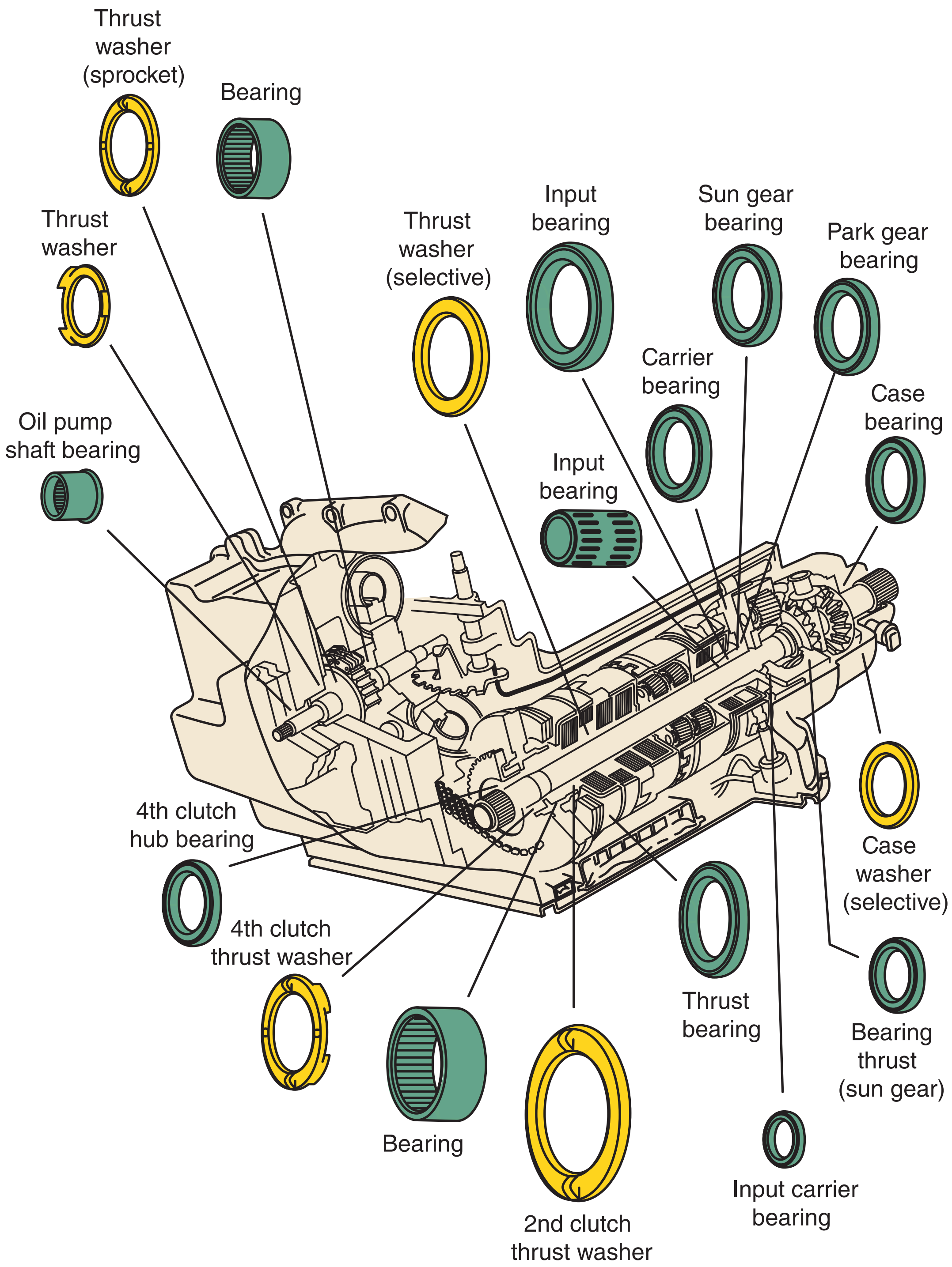
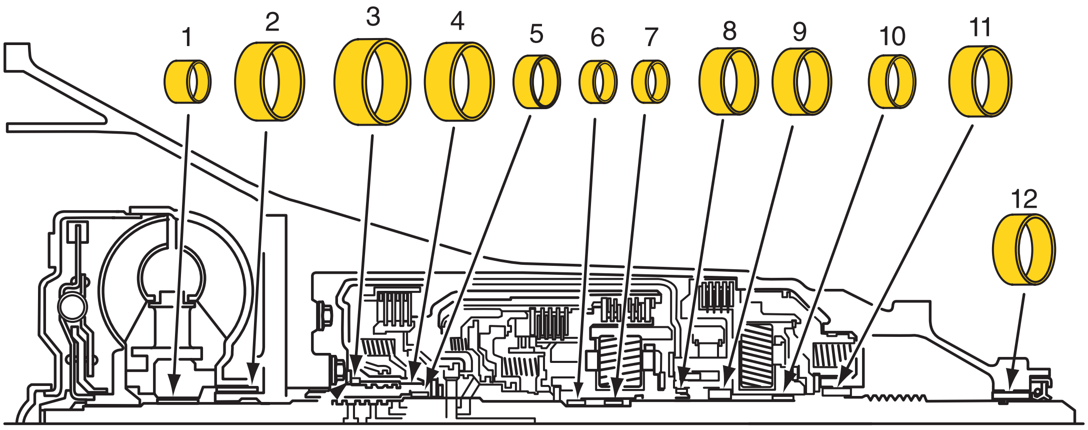


FIGURE 41–55 The location of various bearings and thrust washers in a typical transaxle.

withstand light axial loads. Lip seals are sometimes built into ball bearings to retain lubricants.

Snaprings

Many different sizes and types of snaprings are used in today's transmissions. External and internal snaprings are used as retaining devices throughout the transmission. Internal snaprings are used to hold servo assemblies and clutch assemblies together. In fact, snaprings are also available in several thicknesses and may be used to adjust the clearance in multiple-disc clutches. Some snaprings for clutch packs are waved to smooth clutch application. External snaprings are used to hold gear and clutch assemblies to their shafts.



Legend

1. Bushing, stator shaft (front)
2. Bushing, oil pump body
3. Bushing, reverse input clutch (front)
4. Bushing, reverse input clutch (rear)
5. Bushing, stator shaft (rear)
6. Bushing, input sun gear (front)
7. Bushing, input sun gear (rear)
8. Bushing, reaction carrier shaft (front)
9. Bushing, reaction gear
10. Bushing, reaction carrier shaft (rear)
11. Bushing, case
12. Bushing, case extension

FIGURE 41–56 Bushings are used throughout a transmission.

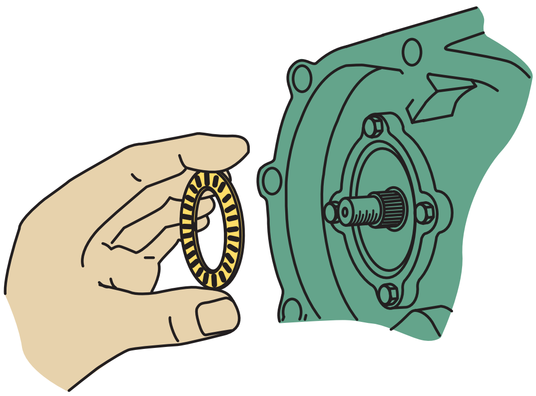


FIGURE 41–57 A Torrington-type axial thrust bearing.

Gaskets and Seals

The gaskets and seals of an automatic transmission help to contain the fluid within the transmission and prevent the fluid from leaking out of the various hydraulic circuits. Different types of seals are used in automatic transmissions; they can be made of rubber, metal, or Teflon **(Figure 41–58)**. Transmission gaskets are made of rubber, cork, paper, synthetic materials, metal, or plastic.

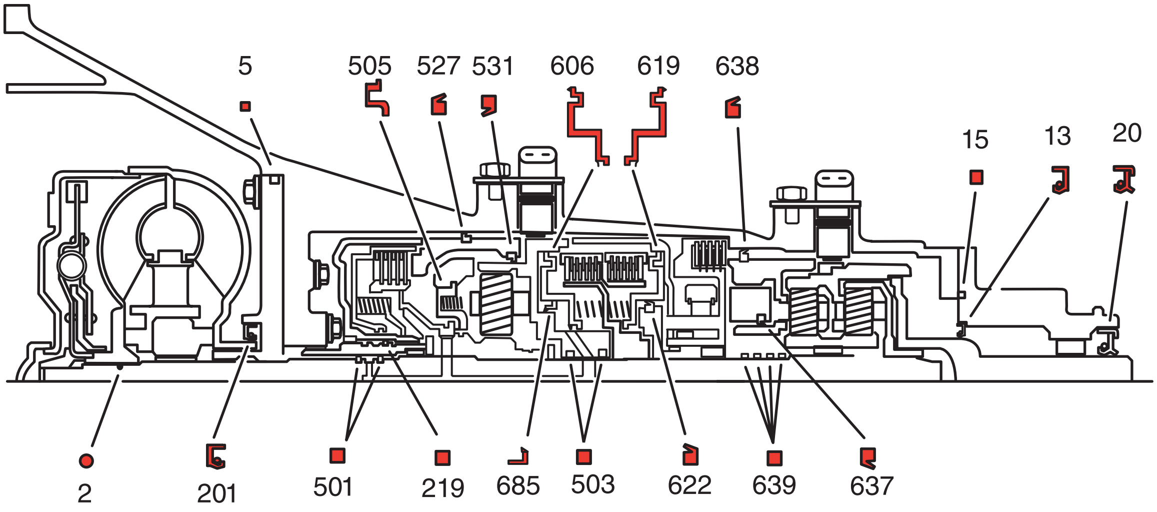
Gaskets

Gaskets are used to seal two parts together or to provide a passage for fluid flow from one part of the transmission to another. Gaskets are easily divided into two separate groups, hard and soft, depending on their application. Hard gaskets are used whenever the surfaces to be sealed are smooth. This type of gasket is usually made of paper. A common application of a hard gasket is the gasket used to seal the valve body and oil pump against the transmission case. Hard gaskets are also often used to direct fluid flow or to seal off some passages between the valve body and the separator plate.

Gaskets that are used when the sealing surfaces are irregular or in places where the surface may distort when the component is tightened into place are called soft gaskets. A typical location of a soft gasket is the oil pan gasket that seals the oil pan to the transmission case. Oil pan gaskets are typically a composition-type gasket made with rubber and cork. However, some late-model transmissions use an RTV sealant instead of a gasket to seal the oil pan.

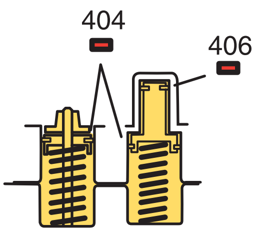
Seals

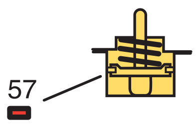
As valves and transmission shafts move within the transmission, it is essential that the fluid and pressure be contained within its bore. Any leakage would decrease the pressure and result in poor transmission operation. Seals are used to prevent leakage around valves, shafts, and other moving parts. Rubber, metal, or Teflon materials are used throughout a



Legend

2 Ring, turbine shaft front oil seal
5 Seal, oil pump
13 Seal, output shaft
15 Seal, case extension
20 Seal assembly, prop shaft front slip yoke oil
57 Seal, Manual 2-1 band servo piston
66 Seal, low and reverse servo piston
67 Ring, low and reverse accumulator piston outer oil seal
69 Ring, low and reverse accumulator piston inner oil seal
201 Seal assembly, torque converter oil
219 Ring, oil seal, overrun clutch housing
404 Seal, 3rd clutch accumulator piston outer
406 Seal, 3rd clutch accumulator piston inner
501 Ring, turbine shaft rear oil seal
503 Ring, turbine shaft intermediate oil seal
505 Piston assembly, overrun clutch
527 Seal, 4th clutch piston inner
531 Seal, 4th clutch piston outer
606 Piston, forward clutch
619 Piston, direct clutch
622 Seal, direct clutch piston intermediate
637 Seal, intermediate clutch piston inner
638 Seal, intermediate clutch piston outer
639 Ring, direct clutch housing oil seal
685 Seal assembly, forward clutch piston intermediate





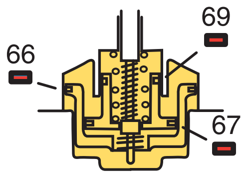


FIGURE 41–58 The location of various seals in a typical transmission.

transmission to provide for static and dynamic sealing. Both static and dynamic seals can provide for positive and nonpositive sealing. A definition of each of the different basic classifications of seals follows:

- *Static.* A seal used between two parts that do not move in relationship to each other, such as the pan and oil pump-to-case gaskets.
- *Dynamic.* A seal used between two parts that do move in relationship to each other. This movement is either a rotating or reciprocating (up and down) motion. The seal of a clutch piston is an example of this type of seal.
- *Positive.* A seal that prevents all fluid leakage between two parts.

- *Nonpositive.* A seal that allows a controlled amount of fluid leakage. This leakage is typically used to lubricate a moving part.

Three major types of rubber seals are used in automatic transmissions: the O-ring, the lip seal, and the square-cut seal. Rubber seals are made from synthetic rubber rather than natural rubber.

O-rings are round seals with a circular cross section. Normally an O-ring is installed in a groove cut into the inside diameter of one of the parts to be sealed. When the other part is inserted into the bore and through the O-ring, the O-ring is compressed between the inner part and the groove. This pressure distorts the O-ring and forms a tight seal between the two parts.

O-rings can be used as dynamic seals but are most commonly used as static seals. An O-ring can be used as a dynamic seal when the parts have relatively low amounts of axial movement **(Figure 41–59)**. If there is a considerable amount of axial movement, the O-ring will quickly be damaged as it rolls within its groove. O-rings are never used to seal a shaft or part that has rotational movement.

Lip seals are used to seal parts that have axial or rotational movement. They are round to fit around a shaft but the entire seal does not serve as a seal; rather, the sealing part is a flexible lip. The flexible lip is normally made of synthetic rubber and shaped so that it is flexed when it is installed to apply pressure at the sharp edge of the lip. Lip seals are used around input and output shafts to keep fluid in the housing and dirt out **(Figure 41–60)**. Some seals are double-lipped.

FIGURE 41–59 A typical O-ring being installed on a clutch piston.

When the lip is around the outside diameter of the seal, it is used as a piston seal. Piston seals are designed to seal against high pressures and the seal is positioned so that the lip faces the source of the pressurized fluid. The lip is pressed firmly against the cylinder wall as the fluid pushes against the lip; this forms a tight seal. The lip then relaxes its seal when the pressure on it is reduced or exhausted.

Lip seals are also commonly used as shaft seals. When used to seal a rotating shaft, the lip of the seal is around the inside diameter of the seal and the outer diameter is bonded to the inside of a metal housing. The outer metal housing is pressed into a bore. To help maintain good sealing pressure on the rotating shaft, a garter spring is fitted behind the lip. This toroidal spring pushes on the lip to provide for uniform contact on the shaft. Shaft seals are not designed to contain pressurized fluid; rather, they are designed to prevent fluid from leaking over the shaft and out of the housing. The tension of the spring and of the lip is designed to allow an oil film of about 0.0001 inch (0.00254 mm). This oil film serves as a lubricant for the lip. If the tolerances increase, fluid will be able to leak past the shaft and if the tolerances are too small, excessive shaft and seal wear will result.

A **square-cut seal** is similar to an O-ring; however, a square-cut seal can withstand more axial movement than an O-ring can. Square-cut seals have a rectangular or square cross section. They are designed this way to prevent the seal from rolling in its groove when there are large amounts of axial movement. Added sealing comes from the distortion of the seal during axial movement. As the shaft inside the seal moves, the outer edge of the seal moves more than the inner edge causing the diameter of the sealing edge to increase, which creates a tighter seal.

Metal Sealing Rings

There are some parts of the transmission that do not require a positive seal and in which some leakage is

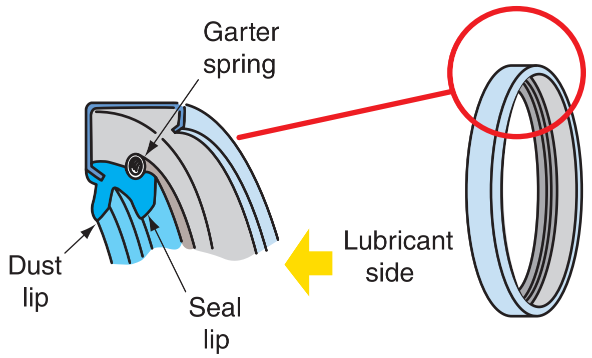


FIGURE 41–60 A typical lip seal.

acceptable. These components are sealed with ring seals that fit into a groove on a shaft **(Figure 41–61)**. The outside diameter of the ring seals slide against the walls of the bore into which the shaft is inserted. Most ring seals in a transmission are placed near pressurized fluid outlets on rotating shafts to help retain pressure. Ring seals are made of cast iron, nylon, or Teflon.

Three types of metal seals are used in automatic transmissions: butt-end seals, open-end seals, and hook-end seals. In appearance, butt-end and open-end seals are much the same; however, when an open-end seal is installed, there is a gap between the ends of the seal. **Hook-end seals (Figure 41–62)** have small hooks at their ends that are locked together during installation to provide better sealing than the open-end or butt-end seals.

Teflon Seals

Some transmissions use Teflon seals instead of metal seals. Teflon provides for a softer sealing surface, which results in less wear on the surface that it rides on and therefore a longer-lasting seal. Teflon seals are similar in appearance to metal seals except for the hook-end type. The ends of locking-end Teflon seals are cut at an angle **(Figure 41–63)** and the locking hooks are somewhat staggered. These seals are often called scarf-cut seals.

Many late-model transmissions are equipped with solid one-piece Teflon seals. Although the one-piece seal requires some special tools for installation, they provide for a nearly positive seal. These Teflon rings form a better seal than other metal sealing rings.

General Motors uses a different type of synthetic seal on some late-model transmissions. The material used in these seals is Vespel, which is a flexible but highly durable plastic-like material.

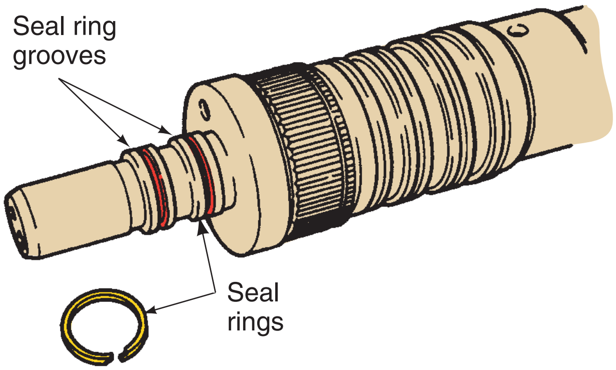


FIGURE 41–61 Metal sealing rings are fit into grooves on a shaft.

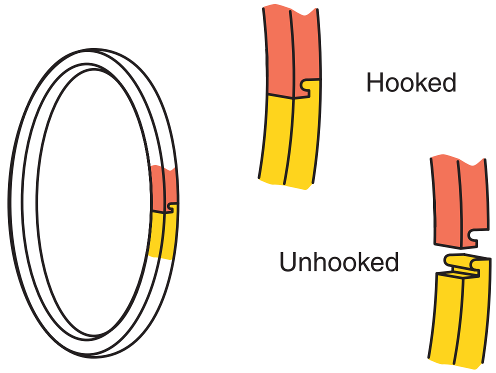


FIGURE 41–62 Hook-end sealing rings.

Final Drives and Differentials

The last set of gears in the drivetrain is the final drive. In most RWD cars, the final drive is located in the rear axle housing. On most FWD cars, the final drive is located within the transaxle. Some FWD cars with longitudinally mounted engines locate the differential and final drive in a separate case that bolts to the transmission. AWD and 4WD vehicles have a final drive unit in the front and rear drive axles.

There are four common configurations used as the final drives on FWD vehicles: helical gear, planetary gear, hypoid gear, and chain drive. The helical, planetary, and chain final drive arrangements are found with transversely mounted engines. Hypoid final drive gear assemblies are normally found in vehicles with a longitudinally placed engine. The hypoid assembly is basically the same unit as would be used on RWD vehicles and is mounted directly to the transmission.

Some transaxles route power from the transmission through two helical-cut gears to a transfer shaft. A helical-cut pinion gear attached to the opposite end of the transfer shaft drives the differential ring gear and carrier. The differential assembly then drives the axles and wheels.

Rather than use helical-cut or spur gears in the final drive assembly, some transaxles use a simple planetary gearset for its final drive. The sun gear of this planetary unit is driven by the final drive sun gear shaft, which is splined to the front carrier and rear ring gear of the transmission's gearset. The final drive sun gear meshes with the final drive planetary pinion gears, which rotate on their shafts in the planetary carrier. The pinion gears mesh with the ring gear, which is splined to the transaxle case. The planetary carrier is part of the differential case, which

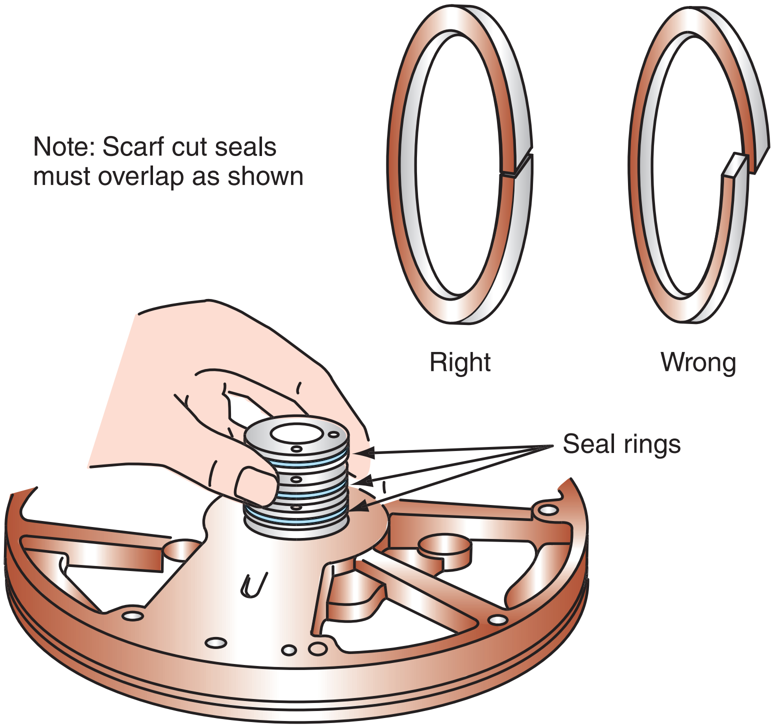


FIGURE 41-63 A scarf-cut seal.

contains typical differential gearing, two pinion gears, and two side gears.

The ring gear of a planetary final drive assembly has lugs around its outside diameter that fit into grooves machined inside the transaxle housing. These lugs and grooves hold the ring gear stationary. The transmission's output is connected to the planetary gearset's sun gear. In operation, the transmission's output drives the sun gear that, in turn, drives the planetary pinion gears. The pinion gears walk around the inside of the stationary ring gear. The rotating planetary pinion gears drive the planetary carrier and differential case. This combination provides maximum torque multiplication from a simple planetary gearset.

Chain-drive final drive assemblies use a multiple-link chain to connect a drive sprocket, connected to the transmission's output shaft, to a driven sprocket that is connected to the differential's pinion shaft. This design allows for remote positioning of the differential within the transaxle housing. Final drive gear ratios are determined by the size of the driven sprocket compared to the drive sprocket.

Hydraulic System

A hydraulic system uses a liquid to perform work. In an automatic transmission, this liquid is automatic transmission fluid (ATF). ATF is one of the most complex fluids produced by the petroleum industry for the automobile.

The transmission's pump is the source of all fluid flow in the hydraulic system. It provides a constant supply of fluid under pressure to operate, lubricate, and cool the transmission. **Pressure-regulating valves** change the fluid's pressure to control the shift quality of a transmission and the shift points of the transmission equipped with a governor. **Flow-directing valves** direct the pressurized fluid to the appropriate apply device to cause a change in gear ratios. The hydraulic system also keeps the T/C filled with fluid.

The reservoir for ATF is the transmission's oil pan. Fluid is drawn from the pan and returned to it. The pressure source is the oil pump. The valve body contains control valving to regulate or restrict the pressure and flow of fluid within the transmission. The output devices for the hydraulic system are the servos or clutches operated by hydraulic pressure.

Hydraulic Principles

An automatic transmission uses ATF fluid pressure to control the action of the planetary gearsets. This fluid pressure is regulated and directed to change gears automatically through the use of various pressure regulators and control valves.

GO TO Chapter 3 for an explanation of basic hydraulic theory and the mechanical advantage gained by using hydraulics.

Fluids work well in increasing force because they are perfect conductors of pressure. Fluids cannot be compressed. Therefore, when a piston in a cylinder moves and displaces fluid, that fluid is distributed equally within the circuit.

Application of Hydraulics in Transmissions

A common hydraulic system within an automatic transmission is the servo assembly, which is used to control the application of a band. The band must tightly hold the drum or planetary carrier it surrounds when it is applied. The holding capacity of the band is determined by the construction of the band and the pressure applied to it. This pressure or holding force is the result of the action of a servo. The servo multiplies the force through hydraulic action.

If a servo has a surface area of 2.5 square inches (1,613 mm^2) and has a pressure of 100 psi (7 kg/cm^2) applied to it, the apply force of the servo is 250 pounds (18 kg/cm^2) **(Figure 41–64).** The force exerted by the servo is further increased by its lever-type linkage and the self-energizing action of the band. The total force applied by the band stops and holds the rotating drum connected to a planetary gearset member.

A multiple-disc assembly is also used to stop and hold gearset members. This assembly also uses hydraulics to increase its holding force. If the fluid pressure applied to the clutch assembly is 70 psi (4.9 kg/cm^2) and the diameter of the clutch piston is 6 inches (152 mm), the force applying the clutch pack is 1,979 pounds (898 kg). If the clutch assembly uses a Belleville spring or piston spring, which adds a mechanical advantage of 1.25, the total force available to engage the clutch will be 1,979 pounds (898 kg) multiplied by 1.25, or 2,474 pounds (1,122.5 kg).

Functions of ATF

The ATF circulating through the transmission and torque converter and over the parts of the transmission cools the transmission. The heated fluid typically moves to a transmission fluid cooler, where the heat is removed. As the fluid lubricates and cools

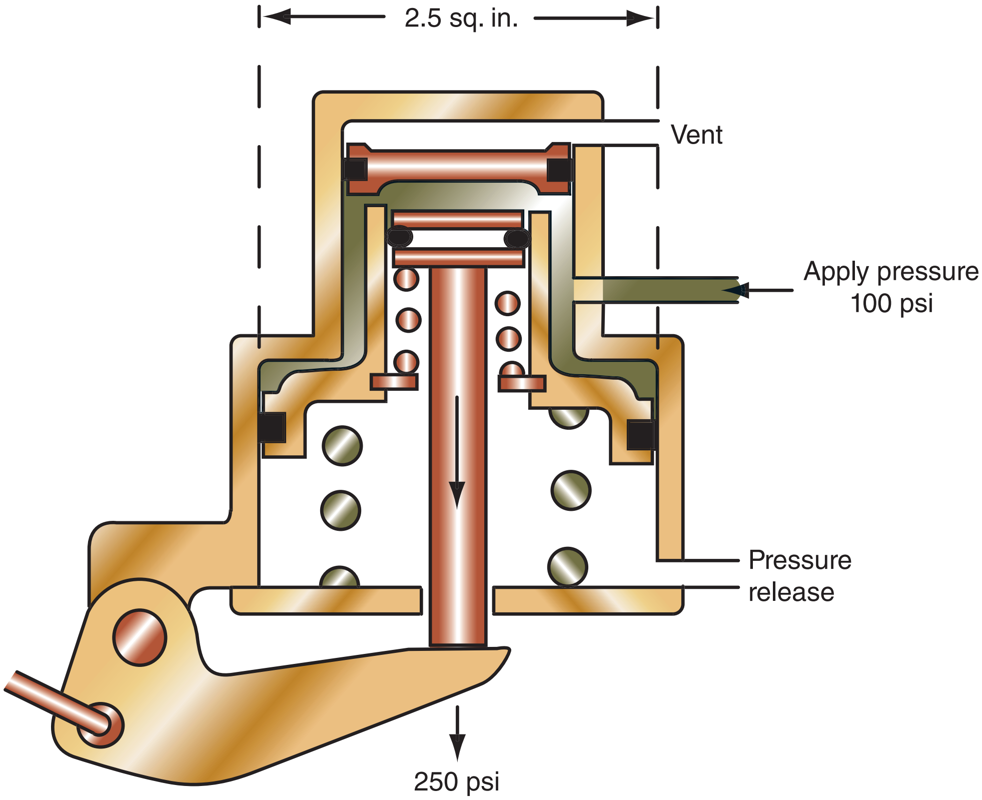


FIGURE 41–64 Calculating the output force developed by a servo assembly.

the transmission, it also cleans the parts. The dirt is carried by the fluid to a filter, where the dirt is removed.

Another critical job of ATF is its role in shifting gears. ATF moves under pressure throughout the transmission and causes various valves to move. The pressure of the ATF changes with changes in engine speed and load.

ATF is also used to operate the various apply devices (clutches and bands) in the transmission. At the appropriate time, a switching valve opens and sends pressurized fluid to the apply device that engages or disengages a gear. The valving and hydraulic circuits are contained in the valve body.

Reservoir

A fluid reservoir stores fluid and provides a constant source of fluid for the system. In an automatic transmission, the reservoir is the pan, typically located at the bottom of the transmission case. ATF is forced out of the pan by atmospheric pressure and into the pump and is then returned to it after it has circulated through the selected circuits. A transmission dipstick placed within a filler tube is typically used to check the level of the fluid and to add ATF to the transmission. Other transmissions have a side plug on the pan or the transmission to check and replenish fluid level.

Venting

All reservoirs must have an air vent that allows atmospheric pressure to force the fluid into the pump when the pump creates a low pressure at its inlet port. The pans of many automatic transmissions vent through the handle of the dipstick; others rely on a vent in the transmission case. Transmissions must also be vented to allow for the exhaust of built-up air pressure that results from heat and the moving components inside the transmission. The movement of these parts can force air into the ATF, which would not allow it to increase in pressure, cool, or lubricate the transmission properly.

Transmission Coolers

The removal of heat from ATF is extremely important to the durability of the transmission. Excessive heat causes the fluid to break down. Once broken down, ATF no longer lubricates well and has poor resistance to oxidation. Oxidized ATF may damage transmission seals. When a transmission is operated for some time with overheated ATF, varnish is formed inside the transmission. Varnish buildup on valves can cause them to stick or move slowly. The result is poor shifting and glazed or burned friction surfaces. Continued operation can lead to the need for a complete rebuilding of the transmission.

It is important to note that ATF is designed to operate at 175° F (80° C). At this temperature, the fluid should remain effective for 100,000 miles (160,000 km). However, when the operating temperature increases, the useful life of the fluid quickly decreases. A 20° F increase in operating temperature will decrease the life of ATF by one-half.

Transmission housings are fitted with ATF cooler lines **(Figure 41–65A)** that direct the hot fluid from the torque converter to the transmission cooler, normally located in the vehicle's radiator. The heat of the fluid is reduced by the cooler and the cool ATF returns to the transmission. In some transmissions, the cooled fluid flows directly to the transmission's bushings, bearings, and gears. Then, the fluid is circulated through the rest of the transmission. The cooled fluid in other transmissions is returned to the oil pan, where it is drawn into the pump and circulated throughout the transmission.

Some vehicles, such as those designed for heavy-duty use, are equipped with an auxiliary fluid cooler **(Figure 41–65B)**, in addition to the one in the radiator. This cooler removes additional amounts of heat from the fluid before it is sent back to the transmission.

Valve Body

For efficient transmission operation, the bands and multiple-disc packs must be released and applied at the proper time. The **valve body** assembly **(Figure 41–66)** is responsible for the control and distribution of pressurized fluid throughout the transmission. This assembly is made of two or three main parts: a valve body, separator plate, and transfer plate. These parts are bolted as a single unit to the transmission housing. The valve body is machined from aluminum or iron and has many precisely machined bores and fluid passages. Various valves are fitted into the bores, and the passages direct fluid to various valves and other parts of the transmission. The separator and transfer plates are designed to seal off some of these passages and to allow fluid to flow through specific passages.

The purpose of a valve body is to sense and respond to engine and vehicle load as well as to meet the needs of the driver. Valve bodies are normally fitted with three different types of valves: spool valves, check ball valves, and poppet valves. The

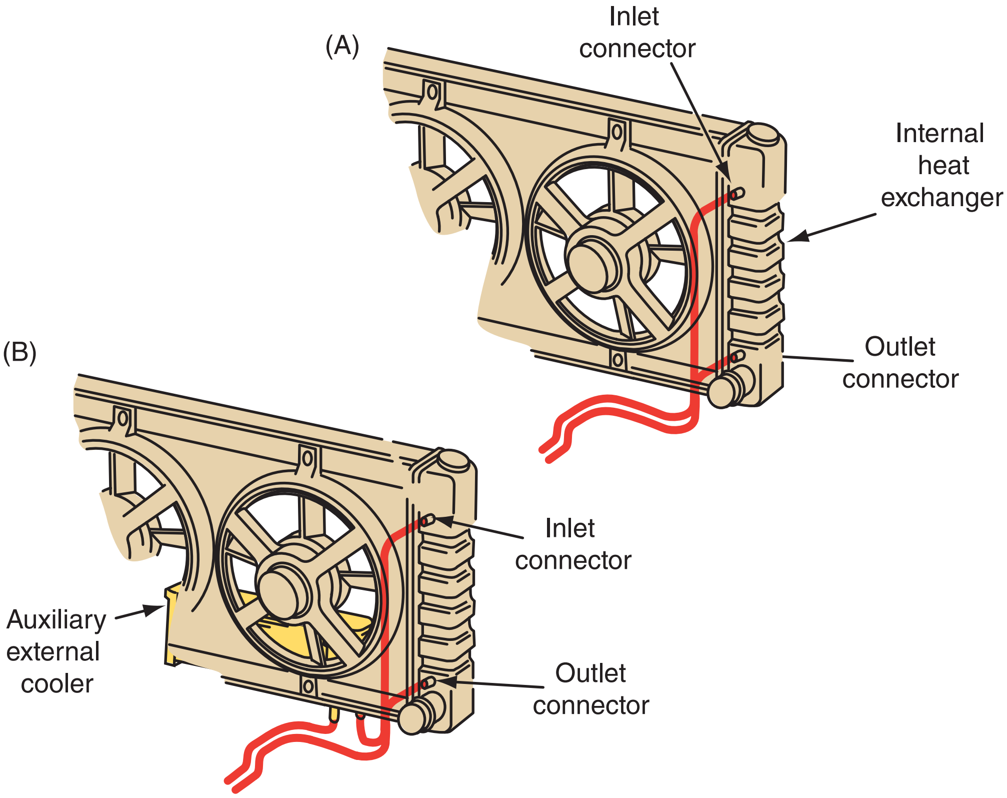


FIGURE 41–65 (A) A transmission cooler (heat exchanger) located in a radiator. (B) An auxiliary cooler added to the normal cooler circuit.

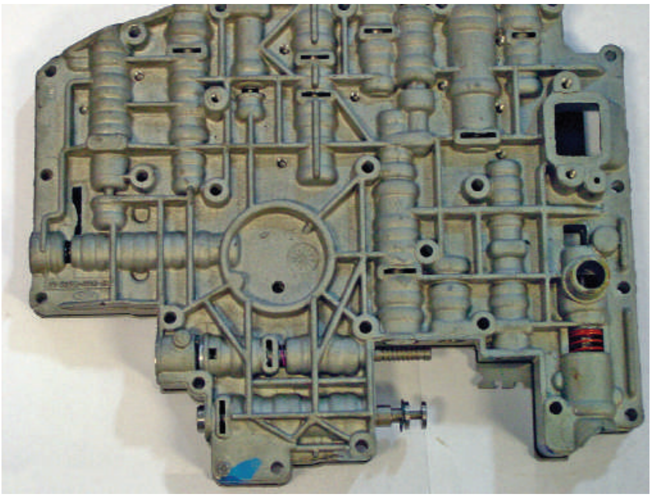


FIGURE 41–66 A typical valve body.

purpose of these valves is to start, to stop, or to use movable parts to regulate and direct the flow of fluid throughout the transmission.

Check Ball Valve The **check ball valve** is a ball that operates on a seat located on the valve body. The check ball operates by having a fluid pressure or manually operated linkage force it against the ball seat to block fluid flow **(Figure 41–67)**. Pressure on the opposite side unseats the check ball. Check balls and poppet valves can be normally open, which allows free flow of fluid pressure, or normally closed, which blocks fluid pressure flow.

At times, the check ball has two seats to check and direct fluid flow from two directions, being seated and unseated by pressures from either source.

Poppet Valve A poppet valve **(Figure 41–68)** can be a ball or a flat disc. In either case, the poppet valve blocks fluid flow. Often the poppet valve has a stem to guide the valve's operation. The stem normally fits into a hole acting as a guide to the valve's opening and closing. Poppet valves tend to pop open and

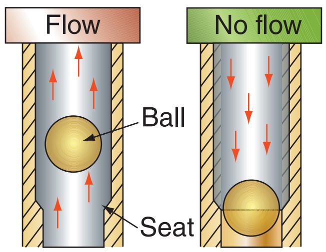


FIGURE 41–67 The operation of a check ball valve.

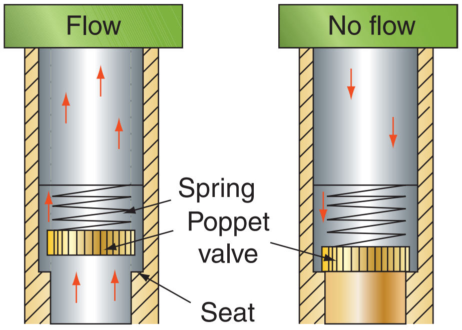


FIGURE 41-68 Typical poppet valve operation.

closed, hence their name. Normally poppet valves are held closed by a spring.

Spool Valve The most commonly used valve in a valve body is the **spool valve**. A spool valve **(Figure 41–69)** looks similar to a sewing thread spool. The large circular parts of the valve are called the lands. There is a minimum of two lands per valve. Each land of the assembly is connected by a stem. The space between the lands and stem is called the valley. Valleys form a fluid pressure chamber between the spools and valve body bore. Fluid flow can be directed into other passages depending on the spool valve and valve body design.

Precisely machined around the periphery of each valve, the land is the part of the valve that rides on a thin film of fluid in a bore of the valve body. The land must be treated very carefully because any damage, even a small score or scratch, can impair smooth valve operation. As the spool valve moves, the land covers (closes) or uncovers (opens) ports in the valve body.

The reaction area, also known as the face, is the space at the outside of the lands at the end of the valve. Forces acting against the reaction area that cause the valve to move include spring tension, fluid pressure, or mechanical linkage.

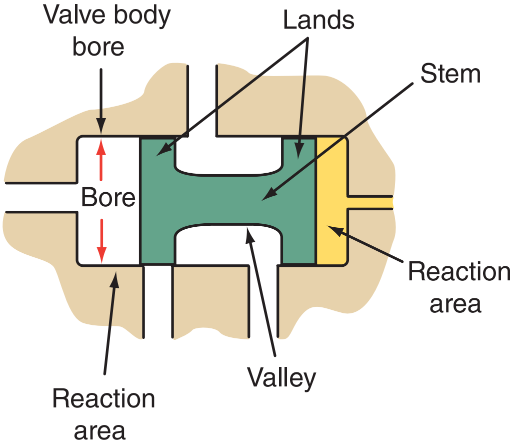


FIGURE 41-69 Components of a spool valve assembly.

Oil Pump

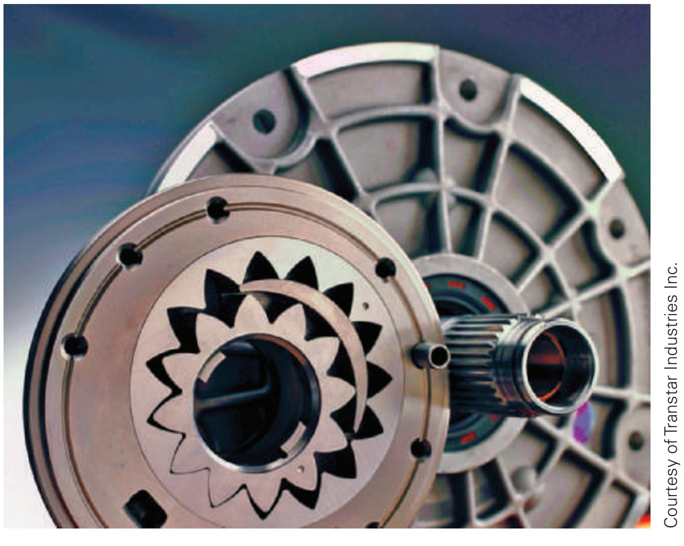
The source of fluid flow through the transmission is the oil pump **(Figure 41–70)**. Three types of oil pumps are commonly used in automatic transmissions: gear type **(Figure 41–71A)**, rotor type, and vane type **(Figure 41–71B)**. Oil pumps are driven by the pump drive hub of the T/C or oil pump shaft and/or converter cover on transaxles. Therefore, whenever the T/C cover is rotating, the oil pump is driven. The oil pump creates fluid flow throughout the transmission. Some transmissions use an off-axis oil pump, meaning the pump is relocated away from the input shaft. A chain is used to drive the pump.

Many transmissions use variable displacement vane pumps. These increase transmission efficiency as less fluid is needed and pumped during high-speed operating conditions. On modern transmission, a pressure control solenoid is often used to vary the pump output by changing the volume of the pump housing **(Figure 41–72)**.

If the vehicle is equipped with auto stop/start, the transmission will either have an electrically driven auxiliary oil pump or an accumulator to provide oil pressure when the engine shuts off.

Pressure Regulator Valve

Transmission pumps are capable of creating excessive amounts of pressure that may cause damage; therefore, the transmission is equipped with a pressure regulator valve, which is normally



Courtesy of Transtar Industries Inc.

FIGURE 41-70 A gear-type oil pump.

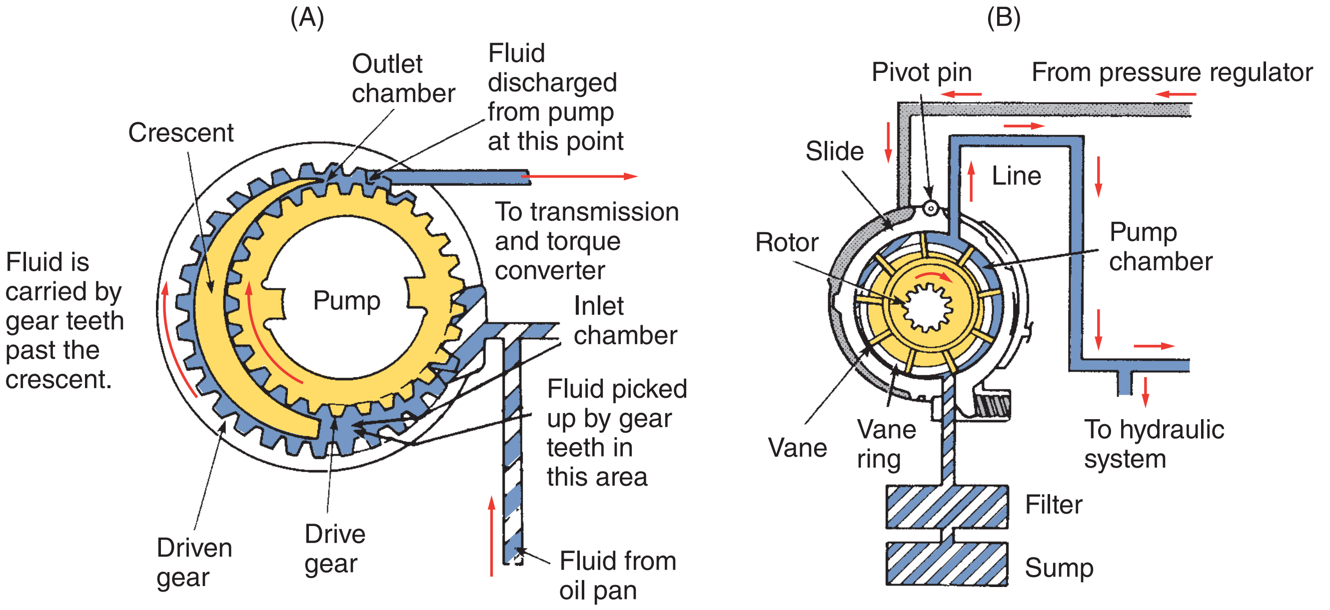


FIGURE 41–71 (A) Operation of a gear-type pump and (B) a vane-type pump.

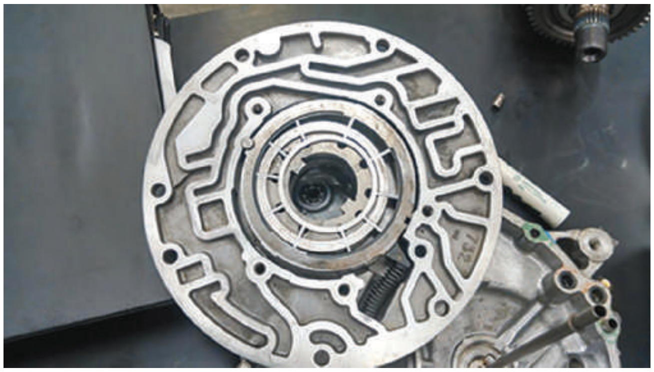


FIGURE 41–72 A variable displacement pump.

located in the valve body. Pressure regulating valves are typically spool valves that toggle back and forth in their bores to open and close an exhaust passage. By opening the exhaust passage, the valve decreases the pressure of the fluid. As soon as the pressure decreases to a predetermined amount, the spool valve moves to close off the exhaust port and pressure again begins to build. The action of the spool valve regulates the fluid pressure.

Many late-model transmissions use an electronic pressure control (EPC or PC) solenoid to regulate system pressure **(Figure 41–73)**.

Governor Assembly

Older transmissions were equipped with a **governor** assembly driven by the transmission's output shaft. It measured road speed and sent a fluid pressure signal to the valve body to either upshift or downshift. When vehicle speed is increased, the pressure developed by the governor is directed to the shift valve. As the speed (and therefore the pressure) increases, the spring tension and throttle pressure on the shift valve are overcome and the valve moves. This action causes an upshift. Likewise, a decrease in speed results in a decrease in pressure and a downshift.

Pressure Boosts

When the engine is operating under heavy load conditions, fluid pressure must be increased to increase the holding capacity of a hydraulic member. Increasing the fluid pressure holds the band and clutch control units tighter to reduce the chance of slipping while under heavy load. This is accomplished by sending pressurized fluid to one side of the pressure regulator's spool valve. This pressure works against the spool valve's normal movement to open the exhaust port and allows pressure to build to a higher point than normal.

Engine load can be monitored electronically by various electronic sensors (primarily the TP and MAP sensors) that send information to an electronic control unit, which in turn controls the pressure at the valve body. Load can also be monitored by throttle pressure. On older vehicles, throttle pedal movement moves a **throttle valve** in the valve body

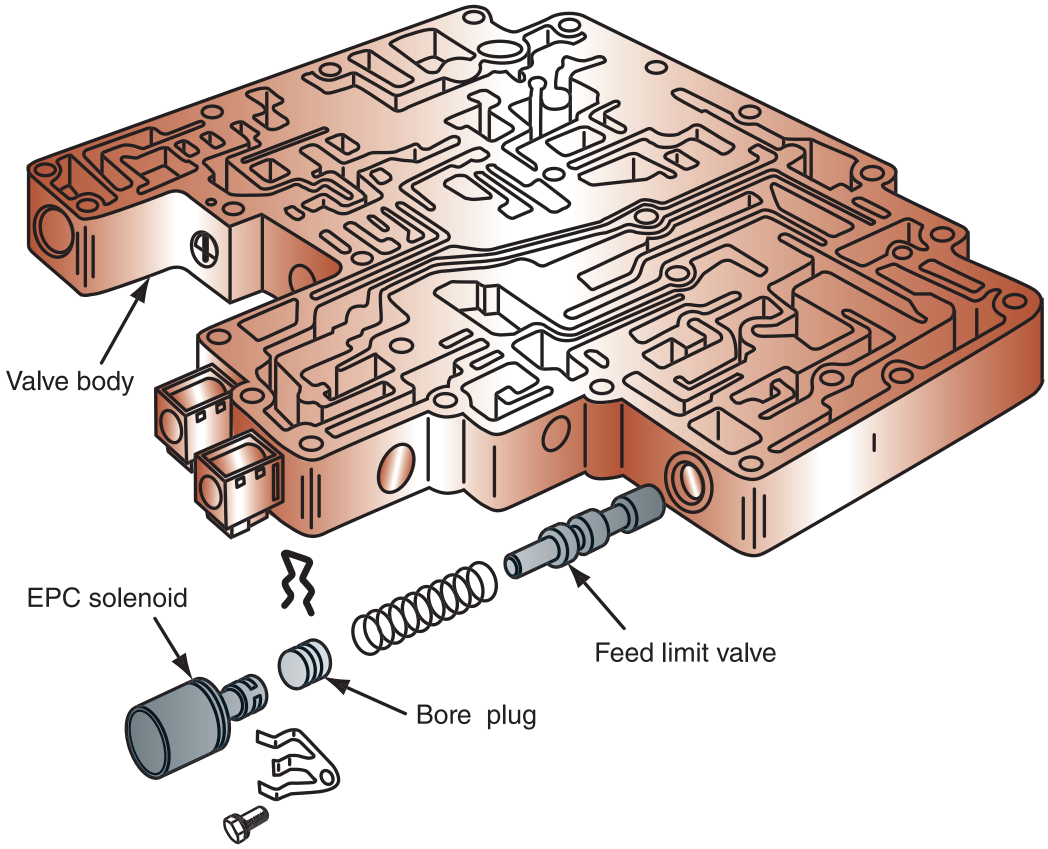


FIGURE 41–73 Normally the EPC solenoid is inserted into the valve body.

via a throttle cable. When the throttle plate is opened, the throttle valve opens and applies pressure to the pressure regulator. This delays the opening of the pressure regulator valve, which allows for an increase in pressure. When the driver lets off the throttle pedal, the pressure regulator valve is free to move and normal pressure is maintained.

Many early transmissions were equipped with a vacuum modulator, which uses engine vacuum to change transmission pressure. The vacuum modulator allows for an increase in pressure when vacuum is low and decreases it when vacuum is high.

MAP Sensor

Engine load can be monitored electronically through the use of various electronic sensors that send information to an electronic control unit, which in turn controls the pressure at the valve body. The most commonly used sensor is the MAP sensor. The MAP sensor senses air pressure in the intake manifold. The control unit uses this information as an indication of engine load. A pressure-sensitive ceramic or silicon element and electronic circuit in the sensor generates a voltage signal that changes in direct proportion to pressure. A MAP sensor measures manifold air pressure against a precalibrated absolute pressure; therefore, the readings from these sensors are not adversely affected by changes in operating altitudes or barometric pressures.

Kickdown Valve

Older systems may have a **kickdown** circuit, which provides a downshift when the driver requires additional power. When the throttle pedal is quickly opened wide, throttle pressure rapidly increases and directs a large amount of pressure onto the kickdown valve. This moves the kickdown valve, which opens a port and allows mainline pressure to flow against the shift valve. The spring tension on the shift valve, the kickdown pressure, and throttle pressure will push on the end of the shift valve, causing it to move to the downshift position and forcing a quick downshift.

Shift Quality

All transmissions are designed to change gears at the correct time according to engine and vehicle speed, load, and driver intent. However, transmissions are

also designed to provide for positive change of gear ratios without jarring the driver or passengers. If a band or clutch is applied too quickly, a harsh shift will occur. **Shift feel** is controlled by the pressure at which each hydraulic member is applied or released, the rate at which each is pressurized or exhausted, and the relative timing of the apply and release of the members.

To improve shift feel during gear changes, a band is often released while a multiple-disc pack is being applied. The timing of these two actions must be just right or both components will be released or applied at the same time, which would cause engine flare-up or clutch and band slippage. Several other methods are used to smooth gear changes and improve shift feel.

Multiple-disc packs sometimes contain a wavy spring-steel separator plate that helps smooth the application of the clutch. Shift feel can also be smoothed out by using a restricting **orifice** or an accumulator piston in the band or clutch apply circuit. A restricting orifice or check ball in the passage to the apply piston restricts fluid flow and slows the pressure increase at the piston by limiting the quantity of fluid that can pass in a given time.

Manufacturers have also applied electronics to get the desired shift feel. One of the most common techniques is the pulsing (turning on and off) of the shift solenoids, which prevents the immediate engagement of a gear by allowing some slippage.

GO TO Chapter 42 for a discussion on electronically-controlled transmissions.

Accumulators

Shift quality with a brake or clutch is dependent on how quickly it is engaged by hydraulic pressure and the amount of pressure exerted on the piston. Some apply circuits use an **accumulator** to slow down application rates without decreasing the holding force of the apply device.

An accumulator **(Figure 41–74)** works like a shock absorber and cushions the application of servos and disc packs. An accumulator cushions sudden increases in hydraulic pressure by temporarily diverting some of the apply fluid into a parallel circuit or chamber. This allows the pressure to gradually increase and provides for smooth engagement of a brake or clutch.

An accumulator is basically a large diameter piston located in a bore and held in position by a heavy, calibrated spring that acts against hydraulic pressure. Accumulators are placed in the hydraulic circuit between the shift valve and the holding device.

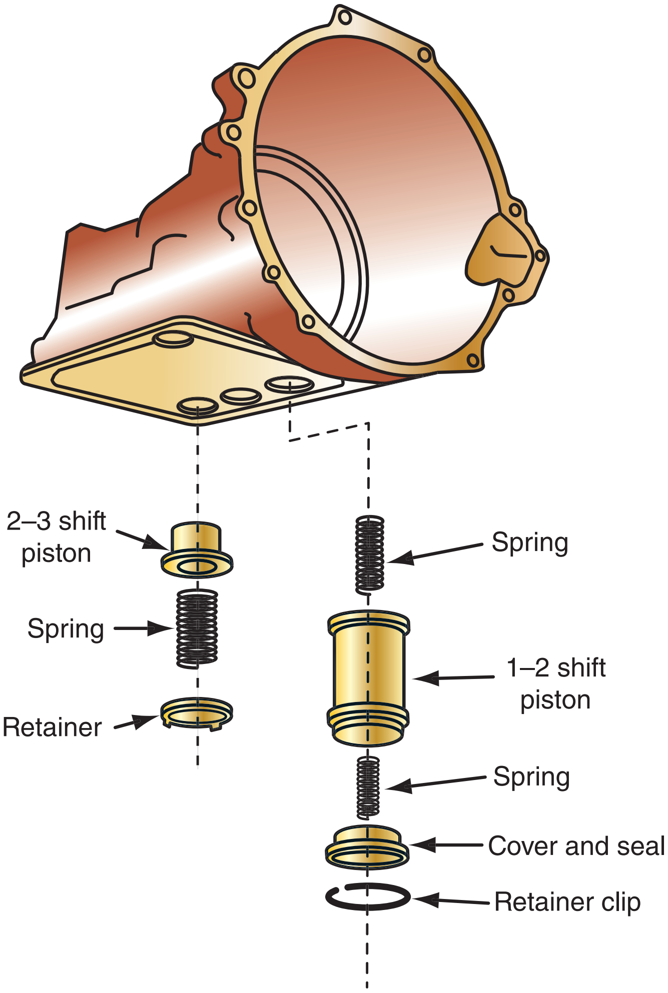


FIGURE 41–74 An accumulator assembly is used to control shift feel.

Some transmission designs do not rely on an accumulator for shift quality; rather, they have a restrictive orifice in the line to the servo or multiple-disc pack's piston. This restriction decreases the amount of initial apply pressure but will eventually allow for full pressure to act on the piston.

Several transmissions use servo units that also work as an accumulator. These units are typically used with the intermediate band and for upshifts out of second or third gear. This servo/accumulator unit actually keeps the band applied during the initial engagement of the clutch pack. As the clutch becomes more engaged, the band is released. This action prevents the harsh engagement of the upshift.

Other designs have multiple accumulators built into the servo assembly. Doing this allows the accumulators to respond directly to the action of the servo.

Shift Timing

For non-electronic systems, shift timing is determined by throttle pressure and governor pressure acting on opposite ends of the shift valve. When a vehicle is accelerating from a stop, throttle pressure is high and governor pressure is low. As vehicle speed increases, the throttle pressure decreases and the governor pressure increases. When governor pressure overcomes throttle pressure and the spring tension at the shift valve, the shift valve moves to direct pressure to the appropriate apply device and the transmission upshifts.

Gear Changes

An automatic transmission will change gear ratios and direction automatically or at the command of the driver. Automatic shifting allows for forward gear ratio changes in response to engine speed and load. And, in the case of electronically controlled units, in response to the PCM's interpretation of operating conditions. The transmission will not automatically move into park, reverse, or neutral. The driver makes these gear selections. The driver can also select certain forward gears. The forward gears available for manual selection vary with each transmission model.

A discussion on how gear changes are made is a summary of the operation of the transmission's components. Keep in mind, the way a particular transmission operates depends on its construction and components. This discussion is based on a common four-speed design using a Simpson gearset and an add-on overdrive planetary unit **(Figure 41–75)**. There are no electronic controls mentioned in this discussion because it is important for you to understand how the gearset responds to the various hydraulic components in a transmission before you can understand how electronics improve the performance of a transmission. The clutch, brake, and band application for this typical transmission is shown in **Figure 41–76**. Refer to both figures as you read the following discussion.

Park/Neutral

When park is selected, the shift linkage moves the park pawl or lever into the park gear, located on the output shaft or final drive shaft **(Figure 41–77)**. The shift linkage also moves the manual shift valve to block the fluid passages to the clutches and bands. No member of the gearset receives input torque and no member is held, therefore there is no output. Fluid flows to feed the torque converter and to lubricate and cool the transmission. In the neutral position, all of the same conditions of the park mode exist, except the park lever is not engaged to the park gear.

Reverse

When reverse is selected, the manual shift valve is moved and fluid is sent to the front clutch and the low/reverse band. The pressure of the fluid is greater than mainline because boost pressure is added to the circuit at the pressure regulator valve. This added

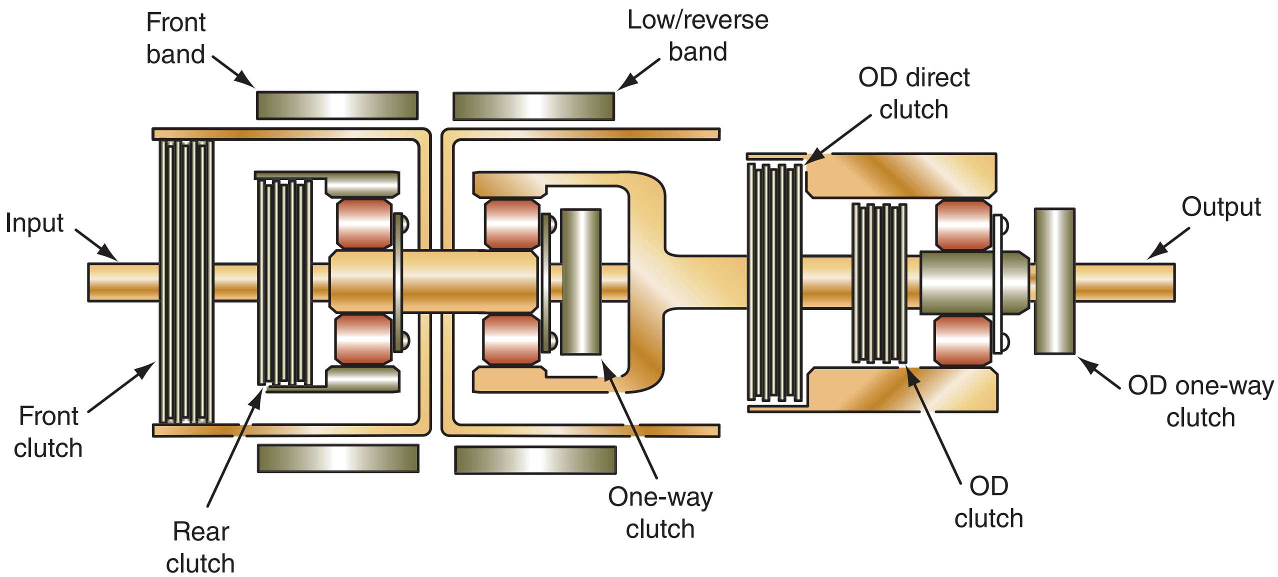


FIGURE 41–75 A typical four-speed transmission using a Simpson gearset and an add-on overdrive planetary unit.

Transmission clutches and bands						Overdrive clutches		
Lever position	Front clutch	Rear clutch	One-way clutch	Front band	Low/rev band	OD clutch	Direct clutch	One-way clutch
P—Park								
R—Reverse		X			X		X	
N—Neutral								
D—Drive								
First		X	X				X	X
Second		X		X			X	X
Third	X	X					X	X
Fourth	X	X				X		
2—Range second		X	X	X			X	X
1—Range first		X	X		X		X	X

FIGURE 41–76 The clutch, brake, and band application for the transmission shown in Figure 41–68.

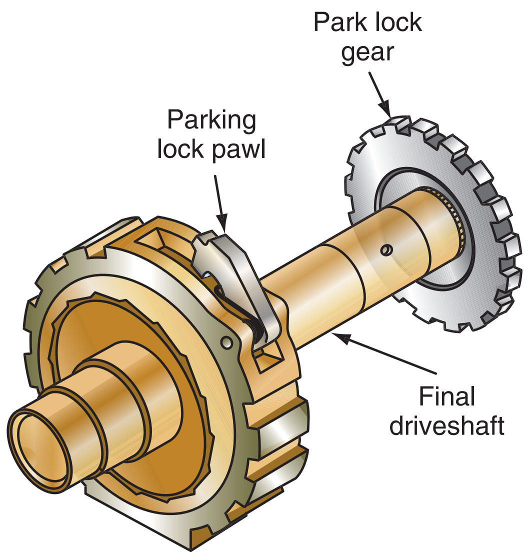


FIGURE 41–77 A Park gear and shaft assembly.

pressure provides good clamping and prevents clutch and band slippage.

The front clutch locks into the drive shell and the sun gear becomes the input. The low/reverse band holds the rear planetary carrier. The sun gear rotates in a clockwise direction and drives the rear planet pinions in a counterclockwise direction. The pinions then cause the rear ring gear to rotate in a counterclockwise direction. Since the rear ring gear is splined to the output shaft, the output shaft rotates in the opposite direction as the input shaft.

While the transmission is in reverse, the separate overdrive planetary gearset is in direct drive. This is accomplished by the engagement of the overdrive direct clutch that locks the sun and ring gears together. This clutch also provides for engine braking in reverse and the forward reduction gears.

Drive Range

When the shift linkage is moved to the D position, the manual shift valve allows fluid flow to engage the rear clutch. Fluid pressure is also directed to the shift valve. When the vehicle is stopped and in first gear, the various gear shift valves are closed by spring tension.

Input is transmitted through the rear clutch to the front ring gear in a clockwise direction. The front carrier is splined to the output shaft and is held by the weight of the vehicle at the drive wheels. The front ring gear drives the front planet pinions in the same direction. The planets, in turn, drive the common sun gear in the opposite or counterclockwise direction. The rear carrier is held by the one-way clutch as the planet pinions attempt to rotate the rear ring gear, they walk the rear carrier in a counterclockwise

direction. The ring gear is splined to the output shaft and the output is in the same direction as the input but at greater torque. This is first gear.

While the transmission is in the forward gears, the separate overdrive planetary gearset is in direct drive. The direct drive mode keeps transmission output connected to the input of the transmission. This unit also uses a one-way clutch that locks the shaft connecting the two planetary units to the output shaft.

This mode of operation will continue as long as the one-way clutch is locked or until the 1-2 shift valve forces an upshift. The clutch will remain locked until engine torque is released from the planetary unit or when the inertia of the vehicle is coasting and driving the planetary unit by the output shaft. The rear carrier rotates in a clockwise direction with the output shaft. This releases the one-way clutch. Since there is no longer a reactionary member, the transmission is effectively in neutral.

As the vehicle accelerates in first gear, the automatic movement of the shift valve controls progressive shifts through the other forward gears. As the vehicle moves forward, throttle pressure builds and helps the shift valve spring keep the valve in position. As output shaft and vehicle speed increases, governor pressure builds. Once governor pressure is great enough to overcome the combined pressure of the spring and throttle pressure, the 1-2 shift valve is pushed open. Fluid is directed to the front band, which holds the driving shell and the sun gear.

The rear clutch is still engaged and drives the front ring gear and front planet pinions in a clockwise direction. The front planets drive the front carrier and the output shaft with some reduction. This is second gear. The rear planetary unit is ineffective because the rear carrier freewheels in the one-way clutch.

As the output shaft speed increases, governor pressure continues to build. Much more pressure is needed to move the 3-2 shift valve than was required to move the 1-2 shift valve. This is because it is held by a heavier spring tension and throttle pressure. Once governor pressure is great enough to overcome the pressure holding the 2-3 shift valve, the shift valve moves and opens the fluid circuit to the front clutch. At this time, fluid flow to the front band is stopped and the sun gear is released. The rear clutch remains applied and input is applied to the front ring gear through the rear clutch and to the sun gear through the front clutch. The front carrier is locked between these two input members and drives the output shaft at the same speed as the input. This is third gear.

To move the 3-4 shift valve requires more pressure than the 1-2 and 2-3 shift valves. Again this is due to high spring tensions. Once vehicle and output shaft is great enough to increase governor pressure enough to move the 3-4 shift valve, fluid is sent to the overdrive clutch. When this happens, the 2-3 shift valve remains open and direct drive output is available to the overdrive planetary.

When pressure is first applied to the overdrive clutch, the overdrive clutch piston compresses the spring for the direct clutch and releases it. Then the pressure engages the overdrive clutch and locks the sun gear to the transmission housing.

Automatic Downshifting

Upshifts occur because governor pressure builds up enough to overcome the spring tension and the throttle pressure on a shift valve. Down shifting occurs when governor pressure decreases to the point where it can no longer overcome those pressures. Down shifting will also occur when throttle pressure has increased and is able to overtake governor pressure.

During a coast condition, governor and throttle pressure decreases as the vehicle slows. The transmission will begin its downshift sequence by responding to these lower pressures. Since the 3-4 shift valve has the highest spring tension on it, it will be the first shift valve to move with the decreased governor pressure. The last shift valve to move is the 1-2 shift valve because the spring tension on it is the lowest of all shift valves.

Forced downshifts occur when the throttle is quickly opened during acceleration and increases throttle pressure. If governor pressure is not great enough to overcome the combined pressure of the shift valve spring and throttle pressure, the shift valve will close. This drops the transmissions into the lower gear until governor pressure builds up enough to overtake the pressure on the shift valve.

Manual Low

When the driver selects a gear other than D, the manual shift valve controls the action of the other shift valves. By selecting a gear, the driver tells the transmission to stay in that gear or start off in that gear. The latter is often used when initiating movement when the vehicle is on ice or other slippery surfaces.

Basically the movement of the gear selector into a manual gear inhibits the shift valve. When the driver selects Drive 2 while the transmission is in third gear, the transmission may downshift regardless of vehicle and engine speed. The manual shift valve cuts off line pressure to the 2-3 shift valve and the transmission drops to second gear.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2014	**Make:** Toyota	**Model:** Sienna	**Mileage:** 94,633	**RO:** 17045
Concern:	Customer states the transmission doesn't feel as if it is shifting properly.			
History:	Van was serviced two months ago and no problems were noted. Vehicle was used for a family vacation last month.			
After verifying the transmission is slipping, the technician inspects the fluid and notes the level is low, the fluid is very dark and smells burnt. Knowing the vehicle had been serviced recently and no problems were noted, he inspects the transmission for fluid leaks and makes sure there are no restrictions in front of the A/C condenser and radiator. No problems are found but notices an added-on wire is coming from the under hood fuse box. Checking the rear of the van he finds an aftermarket trailer hitch was installed. A conversation with the owner confirms that the hitch was installed to pull a small camper while on vacation. What the owner did not realize is that without an additional transmission cooler and other modifications, the van is not rated for pulling a trailer.				
Cause:	Vehicle used to tow a trailer but is not equipped for towing. Additional load damaged the transmission.			
Correction:	Replaced transmission with rebuilt unit and recommended that an auxiliary transmission cooler be installed.			

KEY TERMS

Accumulator
Annulus
Band
Check ball valve
Continuously variable transmission (CVT)
Coupling point
Flow-directing valves
Governor
Hook-end seals
Impeller
Kickdown
Lip seals
Multiple-disc assembly
Orifice
Overrunning clutch
Planetary carrier
Planetary pinions
Pressure regulating valves
Ravigneaux geartrain
Rotary oil flow
Servo
Shift feel
Simpson geartrain
Spool valve
Square-cut seal
Stator
Sun gear
Throttle valve
Torque converter clutch (TCC)
Torrington bearing
Turbine
Two-mode hybrid system
Valve body
Vortex oil flow

SUMMARY

- The torque converter is a fluid clutch used to transfer engine torque from the engine to the transmission. It automatically engages and disengages power transfer from the engine to the transmission in relation to engine rpm. It consists of three elements: the impeller (input), turbine (output), and stator (torque multiplier).
- Two types of oil flow take place inside the torque converter: rotary and vortex flow.
- An overrunning clutch keeps the stator assembly from rotating in one direction and permits overrunning when turned in the opposite direction.
- A lockup torque converter eliminates the slip that takes place between the impeller and turbine at the coupling stage of operation.
- Planetary gearsets transfer power and alter the engine's torque. Compound gearsets combine two simple planetary gearsets so that load can be spread over a greater number of teeth for strength

and also so the largest number of gear ratios possible can be obtained in a compact area. A simple planetary gearset consists of a sun gear, a carrier with planetary pinions mounted to it, and an internally toothed ring gear.

- Planetary gear controls include transmission bands, servos, and clutches. A band is a braking assembly positioned around a drum. There are two types: single wrap and double wrap. Simple and compound servos are used to engage bands. Transmission clutches, either overrunning or multiple disc, are capable of both holding and driving members.
- There are two common designs of compound gearsets, the Simpson gearset, in which two planetary gearsets share a common sun gear, and the Ravigneaux gearset, which has two sun gears, two sets of planet gears, and a common ring gear.
- Some transmissions rely on two simple planetary gearsets connected in tandem.
- Lepelletier gearsets rely on a combination of Simpson and Ravigneaux gearsets.
- Many Honda transaxles do not use a planetary gearset; rather, constant-mesh helical and square-cut gears are used similar to that of a manual transmission.
- The operation of most CVTs is based on a steel belt linking two variable pulleys.
- Many hybrid vehicles have CVTs that rely on a planetary gearset and two electric motors rather than pulleys and belts.
- An automatic transmission uses ATF pressure to control the action of the planetary gearsets.
- ATF fluid pressure is regulated and directed to change gears automatically through the use of various pressure regulators and control valves. The transmission's pump is driven by the torque converter shell at engine speed. The purpose of the pump is to create fluid flow and pressure in the system. Excessive pump pressure is controlled by the pressure regulator valve. Three common types of oil pumps are installed in automatic transmissions: the gear, rotor, and vane.
- The valve body is the control center of the automatic transmission. It is made of two or three main parts. Internally, the valve body has many fluid passages called worm tracks.
- The purpose of a valve is to start, stop, or to direct and regulate fluid flow. Generally, in most valve bodies used in automatic transmissions, three types of valves are used: check ball, poppet, and, most common, the spool.
- To prevent stalling, the automatic transmission pump has a pressure regulator valve normally located in the valve body. It maintains a basic fluid pressure. The valve's movement to the exhaust position is controlled by calibrated coil spring tension.
- Bearings that take radial loads are called bushings and those that take axial loads are called thrust washers.
- The gaskets and seals of an automatic transmission help to contain the fluid within the transmission and prevent the fluid from leaking out of the various hydraulic circuits. Different types of seals are used in automatic transmissions; they can be made of rubber, metal, or Teflon.
- Three major types of rubber seals are used in automatic transmissions: the O-ring, the lip seal, and the square-cut seal.
- Three types of sealing rings are used in automatic transmissions: butt-end seals, open-end seals, and hook-end seals.

REVIEW QUESTIONS

Short Answer

1. Explain the difference between rotary and vortex fluid flow in a torque converter.
2. What component keeps the stator assembly from rotating when driven in one direction and permits rotation when turned in the opposite direction?
3. When a transmission is described as having two planetary gearsets in tandem, what does this mean?
4. The four common configurations used as the final drives on FWD vehicles are the ___ gear, ___ gear, ___ gear, and ___.
5. The three types of metal seals used in automatic transmissions are the ___, ___, and ___ seals.
6. How can shift feel be controlled?
7. What determines the timing of the shifts in an automatic transmission?
8. Why must hydraulic line pressures increase when there is an increase of load on the engine?
9. Three major types of rubber seals are used in automatic transmissions: the ___, the ___, and the seal.

True or False

1. *True or False?* The vent in a transmission housing is designed to allow fluid to escape when there is excessive pressure in the system.
2. *True or False?* The Ravigneaux gearset has one sun gear, two sets of planet gears, and two ring gears.

Multiple Choice

1. To achieve a slow overdrive in a simple planetary gearset, the ___.
   a. sun gear must be the input member
   b. ring gear must be the input member
   c. planetary carrier must be the input member
   d. ring gear must be held
2. In a simple planetary gearset, when the planetary carrier is held, the gearset produces a ___.
   a. reverse
   b. direct drive
   c. fast overdrive
   d. forward reduction
3. Overrunning clutches are capable of ___.
   a. holding a planetary gear member stationary
   b. driving a planetary gear member
   c. both a and b
   d. neither a nor b
4. In the coupling stage of conventional torque converter operation, ___.
   a. both the impeller and turbine are turning at essentially the same speed
   b. both the stator and turbine are stationary
   c. both the stator and impeller are stationary
   d. the stator turns with the turbine and impeller

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that bearings that take radial loads are called Torrington washers. Technician B says that bearings that take axial loads are called thrust washers. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Technician A says that rotary oil flow is the oil flow around the circumference of the torque converter caused by the rotation of the torque converter on its axis. Technician B says that the vortex flow is caused by the rotation of the torque converter on its axis. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. Technician A says that a stator aids in directing the flow of fluid from the impeller to the turbine. Technician B says that a stator is equipped with a one-way clutch that allows it to remain stationary when necessary. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. Technician A says that a Simpson gearset is two planetary gearsets that share a common sun gear. Technician B says that a Ravigneaux gearset has two sun gears, two sets of planet gears, and a common ring gear. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. Technician A says that that one of the primary purposes of the pressure regulator valve is to fill the torque converter with fluid. Technician B says that the pressure regulator valve directly controls throttle pressure. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. Technician A says that the purpose of a valve body is to increase oil pressures in response to increases in engine speed. Technician B says that valve bodies are normally fitted with three different types of valves, which start, stop, or use movable parts to regulate and direct the flow of fluid throughout the transmission. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. Technician A says that changes in engine load cause changes in hydraulic pressure inside the transmission. Technician B says that engine load is monitored by throttle pedal movement or by engine vacuum. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. Technician A says that the rear hub of the torque converter is bolted to the flexplate. Technician B says that the flexplate is designed to be flexible enough to allow the front of the converter to move forward or backward if it expands or contracts because of heat or pressure. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. While discussing a Lepelletier system: Technician A says that two simple planetary gearsets are connected in tandem. Technician B says that these systems rely on various combinations of the planetary gears to obtain many forward gears. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. While discussing the CVT transaxle used in Toyota hybrid vehicles: Technician A says that the transaxle contains two electric motor/generators, a differential, and a simple planetary gearset. Technician B says that the planetary gearset adjusts the diameter of the pulleys to provide the various speed ratios. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 42

ELECTRONIC AUTOMATIC TRANSMISSIONS

OBJECTIVES

- Describe what determines the shift characteristics of each selector lever position.
- Identify the input and output devices in a typical electronic control system and briefly describe the function of each.
- Diagnose electronic control systems and determine needed repairs.
- Conduct preliminary checks on the EAT systems and determine needed repairs or service.
- Perform converter clutch system tests and determine needed repairs or service.
- Inspect, test, and replace electrical/electronic sensors.
- Inspect, test, and replace actuators.

Electronic transmission control provides automatic gear changes when certain operating conditions are met. Through the use of electronics, transmissions have better shift timing and quality. As a result, the transmissions contribute to improved fuel economy, lower exhaust emission levels, and improved driver comfort. Although these transmissions function in the same way as earlier hydraulically based transmissions, a computer determines their shift points and the shift quality. The computer uses inputs from different sensors and matches the information to a predetermined program.

Today's electronic transmissions also have self-diagnostic capabilities and can accurately control mainline pressure, apply pressures, TCC operation, and engine torque during shifts. Electronically controlled transmissions typically do not have governors nor throttle pressure devices. The control unit monitors and controls

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE		REPAIR ORDER		
Year: 2007	**Make:** Kia	**Model:** Optima	**Mileage:** 164,366	**RO:** 17087
Concern:	Customer states the transmission won't shift, acts like it's stuck in one gear.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

the action of shift solenoids **(Figure 42–1)**. The solenoids do not directly control the transmission's clutches and bands. The clutches and bands are engaged or disengaged in the same way as hydraulically controlled units. The solenoids simply control the fluid pressures and do not perform a mechanical function.

In an electronic automatic transmission (EAT) system, there is a central processing unit, inputs, and outputs **(Figure 42–2)**. Often the central processing unit is a separate computer designated for transmission control. The computer receives information from various inputs and controls the solenoids that control hydraulic pressure and fluid flow to the apply devices and to the clutch of the torque converter. This computer may be the **transmission control module (TCM)**, the body control

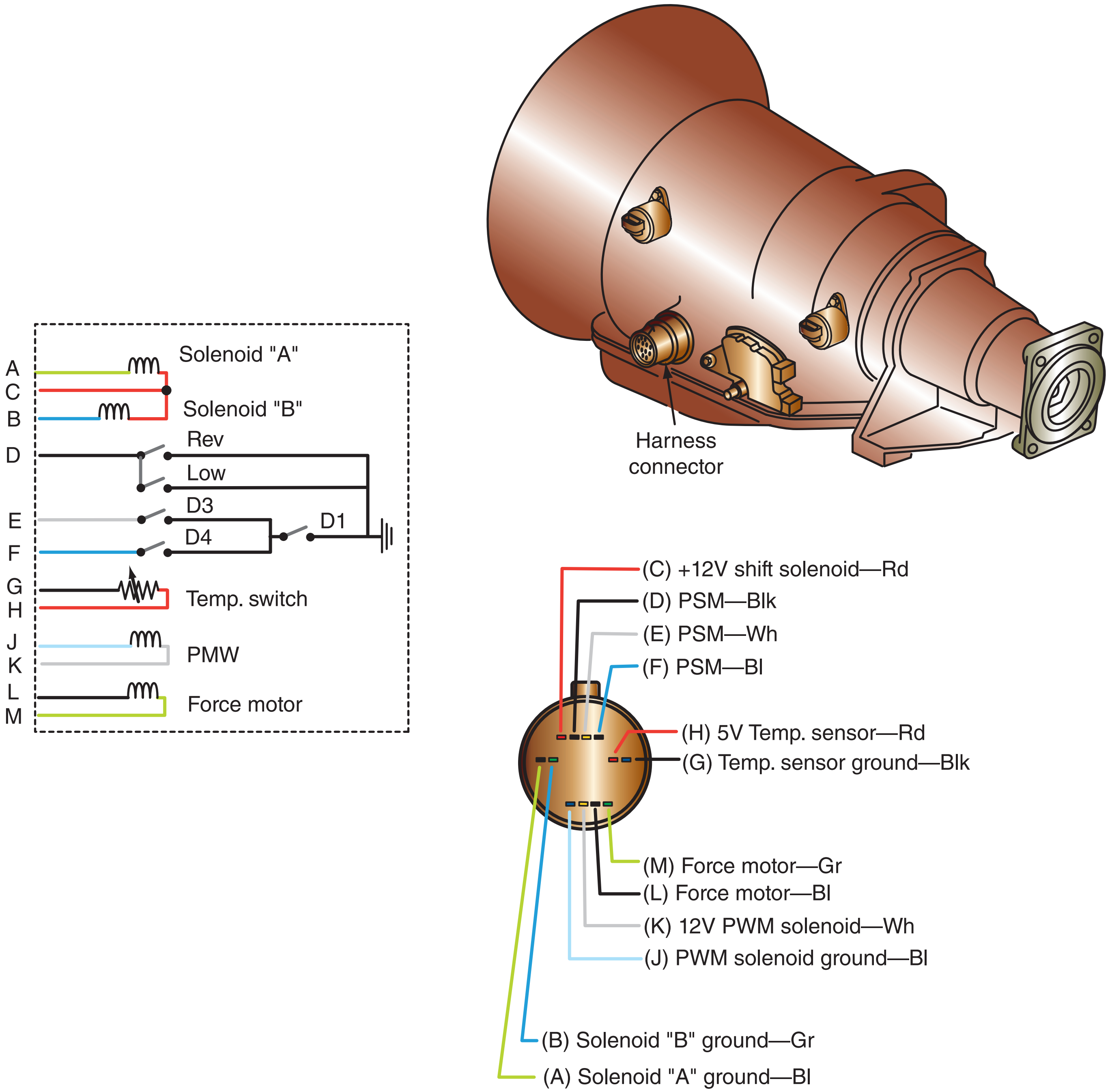


FIGURE 42–1 The key components of a typical EAT.

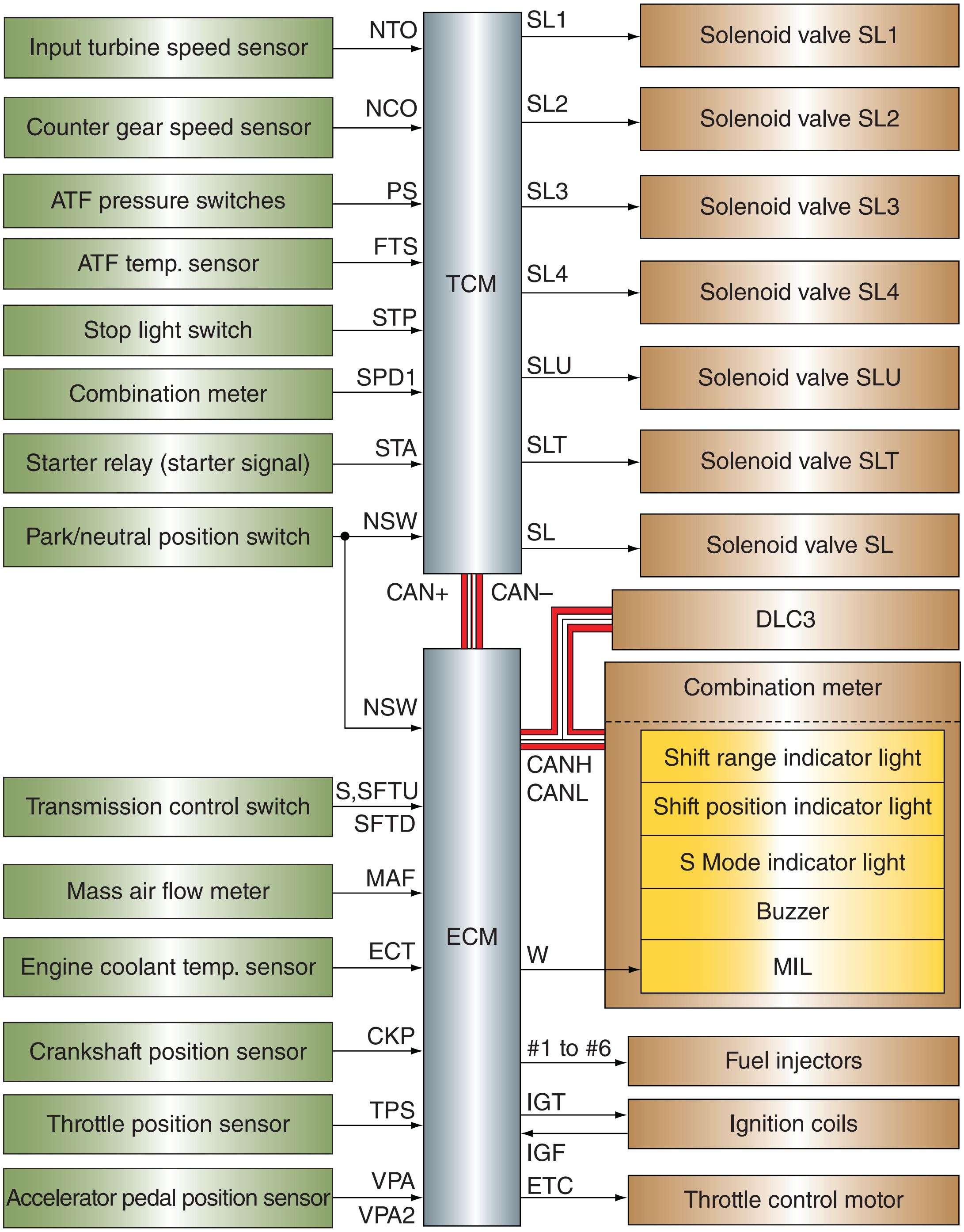


FIGURE 42–2 The different inputs, modules, and outputs in an EAT circuit.

module (BCM), or the powertrain control module (PCM). Some manufacturers mount the TCM on the valve body inside the transmission. Doing this reduces the number of required electrical connectors and the amount of wiring. The TCM is tied into the serial (CAN) bus and shares information with the PCM.

Transmission Control Module

A TCM is programmed to provide gear changes at the optimum time. The TCM controls shift timing, shift feel, and the operation of the torque converter clutch. To determine the best operating strategy for

the transmission, the TCM uses inputs from some engine-related and driver-controlled sensors. The TCM also receives input signals from specific sensors connected to the transmission. By monitoring all of these inputs, the TCM can determine when to shift gears or when to apply or release the torque converter clutch.

The decision to shift or not to shift is based on the shift schedules and logic. A **shift schedule** contains the actual shift points to be used by the computer according to the input data it receives from the sensors. Shift schedule logic chooses the appropriate gear and then determines the correct shift schedule or pattern that should be followed. Each possible engine/transmission combination for a vehicle has a different set of shift schedules. The shift schedules set the conditions required for a change in gears. The computer frequently reviews the input information and can make quick adjustments to the schedule, if needed and *as* needed. To control shift quality, the TCM works with the PCM to momentarily alter engine output. This is accomplished by changing the ignition timing during a shift. The reduction in engine torque during shifting allows for smooth gear changes.

The electronic control systems used by the manufacturers differ with the transmission models and the engines to which they are attached. The components in each system and their operation also vary with the different transmissions. However, all operate in a similar fashion and use basically the same parts.

Inputs

The computer may receive information from two different sources: directly from a sensor or through the CAN communication bus that connects all of the vehicle's computer systems **(Figure 42–3)**. Normal engine-related inputs are used by the TCM to determine the best shift points. Many of these inputs are available at the common data bus. Other information, such as engine and body identification, the TCM's target idle speed, and speed control operation are not the result of monitoring by sensors; rather, these have been calculated or determined by the TCM and made available on the bus.

Typical data inputs used by the TCM include:

- Accelerator pedal position (APP) and throttle position (TP)
- Engine load
- Engine speed
- Gear range or manual gear selection
- Vehicle speed
- Manifold absolute pressure (MAP)
- Mass airflow (MAF)
- Intake air temperature (IAT)
- Barometric pressure (BARO)
- Engine coolant temperature (ECT)
- ATF temperature
- Crankshaft position (CKP) sensors
- Line pressure
- Input shaft speed
- Intermediate speed
- Output shaft speed
- Brake application
- A/C on-off
- Cruise control on-off

These provide the TCM with information about the operating condition of the engine and transmission. Through these, the TCM is able to control shifting and torque converter clutch operation according to the temperature, speed, and load of the engine.

Inputs that are tied directly to the TCM are typically not available on the bus circuit. Many of these sensors produce an analog signal that must be changed to a digital signal before the TCM can respond. This conversion is handled by an analog-to-digital (A/D) converter, the PCM, or a digital radio adapter controller (DRAC). These typically convert an analog AC signal to a digital 5-volt square wave.

The TCM constantly monitors what is happening inside the transmission with various speed and gear range sensors that tell it if the gears are shifting correctly and at what speeds. Once the TCM commands a gear change, solenoids are energized to hydraulically control the engagement of the proper clutch or band.

On-Off Switches Several simple switches are used in the control of an EAT. The number and purpose of each depends on the system. A brake pedal position (BPP) switch tells the TCM when the brakes are applied. At that time, the torque converter clutch disengages. The BPP switch closes when the brakes are applied and opens when they are released. Its input has little to do with the up-and-down shifting of gears, except that in some systems it signals a need for engine braking.

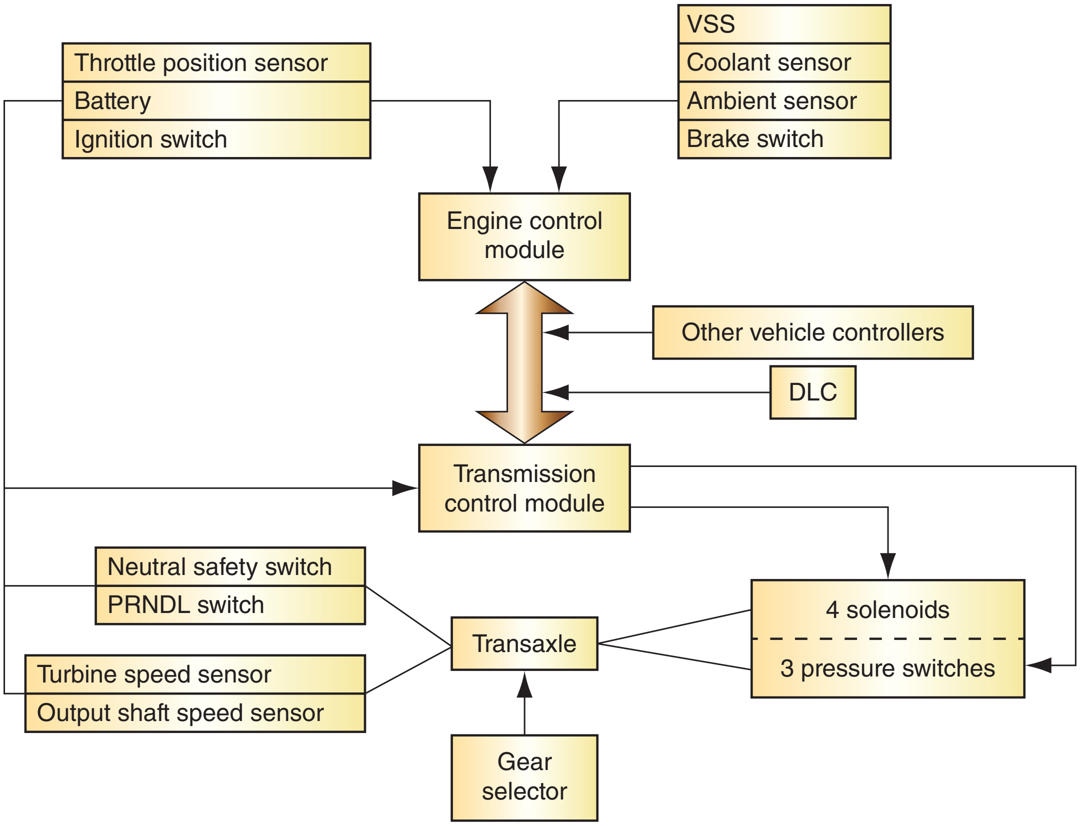


FIGURE 42–3 The electric circuit for a typical electronically controlled transmission. Note: The CCD data BUS is the data source for other inputs in this multiplexed circuit.

The transmission control (TC) switch is a momentary contact switch located on the selector lever that allows the driver to cancel operation of overdrive. When the TC switch is depressed, a signal is sent to the PCM to disengage overdrive operation. At the same time, the PCM illuminates the transmission control indicator lamp (TCIL) to notify the driver that overdrive is canceled.

An A/C request switch tells the TCM that the A/C has been turned on. The TCM then changes the line pressure and shift timing to accommodate the extra engine load created by the A/C system. When the A/C clutch is engaged, the electronic pressure control (EPC) is adjusted by the TCM to compensate for the additional load on the engine.

EATs also have cruise control input that informs the TCM when cruise control is active. In this mode, shift patterns are altered to reduce excessive and harsh shifting. There may also be a four-wheel drive low (4WDL) range switch that lets the TCM know when the four-wheel drive transfer case gear is in its low range.

Digital Transmission Range (TR) Sensor The first input that the TCM looks at is the position of the gear shift lever. All shift schedules are based on the gear selected by the driver. These schedules are coded by the position of the gear selector and the current gear range and use throttle angle and vehicle speed as primary determining factors. A digital transmission range (TR) sensor informs the TCM of the gear selected by the driver. This sensor may also contain the neutral safety switch and the reverse light switch. A TR sensor is typically a multiple-pole-type on-off switch **(Figure 42–4)**. The digital TR sensor may be located on the outside of the transmission at the manual lever or it may be internal or part of the TCM.

Accelerator Pedal Position (APP) and Throttle Position (TP) Sensors Depending on if the vehicle is drive by wire, either the APP or the TP sensor sends a voltage signal to the TCM in response to TP. Not only is this signal used to inform the TCM of the driver's intent, it is also used in place of the hydraulic throttle pressure linkage. The APP/TP sensor is very

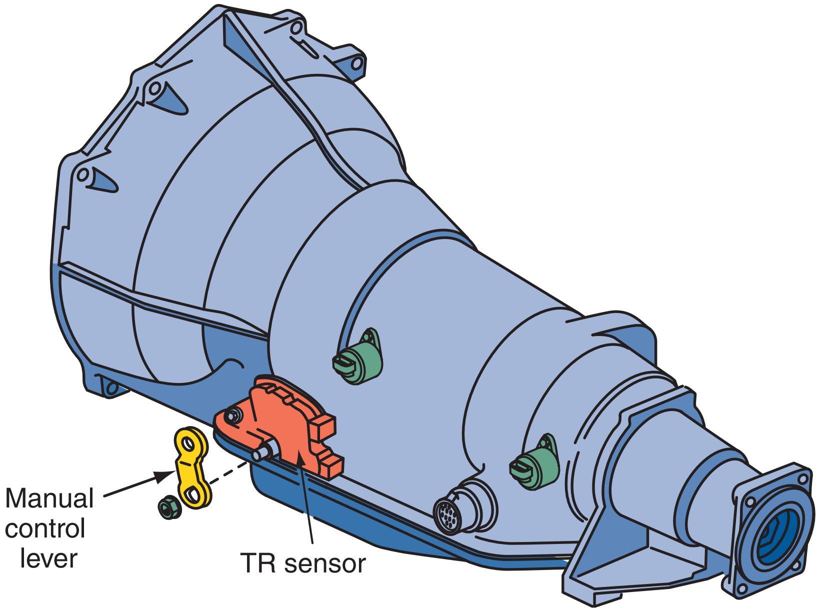


FIGURE 42-4 A TR sensor.

important to the operation of an EAT and is used for shift scheduling, EPC, and TCC control.

If the APP/TP signal is wrong, it can affect transmission kickdown shifts during acceleration as well as upshifts and downshifts. When the TCM is unable to get a good signal, it may substitute a "calculated" TP based on other inputs from the data bus. Regardless, the TCM always calculates a TP based on its programming and inputs. This calculation is one of the most important inputs for shift pattern logic. A very low APP/TP angle causes upshifts to occur early, and very high angles cause early downshifts.

Mass Airflow (MAF) Sensor The MAF sensor measures the mass of air flowing into the engine and is primarily used to calculate injector pulse width. It also is used to calculate engine load and to regulate electronic pressure control (EPC) and shift and TCC scheduling. Depending on the type of fuel injection system used (speed density or airflow), engine load may be determined by the TP sensor, MAP sensor, and/or a vane airflow VAF sensor or MAF sensor.

Signals from a BARO sensor are used to adjust line pressures according to changes in altitude. This sensor input may not be used; its use depends on the type of intake air monitoring system the vehicle is equipped with. On those vehicles using the BARO sensor as an input, the sensor may be integrated in the PCM or it may be mounted externally.

Engine Speed

To ensure that the transmission shifts at the correct time, the TCM must receive an engine speed input. This can be done through the ignition module or PCM and serial data bus or through a direct connection from a dedicated circuit between the CKP sensor and TCM. With the direct connection, all time delays at the bus circuit are eliminated and the TCM always knows the current engine speed. This input is used to determine shift timing, wide-open throttle (WOT) shift control, TCC control, and EPC pressure. Also, to prevent the engine from running at too high of a speed, the TCM will order an upshift.

Temperature Sensors Shift schedules are also influenced by the engine's temperature. Sometimes the engine's temperature is raised by delaying gear shifts. When the engine is overheating, shifts will occur sooner. The computer may also engage the converter clutch in second or third gear if the coolant temperature rises. Engine temperatures are often tied to ATF temperatures in the computer and are critical to the operation of a transmission.

The IAT sensor provides the fuel injection system with mixture temperature information. The IAT sensor is used both as a density corrector for airflow calculation and to proportion cold enrichment fuel flow. It is installed in the air cleaner outlet tube. The IAT sensor also is used in determining line pressures.

The TCM may also use the signal from the IAT to calculate the temperature of the battery. The TCM then uses this temperature to estimate transmission fluid temperature.

Transmission Fluid Temperature (TFT) Sensor The transmission fluid temperature (TFT) sensor is normally located on the valve body. Signals from the sensor tell the TCM what the temperature of the ATF is. The sensor is a thermistor whose output signal varies with ATF temperature. The TCM uses this signal to control shift timing, shift feel, and TCC engagement. When the signal indicates normal operating temperature, the transmission is shifted normally; however, when the fluid is too cold or too hot, shifting is altered.

When the fluid temperature is too high, the TCM will operate the transmission in a way to allow it to cool. Shifts will occur sooner than normal. When the fluid is too cold, shifting is delayed to help warm the fluid. Fluid temperature is used, along with other inputs, to control TCC clutch engagement. When the fluid is cold, the TCM prevents TCC engagement until the fluid reaches a specific temperature.

Some transmissions operate with distinct shift schedules based on fluid temperature. **Figure 42–5** shows the operating characteristics of a Chrysler 45RFE transmission when the ATF is at different temperatures.

If the TFT sensor fails or the TCM determines temperature signals are incorrect, the TCM will look at engine temperature to estimate the temperature of the ATF.

Transmission Pressure Switches Various transmission pressure switches **(Figure 42–6)** can be used to keep the TCM informed as to which hydraulic circuits are pressurized and which clutches and brakes are applied. These input signals can serve as verification to other inputs and as self-monitoring or feedback signals. The most commonly used pressure switch is the transmission fluid pressure (TFP) switch, which monitors fluid pressure to determine when a clutch or band is applied or released.

Voltage-Generating Sensors A variety of speed sensors, most commonly Hall-effect or PM generator sensors, are used in today's EATs. These sensors serve as the governor signal and monitor the operation of the transmission. Some TCMs receive a signal from a vehicle speed sensor (VSS) and use this to determine the correct time to shift. Some EATs have intermediate speed and an output shaft speed (OSS) sensors. These sensors may be used with the

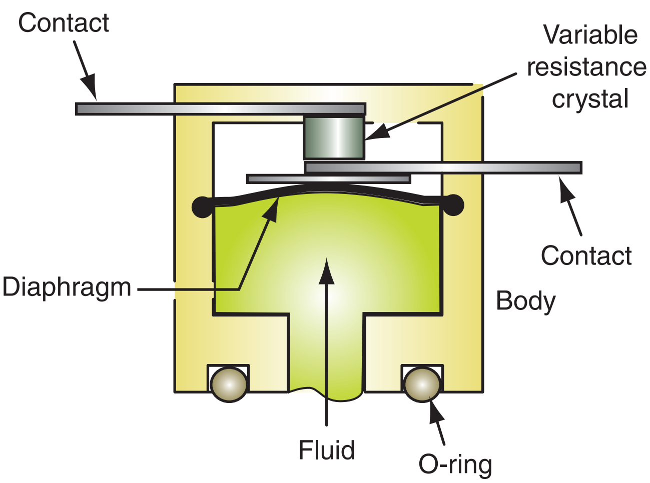


FIGURE 42–6 A pressure switch.

Temperature Range	Gear Operation	TCC Operation
Below –16 °F (–27 °C)	Operates only in Park, Neutral, Reverse, 1st, and 3rd gears	NO
Between –12 °F (–24 °C) and 10 °F (–12 °C)	Upshifts from 2nd to 3rd and 3rd to 4th are delayed and downshifts from 4th to 3rd and 3rd to 2nd are early	NO
Between 10 °F (–12 °C) and 36 °F (2 °C)	All shifts are delayed	NO
Between 40 °F (4 °C) and 80 °F (27 °C)	Normal shifting	NO
Between 80 °F (27 °C) and 240 °F (116 °C)	Normal shifting	YES, normal
More than 240 °F (116 °C), or if the engine is overheating	2nd to 3rd and 3rd to 4th shifts are delayed	YES, but longer
Above 260 °F (127 °C)	2nd to 3rd and 3rd to 4th shifts are greatly delayed	YES, nearly full time

FIGURE 42–5 The operation of a Chrysler 45RFE transmission with the ATF at different temperatures.

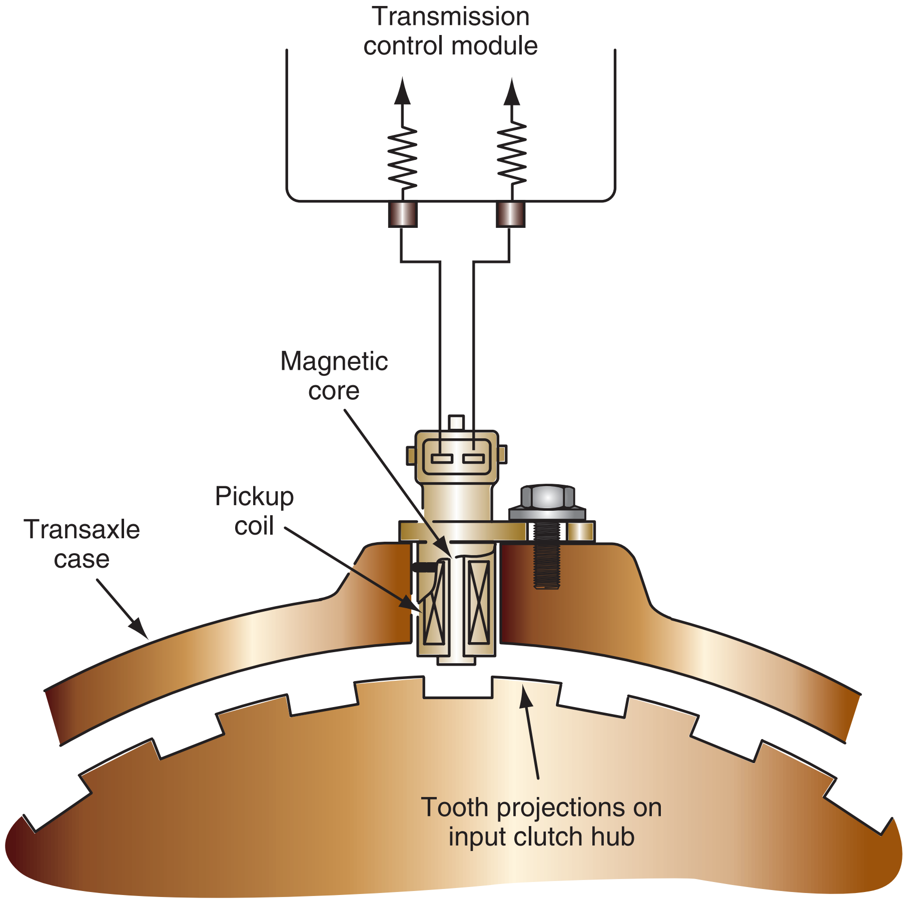


FIGURE 42–7 A voltage generating speed sensor.

VSS or provide a vehicle speed reference for the TCM. When a vehicle has both sensors, the OSS signal is used as a verification signal for the VSS, or vice versa. The OSS is typically used for control of torque converter clutch operation, shift timing, and fluid pressure control.

Many transmissions have an input speed sensor (ISS) or a turbine speed (TSS) sensor. This sensor is identical to the OSS and its signal is used to calculate converter turbine speed **(Figure 42–7)**. It is also used, along with an engine speed input, to determine the amount of T/C slip by providing the TCM with the difference between engine speed and transmission input shaft speed. This is used to determine the amount of pressure applied to the TCC. Comparing input, intermediate and output shaft rotation speeds also allows the TCM to determine if shifts are occurring properly, or if they are too quick or are taking too long **(Figure 42–8)**. Four-wheel drive vehicles may have an additional speed sensor in the transfer case.

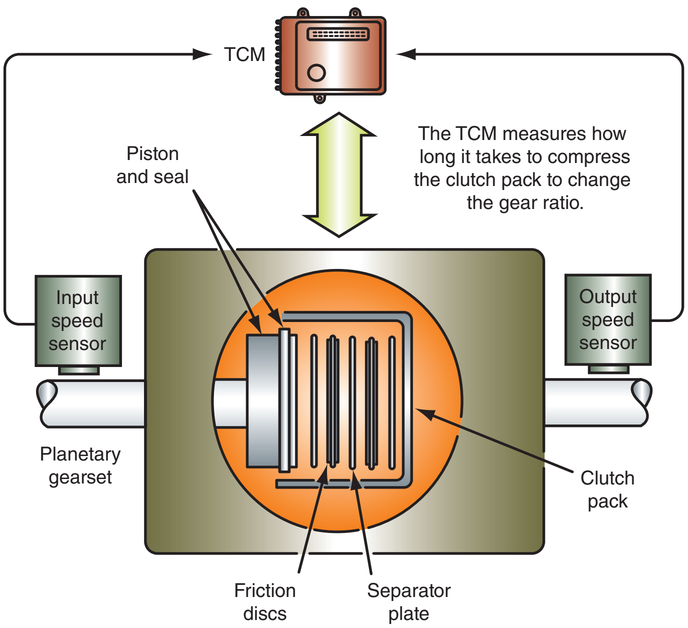
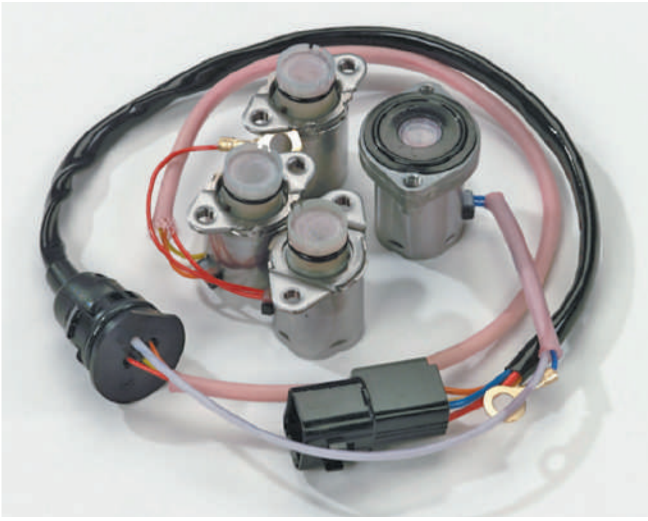


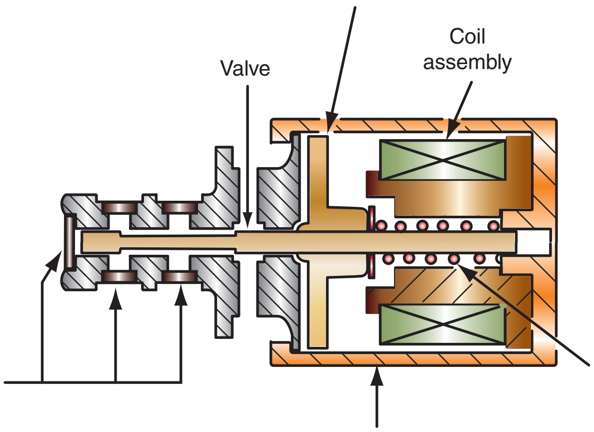
FIGURE 42–8 Monitoring clutch pack performance using speed sensors.

Outputs

Common outputs used with EATs are indicator lamps and solenoids. The indicator lamps can show the selected gear range in the instrument panel. They may also be a MIL designated for the transmission, or this warning light may be incorporated into the



(A)



(B)

FIGURE 42-9 (A) The solenoids for a transmission and their wiring harness. (B) Inside of a shift solenoid.

circuit for the engine's MIL. Shift, pressure control, and TCC solenoids are used in all modern EATs. All of these are controlled by the TCM. The solenoids are typically located inside the transmission and are mounted to the valve body.

Shift Solenoids Shift solenoids **(Figure 42–9A)** are used to regulate shift timing and feel by controlling the delivery of fluid to a manual shift valve or to a clutch pack. These solenoids are on-off solenoids that are normally off and in the open position. When open, line pressure is present at the manual or selected shift valve. When the shift solenoids are energized **(Figure 42–9B)**, they block line pressure and allow pressure to exhaust from around the shift valve. This allows the valve to move. Another way of controlling the shift valve is if the normally open solenoid is used to vent pressure from the shift valve **(Figure 42–10A)**. When commanded closed, pressure builds against the valve and it moves against the spring **(Figure 42–10B)**.

The number and purpose of each depends on the model of transmission. A typical four-speed unit has two shift solenoids. The two solenoids offer four possible on-off combinations to control fluid to the various shift valves. This provides the engagement of the four forward gears **(Figure 42–11)**. Transmissions with additional forward gears rely on additional shift solenoids. For example, the eight-speed 8L90 transmission from GM has five shift solenoids plus a boost solenoid. The on-off combinations of these provide the additional gears. It is important to note that the TCM will stop current flow to a shift solenoid if it detects a fault in the solenoid or its circuit.

Pressure Control Solenoids The pressure control solenoid replaces the conventional TV cable setup to provide changes in line pressure in response to

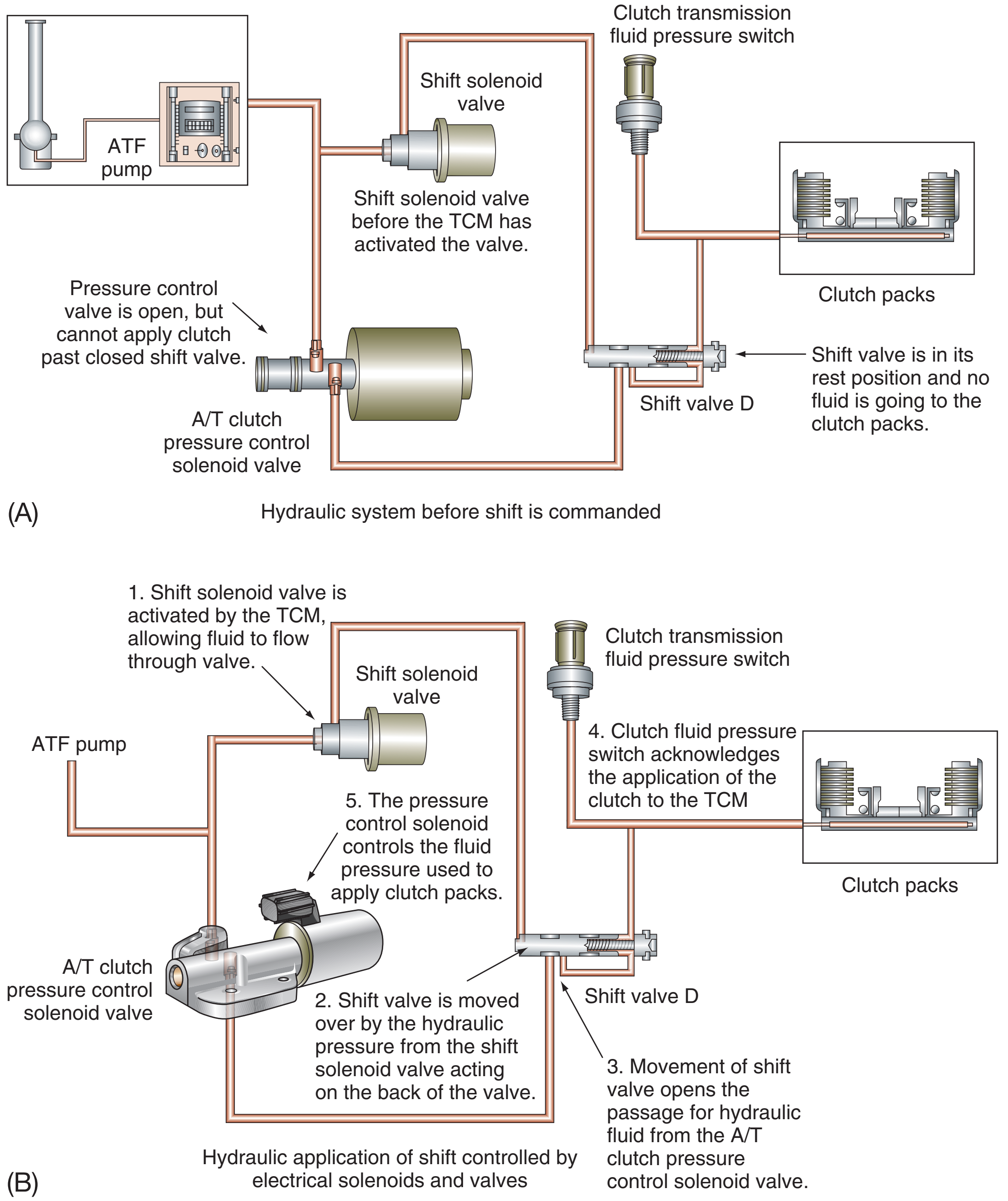


FIGURE 42–10 (A) Fluid flow blocked by the shift valve. (B) Pressure moving the shift valve and applying the clutch pack.

engine running conditions and engine load. The action of the solenoid controls the operating hydraulic pressures to the clutches and brakes to provide smooth and precise shifting. The pressure control solenoid is installed on the valve body.

In most cases, the pressure control solenoid is called an electronic pressure control (EPC) solenoid and is duty cycle controlled by the TCM. Most of these solenoids are **variable force solenoids (VFS)** or pulse width modulated (PWM) solenoids and contain a spool valve or plunger and a spring. To control fluid pressure, the PCM sends a varying signal to the solenoid. This changes the amount the solenoid will cause the spool valve to move. When the solenoid is off, spring tension keeps the valve in place to maintain maximum pressure. When the solenoid is energized it moves the spool valve. The movement of the valve uncovers the exhaust port around the valve, thereby causing a decrease in pressure **(Figure 42–12)**.

TCC Solenoid The TCC solenoid is used to control the application, modulation, and release of the TCC. The operation of the converter clutch is also totally controlled by the TCM. The exception to this is when

Lever Position	Commanded Gear	Shift Solenoid A	Shift Solenoid B	TCC Solenoid
P/R/N	1	ON	OFF	Disabled hydraulically
D	1	ON	OFF	Disabled hydraulically
D	2	OFF	OFF	Controlled electronically
D	3	OFF	ON	Controlled electronically
D	4	ON	ON	Controlled electronically
O/D switched off				
1	1	ON	OFF	Disabled hydraulically
2	2	OFF	OFF	Controlled electronically
3	3	OFF	ON	Controlled electronically
Manual 2	2	OFF	OFF	Controlled electronically
Manual 1	1	ON	OFF	Disabled hydraulically
Manual 1	2	OFF	OFF	Controlled electronically

FIGURE 42–11 The action of the solenoids in a typical four-speed transmission.

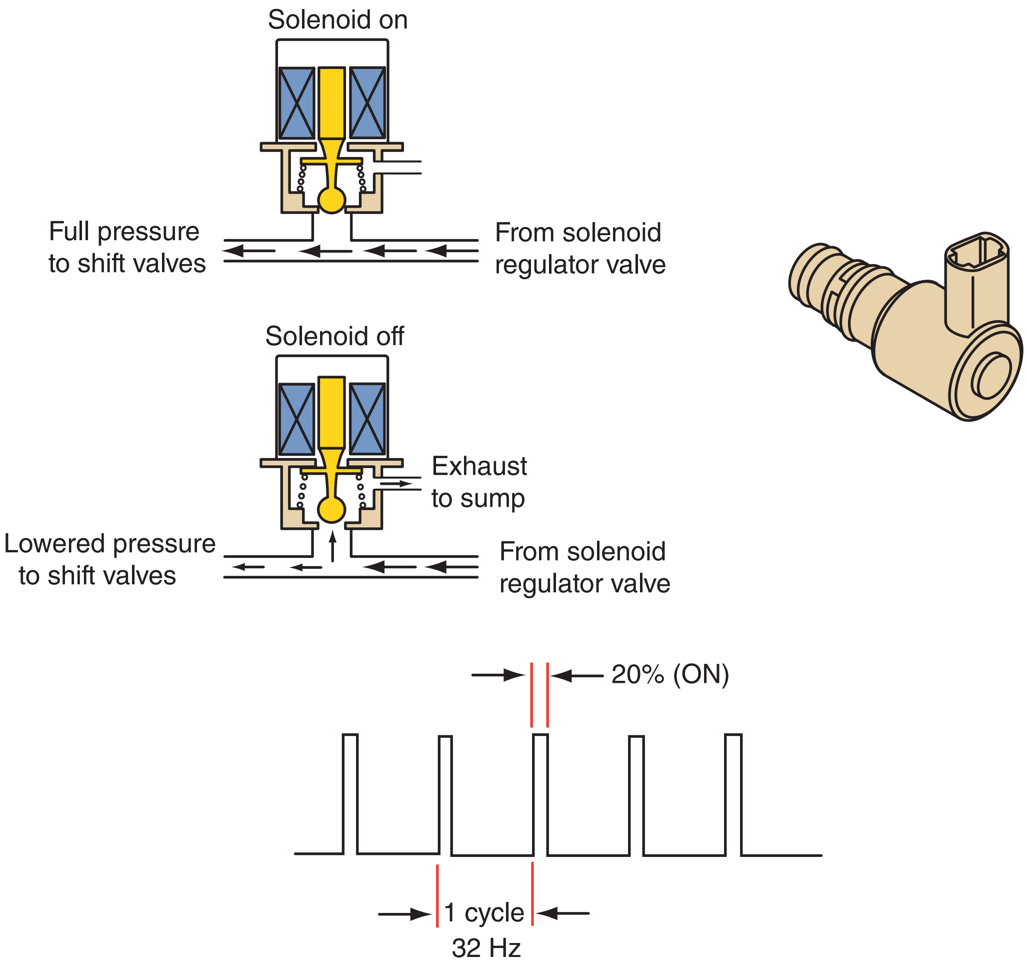


FIGURE 42–12 (Top) A typical PWM solenoid. (Bottom) The signal representing the control or ordered duty cycle from the computer.

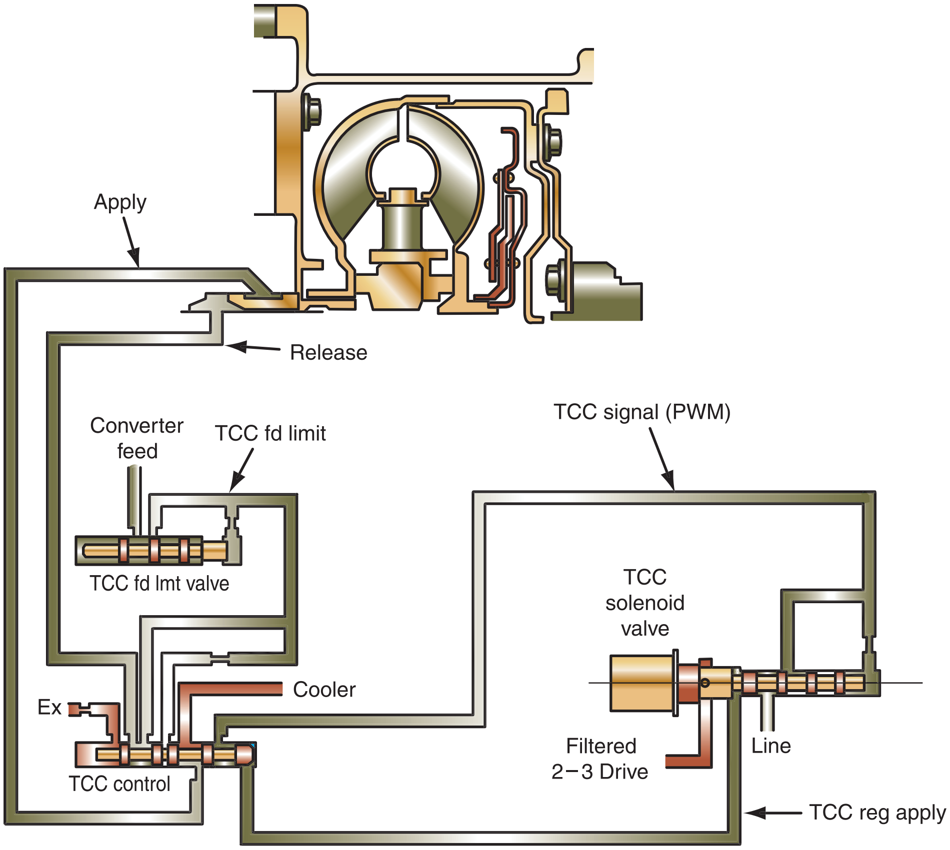


FIGURE 42–13 PWM control of the torque converter clutch allows precise control of clutch application.

the clutch is hydraulically disabled to prevent engagement regardless of the commands from the computer. The converter clutch is hydraulically applied and electrically controlled through a PWM solenoid controlled by the TCM **(Figure 42–13)**. When the solenoid is off, TCC signal fluid exhausts and the converter clutch remains released. Once the solenoid is energized, TCC signal fluid passes to the TCC regulator valve and the clutch, engaging it. Modulating the pressure to the clutch allows for smooth engagement and disengagement and also allows for partial engagement of the clutch.

Whenever the TCM detects a problem in any of the solenoids in a transmission, it will disable the TCC solenoid.

Adaptive Controls

Most late-model EATs have systems that allow the TCM to change transmission behavior based on the current condition of the transmission and engine, current operating conditions, and the habits of the driver. When systems are capable of doing this, they have **adaptive learning** capabilities. Adaptive learning provides consistent quality shifting and increases the durability of the transmission.

These transmissions have a line pressure control system that compensates for the normal wear of a transmission. As parts wear or conditions change, the time required to apply a clutch or brake changes. The TCM monitors the input and output speeds of the transmission during commanded shifts to determine if a shift is occurring too fast (harsh) or too slow (soft) and adjusts the line pressure to maintain the desired shift feel. Adaptive learning takes place as the TCM reads input and output speeds more than 140 times per second.

The system may also monitor the condition of the engine and compensate for any changes in the engine's performance. It also monitors and memorizes the typical driving style of the driver and the operating conditions of the vehicle. With this information, the computer adjusts the timing of shifts and converter clutch engagement to provide good shifting at the appropriate time.

SHOP TALK

EATs with adaptive learning may display harsh and/or abrupt shifting when they are new. This is normal because the TCM has not yet received enough information to learn about the vehicle or driver. This shifting behavior may also occur after the vehicle's battery has been disconnected for a long period.

In addition, some transmissions have part unique numbers (PUN) and transmission unique numbers (TUN) that are used for programing and adaption. In the GM 8L90, each shift solenoid has a PUN that identify the performance characteristics of each solenoid. This information is stored in the TCM and is used for precise control of each solenoid. If the transmission, valve body, solenoids, or TCM require replacement, the data stored by the TCM must be downloaded and programmed into the replacement TCM for the transmission to function correctly.

Limp-In Mode

When the TCM detects a serious transmission problem or a problem in its circuit (or in some cases an engine control or data bus problem), it may switch to a default, limp-in, or fail-safe mode. Limp-in may also be initiated if the TCM loses its battery power feed. This mode allows for limited driving capabilities and is designed to prevent further transmission damage while allowing the driver to drive with decreased power and efficiency to a service facility for repairs.

The capabilities of a transmission while it is in limp-in mode depend on the extent of the fault, the manufacturer, and the model of transmission. When the TCM moves into the limp-in mode, a DTC is set and the transmission will only operate in this mode until the problem is corrected. Examples of operating characteristics during limp-in include:

- The transmission locks in third gear when the gear selector is in the drive position or second gear when it is in a lower position.
- The transmission will remain in whatever gear it was in but will shift into third or second gear and stay there as soon as the vehicle slows down.
- The transmission will only use first and third gears while in the drive position.
- The transmission will operate only in park, neutral, reverse, and second gears and will not upshift or downshift.

Operational Modes

With electronic controls, automatic transmissions can be programmed to operate in different modes. The desired mode is selected by the driver. The mode selection switch can be located on the center console or the instrument panel. Most transmissions with this feature have two selective modes, normally called "Normal" and "Sport." During the normal mode, the transmission operates according to the shift schedule and logic set for normal or regular operation. In the sport mode, the TCM uses different logic and shift schedules to provide for better acceleration and performance with heavy loads. Normally this means delaying upshifts.

If three modes are available, the third mode is called the "Auto" mode. The auto mode is a mixture between the normal and power modes. While in this mode, the TCM will control the shifts in a normal way. However, if the throttle is quickly opened, the shift pattern will switch to the power mode.

Some late-model vehicles have a "Tow/Haul" switch. This operating mode delays upshifts and increases operating pressures when the vehicle is operating with a heavy load. The mode also provides quicker downshifts during deceleration, which allows for more engine braking. The torque converter's lock-up clutch is applied sooner and in more gears than normal during acceleration. This helps to keep the temperature of the fluid in the torque converter down. Also, the clutch remains engaged for a longer period of time during deceleration to improve engine braking. In this mode, the transmission is able to shift into overdrive when the vehicle's load is overcome.

Manual Shifting

One of the features of electronically controlled transmissions is the availability of manual shift controls. Many late-model EATs use electronic shifters instead

FIGURE 42–14 An electronic shifter.

of mechanical linkages **(Figure 42–14)**, which provide the driver the ability to easily shift the transmission manually, but with the convenience of an automatic transmission. Unlike a manual transmission, though, the driver does not need to depress a clutch pedal nor is there a clutch assembly on the flywheel. The driver simply moves the gear selector, uses the paddle shifter, or hits a button and the transmission changes gears. If the driver does not change gears and engine speed is high, the transmission shifts on its own. If the driver elects to let the transmission shift automatically, a switch disconnects the manual control and the transmission operates automatically.

CVT Controls

The electronic control system for a typical CVT consists of a TCM, various sensors, linear solenoids, and an inhibitor solenoid. Pulley ratios are always controlled by the control system. Input from the various sensors determines which linear solenoid the TCM will activate. Activating the shift control solenoid changes the shift control valve pressure, causing the shift valve to move. This changes the pressure applied to the driven and drive pulleys, which change the effective pulley ratio. Activating the start clutch control solenoid moves the start clutch valve. This valve allows or disallows pressure to the start clutch assembly. When pressure is applied to the clutch, power is transmitted from the pulleys to the final drive gearset **(Figure 42–15)**.

The start clutch allows for smooth starting. Because this transaxle does not have a torque converter, the start clutch is designed to slip just enough to get the car moving without stalling or straining the engine. The slippage is controlled by the hydraulic pressure applied to the start clutch. To compensate for engine loads, the TCM monitors the engine's vacuum and compares it to the measured vacuum of the engine while the transaxle was in park or neutral.

The TCM controls the pulley ratios to reduce engine speed and maintain ideal engine temperatures during acceleration. If the car is continuously driven at full throttle acceleration, the TCM causes an increase in pulley ratio. This reduces engine speed and maintains normal engine temperature while not adversely affecting acceleration. After the car has been driven at a lower speed or not accelerated for a while, the TCM lowers the pulley ratio. When the gear selector is placed into reverse, the TCM sends a signal to the PCM. The PCM then turns off the car's air conditioning and causes a slight increase in engine speed.

Audi's stepless Multitronic CVT is based on what it refers to as a variator. The variator is made of vanadium-hardened steel that is encased in oil and offers more durability than belt-driven CVTs. A manual gear selection mode is available and six simulated gear ratios can be selected. In the automatic mode, Multitronic calculates the optimum gear ratio with the aid of a dynamic regulating program, according to engine load, the driver's preferences, and driving conditions.

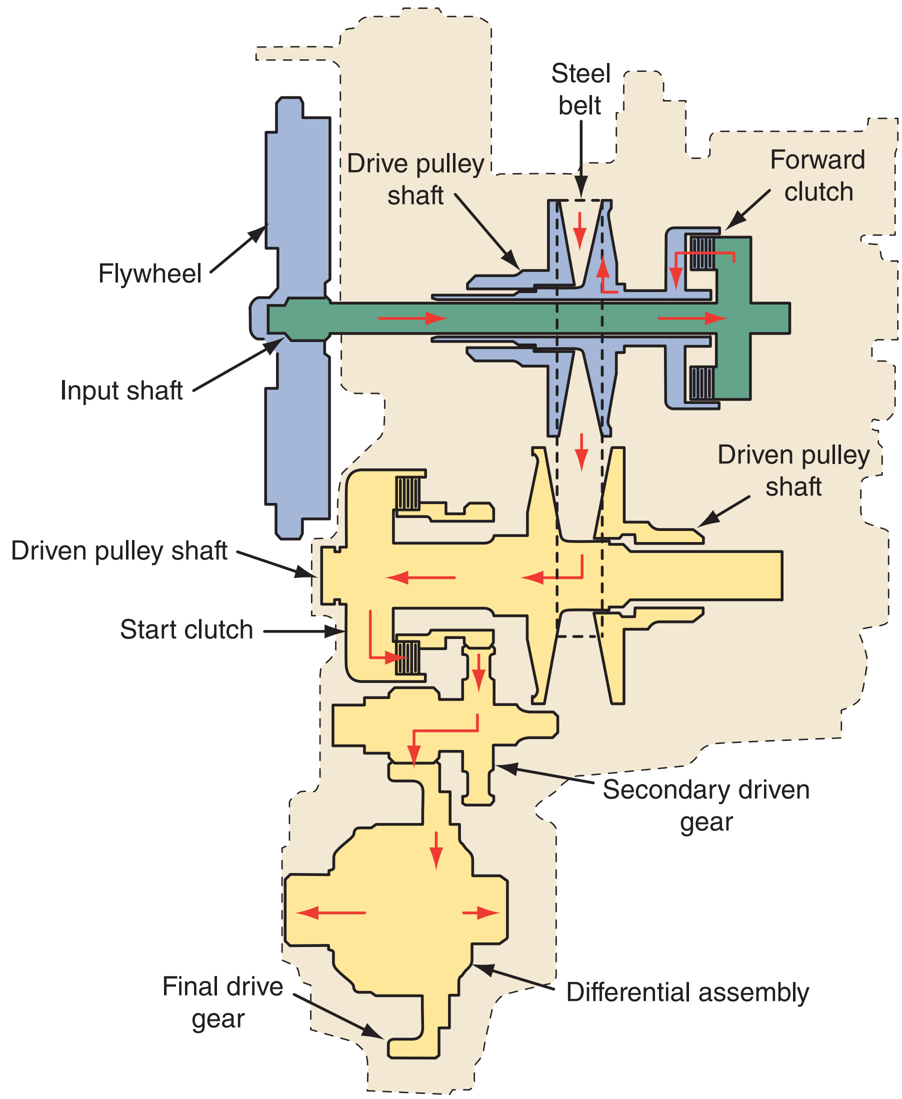


FIGURE 42–15 Components of a CVT assembly.

Hybrid Transmissions

Perhaps the most complex EATs are those used in many hybrid vehicles. The transmissions are fitted with electric motors that not only help propel the vehicle, but also provide a constantly variable drive ratio. These CVTs do not rely on belts and pulleys; rather, it is the electric motors that change the drive gear ratios. It is important to note that some hybrid vehicles rely on conventional CVTs and manual or automatic transmissions. This section covers the common nontraditional hybrid transmissions.

GO TO Chapter 35 for explanations of common hybrid vehicle systems.

Honda IMA Hybrid Models

A modified version of an automatic, manual, or CVT transaxle is used in Honda IMA hybrid vehicles. The transaxle is more compact so that it can fit behind the electric motor mounted at the rear of the engine **(Figure 42–16)** and occupy the same amount of

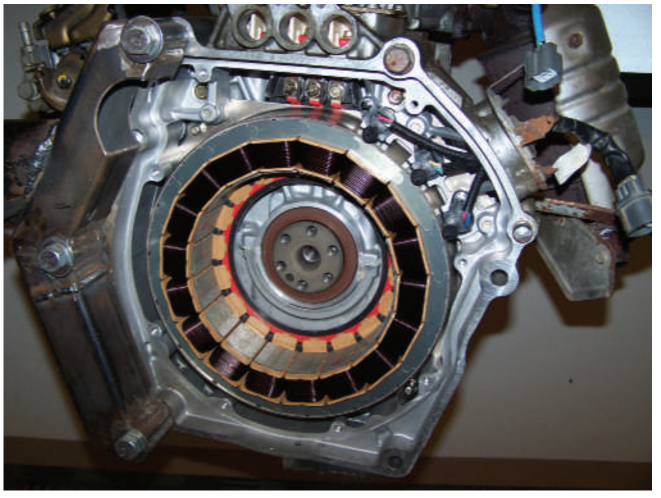


FIGURE 42–16 The IMA motor in Honda hybrids is mounted between the engine and transaxle.

space as the transaxle does in a nonhybrid vehicle. These transaxles operate in the same way as other Honda units. The automatic transaxle is fitted with an integrated electric oil pump and different gear ratios that provide for better acceleration, fuel economy, and regenerative braking.

Toyota and Lexus Hybrids

The power-split device used in Toyota and Lexus hybrids **(Figure 42–17)** operates as a continuously variable transaxle, although it does not use the belts and pulleys normally associated with CVTs. The variability of this transaxle depends on the action of a motor/generator, referred to as MG1, and the torque supplied by another motor/generator, referred to as MG2, and/or the engine.

This transaxle does not have a torque converter or clutch. Rather, a damper is used to cushion engine vibration and the power surges that result from the sudden engagement of power to the transaxle.

The engine and the two electric motors are connected to the planetary gearset. The gearset transfers power between the engine, MG1, MG2, and/or the drive wheels. The system splits power from the engine to different paths: to drive MG1 or drive the car's wheels, or both. MG2 can drive the wheels or be driven by them.

In the planetary gearset, the sun gear is attached to MG1. The ring gear is connected to MG2 and the final drive unit is in the transaxle. The planetary carrier is connected to the engine's output shaft **(Figure 42–18)**. The key to understanding how this system splits power is to realize that when there are two sources of input power, they rotate in the same direction but not at the same speed. Therefore, one can assist the rotation of the other, slow down the rotation of the other, or work together. Also, keep in mind that the rotational speed of MG2 largely depends on the power generated by MG1. Therefore, MG1 basically controls the continuously variable transmission function of the transaxle.

Ford Motor Company Hybrids

Ford's hybrids are equipped with an electronically controlled continuously variable transmission (eCVT). Based on a simple planetary gearset like Toyota's, however, Ford's transaxle is different in construction. In a Ford transaxle, the traction motor is not directly connected to the ring gear of the gearset. Rather, it is connected to the transfer gear assembly.

The effective gear ratios are determined by the speed of the motor/generator, engine, and traction motor. This means these determine the torque that

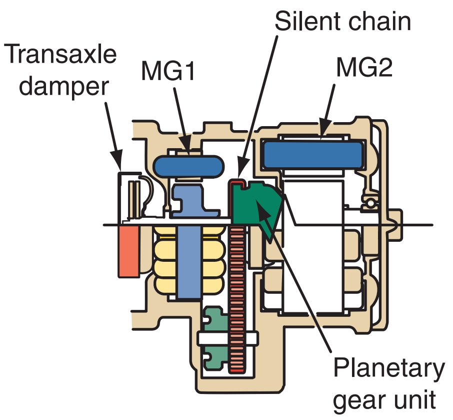


FIGURE 42–17 A typical power-split transaxle for a Toyota hybrid.

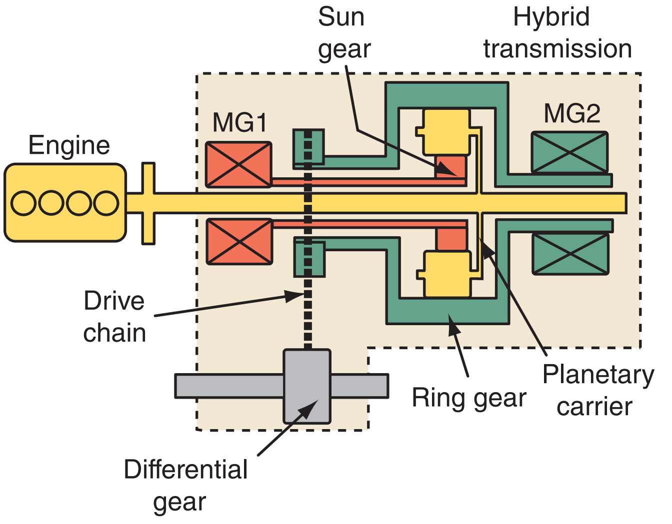


FIGURE 42–18 The arrangement of the electric motors and planetary gears in a power-split transaxle.

moves to the final drive unit in the transaxle. These power plants are controlled by the VSC through the TCM. Based on commands from the VSC and information from a variety of inputs, the TCM calculates the amount of torque required for the current operating conditions. A motor/generator control unit then sends commands to the inverter. The inverter, in turn, sends phased AC to the stator of the motors. The timing of the phased AC is critical to the operation of the motors as is the amount of voltage applied to each stator winding.

Two-Mode Transmissions

The two-mode full hybrid transmission relies on advanced hybrid, transmission, and electronic technologies to improve fuel economy and overall vehicle performance. It is claimed that the fuel consumption of a full-size truck or SUV is decreased by at least 25 percent when it is equipped with this hybrid system.

The system fits into a standard transmission housing and is basically three planetary gearsets coupled to two electronically controlled electric motors, which are powered by a 300-volt battery pack. This combination results in four forward speeds plus continuously variable gear ratios at low speeds and motor/generators for hybrid operation **(Figure 42–19)**.

Operation One motor is used to restart the engine after it shuts down at a traffic light or stop sign. It also assists the engine during low-speed acceleration. The other motor provides all propulsion power when reverse gear is selected and assists the engine during low speeds with a heavy load and when cruising at high speeds. During light-load operation up to 30 mph (48 km/h), the motor can propel the vehicle without the assistance of the engine. Both motors are used as generators to charge the battery pack when the vehicle is decelerating and braking.

The transmission uses clutch-to-clutch technology. The variable gear ratios are available through a mixing of power from the electric motors with the engine's power. When the motors are not providing power, the transmission operates like a conventional four-speed automatic.

The hybrid system has two distinct modes of operation. It operates in the first mode during low-speed and low-load conditions, and the second mode is used while cruising at highway speeds. The system can operate solely on electric or engine power or by a combination of the two. Typically, when one or both of the motors are not providing propulsion power, they are working as generators driven by the engine or by the drive wheels for regenerative braking.

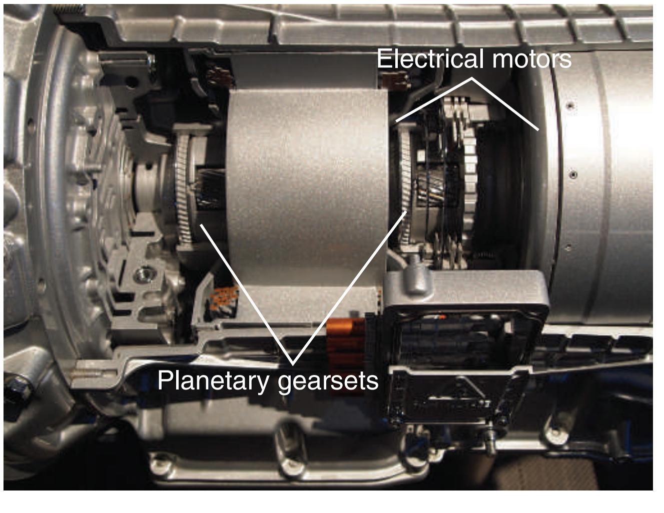


FIGURE 42-19 A planetary gearset is positioned in front of the two electric motors.

Basic EAT Testing

One of the first tasks during diagnosis of an EAT is to determine if the problem is caused by the transmission or by electronics. To determine this, the transmission must be observed to see if it responds to commands given by the computer. Identifying whether the problem is the transmission or electrical will determine what steps need to be followed to diagnose the cause of the problem.

EATs work only as well as the commands they receive from the computer, even if the hydraulic and mechanical parts of the transmission are fine. All diagnostics should begin with a scan tool to check for trouble codes in the system's computer. After the received codes are addressed, you can begin a more detailed diagnosis of the system and transmission. Your next step may be manually activating the shift solenoids by connecting a jumper wire to them or by using a transmission tester that allows you to manually activate the solenoids. Prior to doing this, study the wiring diagram for the solenoids to determine if the computer activates them by supplying voltage to them or by completing the ground circuit **(Figure 42–20)**. In addition, you need to know in which gear certain solenoids are activated.

The best way to diagnose an electronically controlled transmission is to approach solving the problem in a logical way.

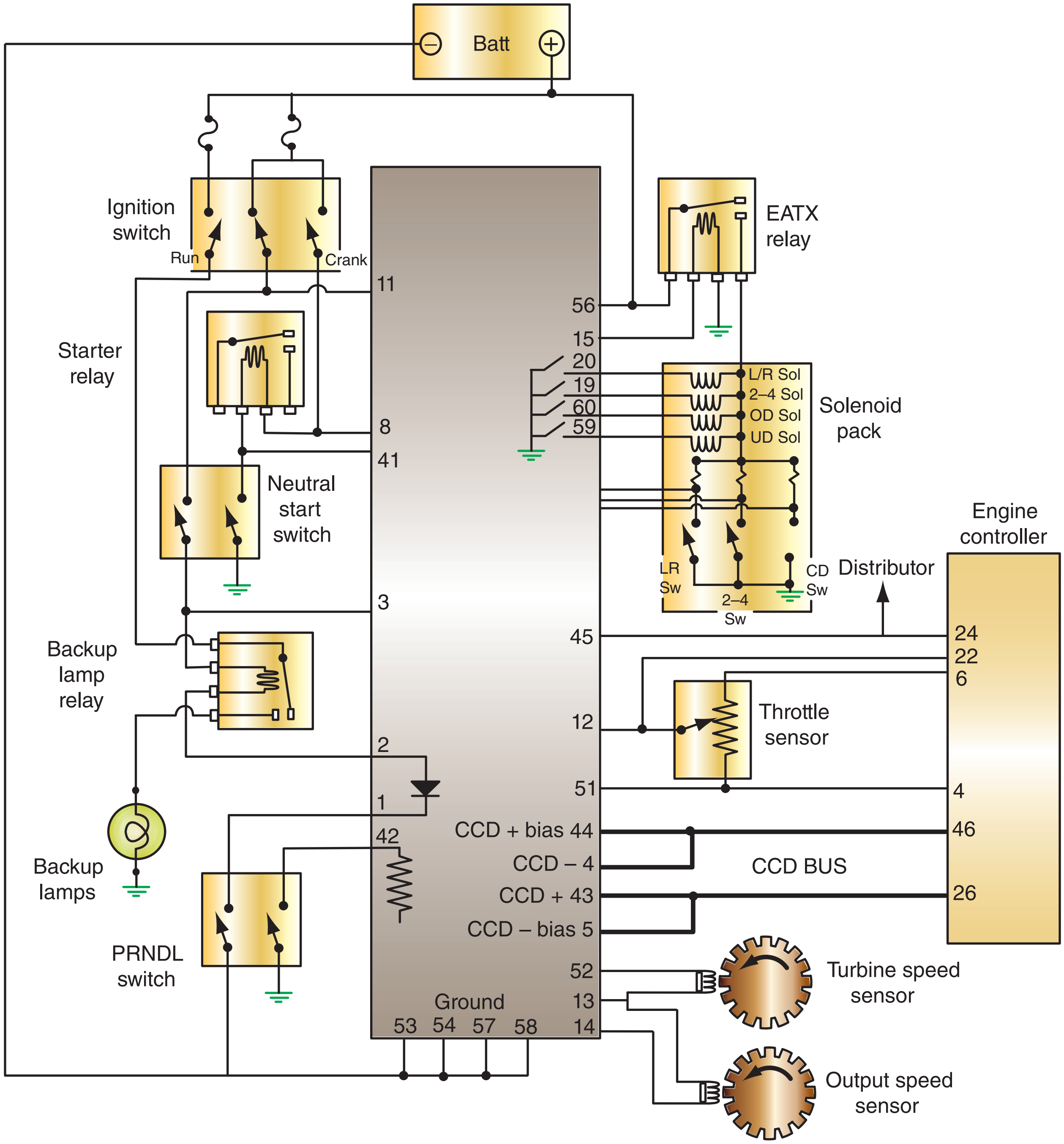


FIGURE 42–20 The electrical circuit for a typical EAT.

Because many EAT problems are caused by the basics, it is wise to conduct all of the preliminary checks required for a nonelectronically controlled transmission. Also, thoroughly inspect the electronic system. This inspection should include a check of the MIL and the retrieval of diagnostic codes. Doing this will also allow you to pull engine-related codes as well as transmission codes. Whenever diagnosing a transmission, remember that an engine problem can and will cause the transmission to act abnormally.

Scan Tool Checks

GO TO Chapter 25 for details on connecting a scan tool and retrieving DTCs.

Using a scan tool is one of the first steps of EAT diagnostics. Prior to retrieving the DTCs, pay attention to the MIL. The MIL is basically an engine malfunction light, but if the TCM detects a problem that

PROCEDURE

The recommended procedure for troubleshooting an EAT involves seven distinct steps that should be followed according to the following order:

STEP 1 Verify the customer's complaint. Pay attention to the conditions that exist when the problem occurs.

STEP 2 Check for any related symptoms, such as engine overheating, a lit MIL, and other driveability problems.

STEP 3 Conduct preliminary inspections and checks.

STEP 4 Check all service information for information that may apply to the complaint, including service bulletins, symptom charts, and recall notices.

STEP 5 Interpret and respond to all diagnostic codes.

STEP 6 Follow the diagnostic routines given by the manufacturer to define and isolate the cause of the problem.

STEP 7 Fix the problem and verify the repair.

may affect emissions, it will send a request over the data bus to the PCM to turn on the MIL lamp. Therefore, if the MIL is lit, the engine or transmission can have a problem. Remember, the MIL does not light after all DTCs are set; it only is lit when there is a fault that could affect emission levels.

When diagnosing an EAT, make sure there are no engine-related codes that could affect the operation of the transmission. If there is an engine problem, fix it before continuing with your diagnosis.

DTCs that relate to transmission faults can be caused by engine or transmission input and/or output devices. These codes may seem to indicate a problem with an input or output circuit but may actually be caused by an internal transmission problem. Remember, codes are set by out-of-range values. Therefore, when the TCM is receiving a too low or high input signal, the cause is not necessarily a bad sensor. The sensor can be fine and a mechanical or hydraulic transmission problem is causing the abnormal signals. Not only can internal transmission problems cause codes to be set, but so can basic electrical problems. Problems such as loose connections, broken wires, corrosion, and poor grounds will affect the signals.

If the TCM is unable to communicate with the PCM, there is a data bus problem. These problems will normally result in poor operation as well as the inability to retrieve DTCs from the TCM. The PCM constantly monitors the data bus and if it is unable to establish communication, it will order a data bus DTC.

Although the first steps in diagnosis include retrieving DTCs, there are problems that will not be evident by a code. These problems are solved with further testing, symptom charts, or pure logic. This logic must be based on an understanding of the transmission and its controls. It is possible to pinpoint the exact cause of a transmission problem: Monitor the serial data with a scan tool **(Figure 42–21)**. The serial data stream allows you to monitor system activity during operation. Comparing the observed values to the manufacturer's

PID Name	Description of PID
EPC	Commanded Electronic Pressure Control Pressure—in psi
GEAR	Commanded Gear—not actual
LINEDSD	Commanded Line Pressure—in psi
OSS	Input from Output Shaft Speed Sensor—in rpm
RPM	Input from Engine Speed Sensor—in rpm
SSA	Commanded State of Shift Solenoid No. 1—ON or OFF
SSB	Commanded State of Shift Solenoid No. 2—ON or OFF
SS1F	Shift Solenoid No. 1 Circuit Fault—YES or NO
SS2F	Shift Solenoid No. 2 Circuit Fault—YES or NO
TCCACT	Slippage of Torque Converter Clutch—in rpm
TCCCMD	Commanded State of Torque Converter Clutch Solenoid—in %
TCCF	Torque Converter Clutch Solenoid Circuit Fault—YES or NO
TFT	Transmission Fluid Temperature—in voltage or degrees
TP	Throttle Position—in voltage
TR	Transmission Range Sensor—by position
TRANRAT	Actual Transmission Gear Ratio—by position
TSS	Input from Turbine Shaft Speed Sensor—in rpm

FIGURE 42–21 Common transmission PIDs for Ford products.

USING SERVICE INFORMATION

At times, the manufacturer will make new software available that will correct common customer complaints. Normally, these are concerns that have no obvious physical or electronic cause. Flashing the TCM may take care of the concern. Always check the latest TSBs from the manufacturer when diagnosing a transmission concern.

specifications will greatly help in diagnostics. However, it is possible that the data displayed by a scan tool is not the actual value. Most computer systems will disregard inputs that are well out of range and rely on a default value held in its memory. These default values are hard to recognize and do little for diagnostics; this is why the use of basic electrical troubleshooting equipment, such as wiring diagrams, diagnostic charts, DMMs, lab scopes, and special transmission testers, to check the system is common.

Preliminary EAT Checks

Critical to proper diagnosis of EAT and TCC control systems is a road test. The road test should be conducted in the same way as one for a nonelectronic transmission except that a scan tool should also be connected to the circuit to monitor engine and transmission operation.

During the road test, the vehicle should be driven in the normal manner. Pay close attention to all gear changes. Also, the various computer inputs should be monitored and the readings recorded for future reference **(Figure 42–22)**. Some scan tools have the

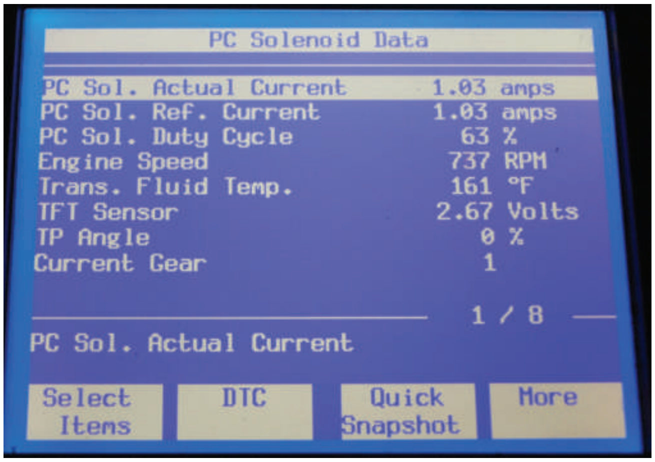


FIGURE 42–22 An example of some of the transmission-related data available on a scan tool.

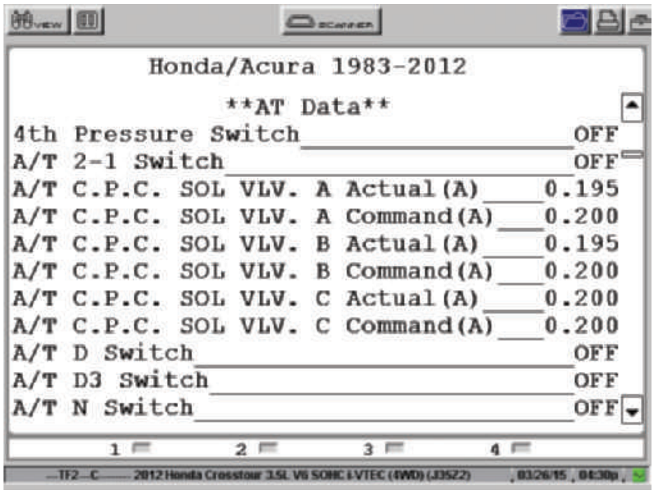


FIGURE 42–23 A display of other transmission specific data.

capability of printing out a report of the test drive. Critical information from the inputs includes engine speed, TP sensor, engine coolant, and transmission fluid temperatures **(Figure 42–23)** operating gear and the time it took to shift gears. If the scan tool does not have the ability to give a summary of the road test, you should record this same information after each gear or change in operating condition.

Often, accurately defining the problem and locating related information in TSBs and other materials can identify the cause of the problem. When a manufacturer recognizes common occurrences of a problem, a bulletin will be issued regarding the fix of the problem. Also, for many DTCs and symptoms, the manufacturers give a simple diagnostic chart or path for identifying the cause of the problem. These are designed to be followed step-by-step and will lead to a conclusion if you follow the path matched to the symptom. Check all available information before moving on in your diagnostics.

Sometimes the symptom will not match any of those described in the service information. This does not mean that it is time to guess; rather, it is time to clearly identify what is working right. By eliminating those circuits and components that are working correctly from a list of possible causes, you can identify what may be causing the problem and what should be tested further.

Common problems that affect shift timing and quality as well as the timing and quality of TCC engagement are incorrect battery voltage, a blown fuse, poor connections, a defective TP sensor or VSS, defective solenoids, crossed wires to the solenoids or sensors, corrosion at an electrical terminal, or faulty installation of an accessory.

Often computer-controlled transmissions will start off in the wrong gear. This can happen for

several reasons, such as either internal transmission problems or external control system problems. Internal transmission problems can be faulty solenoids or stuck valves. External problems can be the result of a complete loss of power or ground to the control circuit or the transmission is operating in its fail-safe mode. Typically, the default gear is simply the gear that is applied when the shift solenoids are off.

Electronic Defaults

While diagnosing a problem, always refer to the appropriate service information to identify the normal "default" operation of the transmission. You could spend time tracing the wrong problem by not recognizing that the transmission is operating in default.

Whenever the computer sees a potential problem that may increase wear and/or damage to the transmission, the system also defaults to limp-in mode. Minor slipping can be sensed by the computer through its input and output sensors. This slipping will cause premature wear and may cause the computer to move into its default mode; some systems may increase fluid pressure to compensate for the problem. A totally burnt clutch assembly will cause limp-in operation as will some internal pressure leaks that may not be apparent until pressure tests are run.

Guidelines for Diagnosing EATs

1. Make sure the battery has at least 12.6 volts before troubleshooting the transmission.
2. Check all fuses and identify the cause of any blown fuses.
3. Check the physical condition of all sensors and the wiring going to them **(Figure 42–24)**.

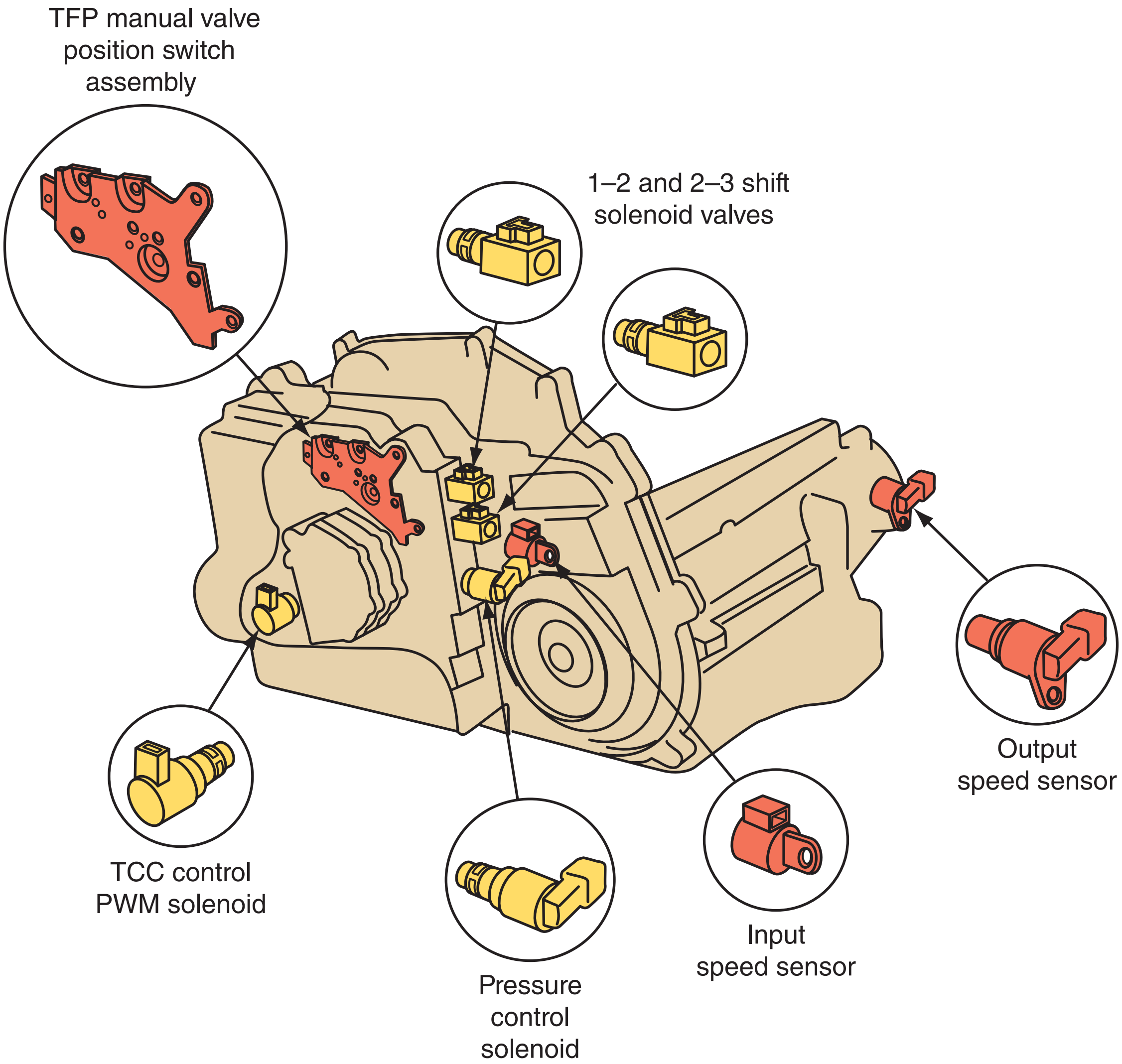


FIGURE 42–24 The typical location of the electronic components in or on a transaxle.

4. Compare the wiring to all suspected components with the wire colors given in the service information.
5. When testing electronic circuits, always use a high-impedance testlight or DMM.
6. If an output device is not working properly, check the power circuit to it.
7. If an input device is not sending the correct signal back to the computer, check the reference voltage it is receiving and the voltage it is sending back to the computer.
8. Compare the voltages in and out of a sensor with the voltages the computer is sending out and receiving.
9. Before replacing a computer, check the solenoid isolation diodes according to the procedures outlined in the service information.
10. Make sure the computer wiring harnesses do not run parallel with any high-current wires or harnesses. The magnetic field created by the high current may induce a voltage in the computer harness. Take necessary precautions to prevent the possibility of static discharge while working with electronic systems.
11. While checking individual components, always check the voltage drop of the ground circuits. This becomes more and more important as cars are made of less material that conducts electricity well.
12. Make sure the ignition is off when you disconnect or connect an electronic component.
13. Check all sensors in cold and hot conditions.
14. Check all wire terminals and connections for tightness and cleanliness.
15. Use a computer cleaning spray or comparable product to clean all connectors and terminals.
16. Use dielectric grease at all connections to prevent future corrosion.
17. If you must break through the insulation of a wire to take an electrical measurement, make sure you tightly tape over the area after you are finished testing.

Warning! Static electricity can destroy or render an electronic part useless. When handling any electronic part, do whatever is possible to reduce the chances of electrostatic buildup on your body and the inadvertent discharge to the electronic part.

Converter Clutch Control Diagnostics

To properly diagnose converter clutch problems, you must know when the TCC should engage and disengage and understand the function of the various controls involved with the system **(Figure 42–25)**. Although the actual controls for a TCC vary with the different models of transmissions, they all have certain operating conditions that must be met before the clutch can be engaged.

Diagnosis of a TCC circuit should be conducted in the same way as any other computer system. The computer will recognize problems within the system and store trouble codes that reflect the problem area of the circuit. A road test should be conducted to see if the problem is related to the TCC **(Figure 42–26)**.

On early electronically controlled systems with a TCC solenoid, the clutch is typically applied when oil flow through the torque converter is reversed. This change can be observed with a pressure gauge. Connect a pressure gauge to the fluid line from the transmission to the cooler. Position the gauge so that it is easily seen from the driver's seat. Then raise the vehicle on a hoist with the drive wheels off the ground and able to spin freely. Operate the vehicle until the transmission shifts into high gear. Then maintain a speed of approximately 55 mph (88 km/h). Once the speed is maintained, watch the pressure gauge.

If the pressure decreases 5 to 10 psi (0.35 to 0.70 kg/cm^2), the converter clutch was applied. With this action, you should feel the engagement of the clutch as well as a drop in engine speed. If the pressure changed but the clutch did not engage, the problem may be inside the converter or at the end of the input shaft. If the input shaft end is worn or the O-ring at the end is cut or worn, there will be pressure loss at the converter clutch. This loss in pressure will prevent full engagement of the clutch. If the pressure did not change and the clutch did not engage, suspect a faulty clutch valve or control solenoid or a fault in the solenoid control circuit.

If the clutch does not engage, check for power to the solenoid. If power is available, make sure the ground of the circuit is good. If there is power available and the ground is good, check the voltage drop across the solenoid. The solenoids should drop very close to source voltage. If less than that is measured, check the voltage drop across the power and ground sides of the circuit. If the voltage drop testing results are good, remove the solenoid and test it with an ohmmeter. Suspect clutch material, dirt, or other material plugging up the solenoid

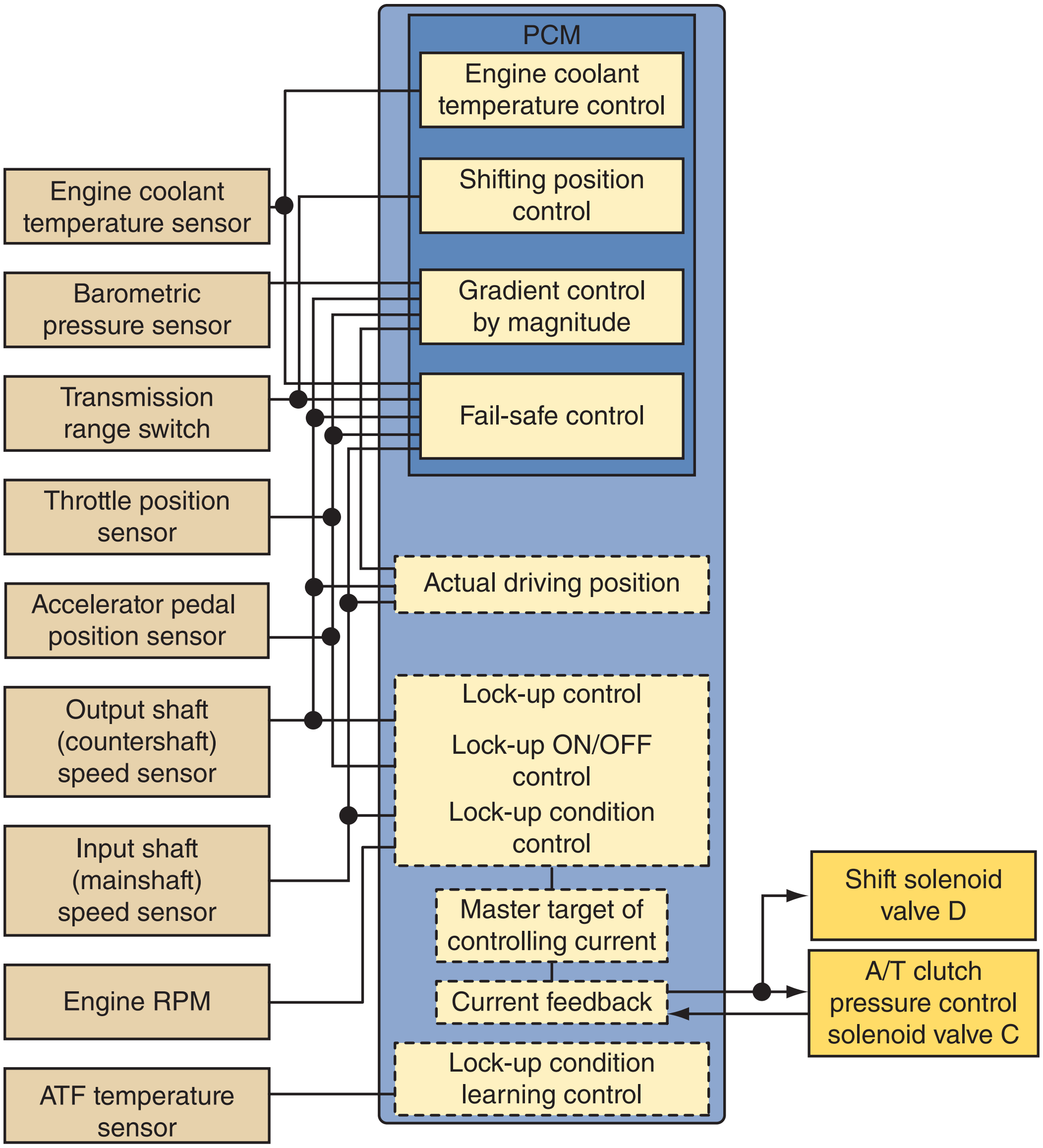


FIGURE 42-25 The electronic control system for a TCC.

valve passages if the solenoid checks out fine with the ohmmeter. Attempt to flush the valve with clean ATF if blockage is found. If the solenoid has a filter assembly, replace the filter after cleaning the fluid passages. Replace the solenoid if the blockage cannot be removed.

The TCC in late-model transmissions is controlled by the PCM or TCM. The computer turns on the converter clutch solenoid, which opens a valve and allows fluid pressure to engage the clutch. When the computer turns the solenoid off, the clutch disengages.

A malfunctioning converter clutch can cause a wide variety of driveability problems. Normally, the application of the clutch should feel like a smooth engagement into another gear. It should not feel harsh, nor should there be any noises related to the application of the clutch.

If the clutch engages at the wrong time, a sensor or switch in the circuit is probably the cause. If clutch engagement occurs at the wrong speed, check all speed-related sensors. A faulty temperature sensor may cause the clutch not to engage. If the sensor is not reading the correct temperature, the PCM may never realize that the temperature is suitable for engagement. Checking the appropriate sensors can be done with a scan tool, DMM, and/or lab scope.

Engagement Quality

If the clutch engages prematurely or is not applied with full pressure, a shudder or vibration results from the rapid grabbing and slipping of the clutch. This symptom can feel like an engine misfire or vibration. The clutch begins to engage then slips because it cannot hold the engine's torque. The torque

Step	Findings	Remedy
Does the TCC engage and disengage?	Yes No	Go to step #2 Go to symptoms chart—diagnose the system
Describe the vibration or shudder during a 3-4 or 4-3 shift.	Light Medium Heavy	Go to step #3 Go to step #3 Go to symptoms chart—is not TCC related
Is the vibration or shudder vehicle speed related and not gear related?	Yes No	Go to symptoms chart—is not TCC related Go to step #4
Is the vibration or shudder engine speed related and not gear related?	Yes No	Go to symptoms chart—is not TCC related Go to step #5
Does the vibration or shudder occur in coast, cruise, or reverse gear?	Yes No	Go to symptoms chart—is not TCC related Go to step #6
Does the vibration or shudder occur during long periods of light braking?	Yes No	Go to symptoms chart—is not TCC related Go to step #7
Did the vibration or shudder only occur in step #2?	Yes No	There is a probable TCC problem—diagnose the system Go to symptoms chart—is not TCC related

FIGURE 42-26 An evaluation form to use while doing a road test to check the torque converter.

capacity of the clutch is determined by the oil pressure applied to it and the condition of the frictional surfaces of the clutch assembly.

If the shudder is only noticeable during the engagement of the clutch, the problem is typically in the converter. When the shudder is only evident after the engagement of the clutch, the cause of the shudder is the engine, transmission, or another component of the driveline. If the shudder is caused by the clutch, the converter must be replaced to correct the problem.

A faulty clutch solenoid or its return spring may cause low apply pressure. The valve controlled by the solenoid is normally held in position by a coil-type return spring. If the spring loses tension, the clutch will engage too soon. Because there is insufficient pressure to hold the clutch, shudder occurs as the clutch begins to grab and then slip. If the solenoid valve and/or return spring are faulty, they should be replaced, as should the torque converter. If the TCC fails to release, it can cause the engine to jerk and stall when the vehicle is stopping.

An out-of-round torque converter prevents full clutch engagement, which will also cause shudder, as will contaminated clutch frictional material. The frictional material can become contaminated by metal particles circulating through the torque converter and collecting on the clutch. Broken or worn clutch dampener springs will also cause shudder.

Detailed Testing of Inputs

There are many different designs of sensors that are part of the control system for an EAT. The transmission will not work properly if it receives bad information from its sensors or from the CAN bus. The transmission may shift at the wrong speeds, shift harshly, or operate only in the limp-in mode.

Some sensors are nothing more than a switch that completes a circuit. Others are complex devices that react to chemical reactions and generate their own voltage during certain conditions. If the preliminary tests pointed to a possible problem in an input circuit, the circuit should be tested. Make sure to check all suspect circuits for resistance problems; conduct voltage drop tests on those circuits. Often the manufacturers will give specific testing procedures for their sensors; always follow them.

GO TO Chapter 25 for details on specific tests of input devices.

Testing Switches

Many different switches are used as inputs or control devices for EATs. Most of the switches are either

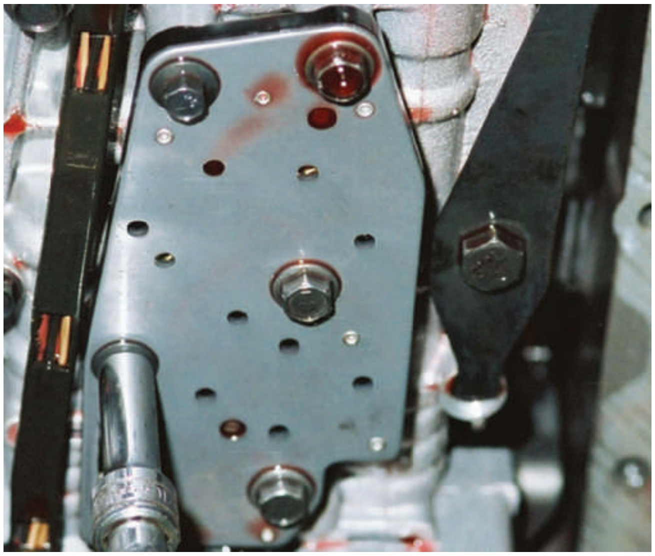


FIGURE 42–27 A typical transmission pressure switch assembly.

mechanically or hydraulically controlled. These switches can be easily checked with an ohmmeter. With the meter connected across the switch's leads, there should be continuity or low resistance when the switch is closed and there should be infinite resistance across the switch when it is open. A testlight can also be used. When the switch is closed, power should be present at both sides of the switch. When the switch is open, power should be present at only one side.

Pressure switches can be checked by applying air pressure to the part that would normally be exposed to fluid pressure **(Figure 42–27)**. When applying air pressure to these switches, check them for leaks. Although a malfunctioning electrical switch will probably not cause a shifting problem, it will if it leaks. If the switch leaks off the applied pressure in a hydraulic circuit to a holding device, the holding member may not be able to function properly. When possible, you should check pressure switches when they are installed and controlled by the vehicle.

Temperature Sensors

Temperature sensors can be checked with an ohmmeter. To do so, disconnect the sensor. In most cases, the sensor can be checked at room temperature **(Figure 42–28)**. Determine the temperature of the sensor and measure the resistance across it. Compare your reading to the chart of normal resistance for that temperature, which is given in the service information.

Thermistor activity can be monitored with a lab scope. Connect the scope across to the output of the thermistor or temperature sensor. Run the engine

Test connections	Specified value
E2 - THO1	90Ω to 156kΩ
E2 - ground	156kΩ or higher
THO1 - ground	156kΩ or higher

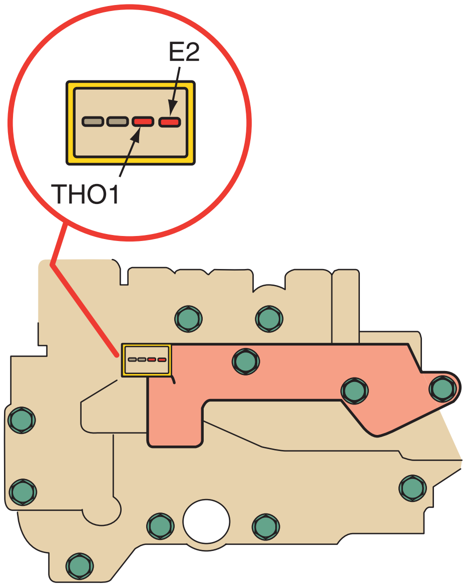


FIGURE 42–28 Checking an ATF temperature sensor.

and watch the waveform. As the temperature increases, there should be a smooth increase or decrease in voltage. Look for glitches in the signal. These can be caused by changes in resistance or an intermittent open.

Speed Sensors

Speed sensors negate the need for hydraulic signals from a governor. When this sensor fails or sends faulty readings, it can cause complaints similar to those caused by a bad TP sensor. The most common complaints are no overdrive, no converter clutch engagement, and no upshifts.

The operation of a PM generator-type speed sensor can be tested with a DMM set to measure AC voltage. Raise the vehicle on a lift. Allow the wheels to be suspended so they can rotate freely. Connect the meter to the speed sensor. Start the engine and put the transmission in gear. Slowly increase the engine's speed until the vehicle is at approximately 20 mph, and then measure the voltage at the speed sensor. Slowly increase the engine's speed and observe the voltmeter. The voltage should increase smoothly and precisely with an increase in speed.

Magnetic pulse generator speed sensors can be tested with a lab scope. Connect the lab scope's

leads across the sensor's terminals. The expected pattern is an AC signal, which should be a perfect sine wave when the speed is constant. When the speed is changing, the AC signal should change in amplitude and frequency. If the readings are not steady and do not smoothly change with speed, suspect a faulty connector, wiring harness, or sensor.

A speed sensor can also be tested when it is out of the vehicle. Connect an ohmmeter across the sensor's terminals. The desired resistance readings across the sensor will vary with every individual sensor; however, you should expect to have continuity across the leads. If there is no continuity, the sensor is open and should be replaced. Reposition the leads of the meter so that one lead is on the sensor's case and the other to a terminal. There should be no continuity in this position. If there is any measurable amount of resistance, the sensor is shorted.

Detailed Testing of Actuators

If you were unable to identify the cause of a transmission problem through the previous checks, you should continue your diagnostics with testing the solenoids. This will allow you to determine if the shifting problem is the solenoids or their control circuit, or if it is a hydraulic or mechanical problem.

GO TO Chapter 25 for details on specific tests of output devices, including solenoids.

Before continuing, however, you must first determine if the solenoids are case grounded and fed voltage by the computer, or if they always have power applied to them and the computer merely supplies the ground. While looking in the service information to find this, also find the section that tells you which solenoids are on and which are off for each of the different gears.

To begin this test you should collect the tools and/or equipment necessary to manually activate the solenoids. Switch panels that connect into the solenoid assembly are available and allow the technician to switch gears by depressing or flicking a switch.

With the tester, the solenoids will be energized in the correct pattern and observe the action of the solenoids. To totally test the transmission, you should shift gears under light, half, and full throttle. If the transmission shifts fine with the movement of the switches, you know that the transmission is fine. Any shifting problem must therefore be caused by something electrical. If the transmission did not respond to the switch movements, the problem is probably in the transmission.

SHOP TALK

This type of tester is easily made. Get a wiring harness for the transmission you want to test. Connect the harness to simple switches. Follow the solenoid/gear pattern when doing this. To change gears, all you will need to do is turn off one switch and turn on the next.

At times, a solenoid will work fine during light throttle operation but may not allow the valve to exhaust enough fluid when pressure increases. To verify that the valve is not exhausting, activate the solenoid and then increase engine speed while pulling on the throttle cable. If the valve cannot exhaust, the transmission will downshift. Restricted solenoids are a common cause of rough shifting under heavy loads or full throttle but good shifting under light throttle.

Testing Actuators with a Lab Scope

You will be able to watch the actuator's electrical activity by observing its action on a lab scope. Normally, if there is a mechanical fault, this will affect its electrical activity as well. Some actuators are controlled by pulse width modulated signals **(Figure 42–29)**. These devices are controlled by varying the pulse width, signal frequency, and/or voltage levels. By watching the control signal, you can see the turning on and off of the solenoid **(Figure 42–30)**. All waveforms should be checked for amplitude, time, and shape. You should also observe changes to the pulse width as operating conditions change. A bad waveform will have noise, glitches, or rounded corners. You should be able to see evidence that the actuator immediately turns off and on according to the commands of the computer.

Testing Actuators with an Ohmmeter

Solenoids can be checked for circuit resistance and shorts to ground. This can typically be done without removing the oil pan. The test can be conducted at the transmission case connector. Individual solenoids can be checked with an ohmmeter by identifying the proper pins in the connector. Remember, lower-than-normal resistance indicates a short, whereas higher-than-normal resistance indicates a problem of high resistance. If you get an infinite reading across the solenoid, the solenoid windings are open. The ohmmeter can also be used to check

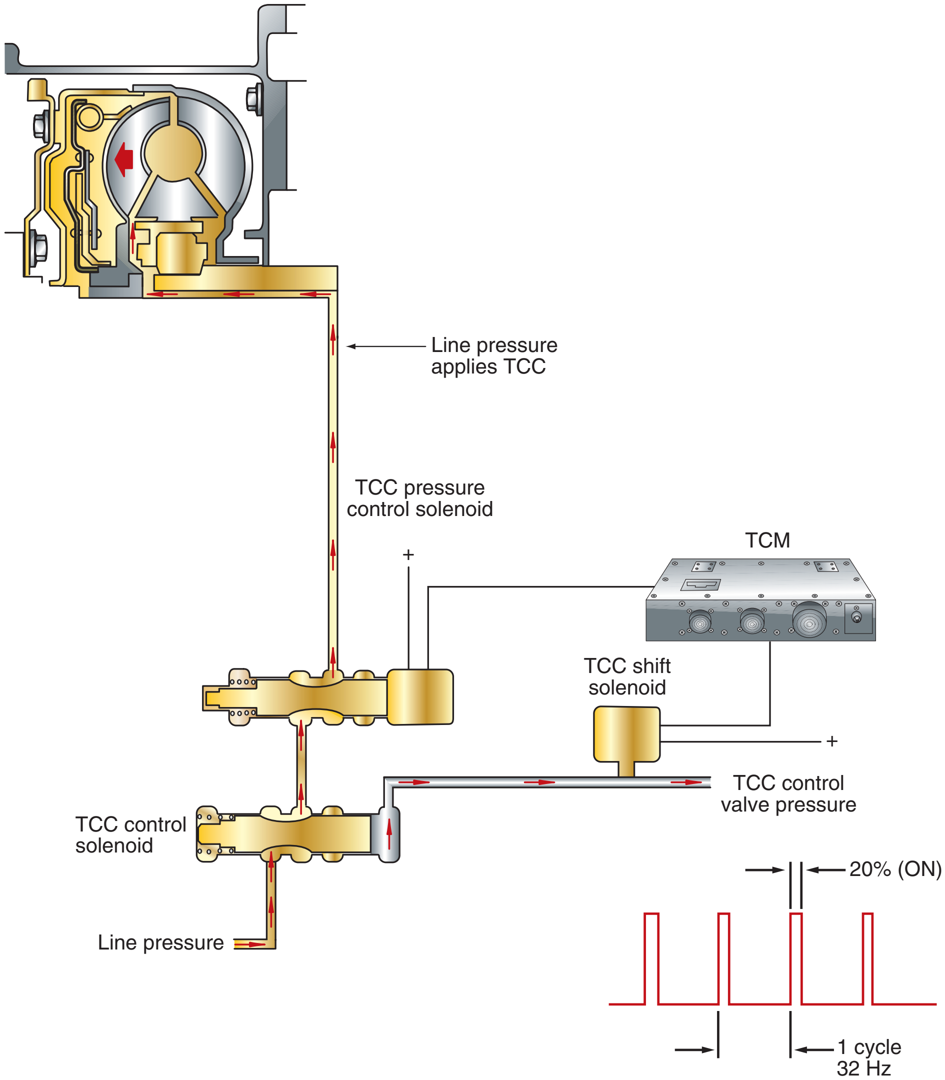


FIGURE 42–29 A typical control signal for a pulse width modulated solenoid.

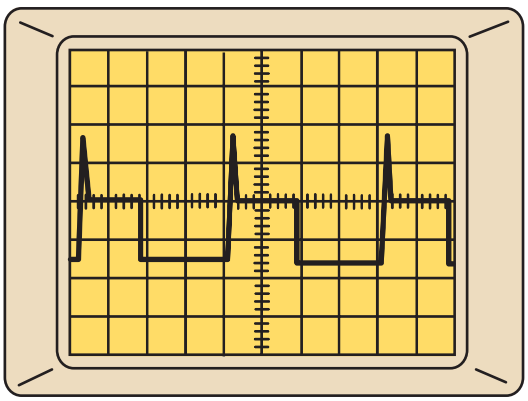


FIGURE 42–30 The activity of a solenoid as it cycles on and off.

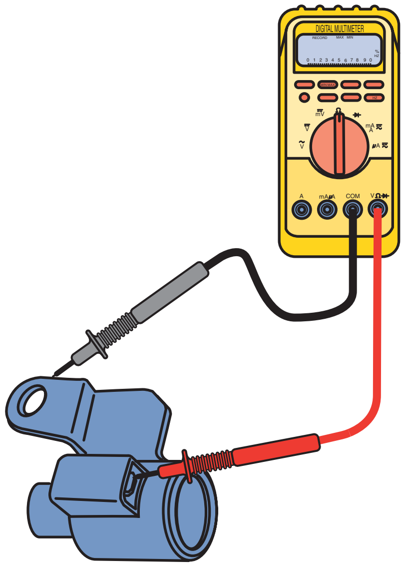


FIGURE 42–31 The meter connections for checking a solenoid for an open or short as well as resistance value.

for shorts to ground. Simply connect one lead of the ohmmeter to one end of the solenoid windings and the other lead to ground **(Figure 42–31)**. The reading should be infinite. If there is any measurable resistance, the winding is shorted to ground.

Components	Pass thru pins	Resistance at 20 °C	Resistance at 100 °C	Resistance to ground (case)
1-2 shift solenoid valve	A, E	19–24Ω	24–31Ω	Greater than 250MΩ
2-3 shift solenoid valve	B, E	19–24Ω	24–31Ω	Greater than 250MΩ
TCC solenoid valve	T, E	21–24Ω	26–33Ω	Greater than 250MΩ
TCC PWM solenoid valve	U, E	10–11Ω	13–15Ω	Greater than 250MΩ
3-2 shift solenoid valve assembly	S, E	20–24Ω	29–32Ω	Greater than 250MΩ
Pressure control solenoid valve	C, D	3–5Ω	4–7Ω	Greater than 250MΩ
Transmission fluid temp. (TFT) sensor*	M, L	3,088–3,942Ω	159–198Ω	Greater than 10MΩ
Vehicle speed sensor	A, B VSS conn	1,420Ω @ 25 °C	2,140Ω @ 150 °C	Greater than 10MΩ
*IMPORTANT: The resistance of this device is necessarily temperature dependent and will therefore vary far more than that of any other device. Refer to the specific transmission fluid temp (TFT) sensor specifications.				

FIGURE 42–32 The appropriate service information lists the resistance values and test points for various transmission solenoids and sensors.

Solenoids can also be tested on a bench. Resistance values are typically given in service information for each application **(Figure 42–32)**. A solenoid may be electrically fine but still may fail mechanically or hydraulically. A solenoid's check valve may fail to seat or its porting can be plugged. This is not an electrical problem; rather, it could be caused by the magnetic field collecting metal particles in the ATF and clogging the port or check valve. These would cause erratic shifting, no shift conditions, wrong gear starts, no limited passing (kickdown) gear, or binding shifts. When a solenoid affected in this way is activated, it will make a slow, dull thud. A good solenoid tends to snap when activated.

Caution! When servicing the transmission of a Honda IMA hybrid, be careful of the high-voltage motor that is sandwiched between the engine and the transmission. Always disconnect the high voltage before working on or near the transmission.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2007	**Make:** Kia	**Model:** Optima	**Mileage:** 164,366	**RO:** 17087
Concern:	Customer states the transmission won't shift, acts like it's stuck in one gear.			
The technician attempts to test drive the car but the transmission is in limp-in mode. Suspecting the transmission is destroyed, based on age and mileage, he attempts to sell a replacement transmission. The customer questions the repair stating the car drove fine one day and had no transmission problems at all and the next day the car would hardly move. The technician then decides to perform some basic diagnostics by retrieving DTCs. He finds several codes, including a P0885, indicating power loss to the TCM.				
Cause:	Found blown fuse ATM fuse. Replaced fuse. Fuse blew again during test drive. Found shift solenoid shorted drawing too many amps.			
Correction:	Replaced ATM solenoid pack. Test drive confirms proper transmission operation.			

KEY TERMS

Adaptive learning
Shift schedule
Transmission control module (TCM)
Variable force solenoid (VFS)

SUMMARY

- A TCM is a separate computer designated for transmission operation or is part of the PCM. The PCM can be a multifunction computer that controls all engine and transmission operations.
- A shift schedule contains the actual shift points to be used by the computer according to the input data it receives from the sensors. Its logic chooses the proper shift schedule for the current conditions of the transmission.
- In most electronically controlled transmission systems, the hydraulically operated clutches are controlled by the transaxle controller.
- The typical output devices are solenoids and motors, which cause something mechanical or hydraulic to change.
- The computer may receive information from two different sources: directly from a sensor or through a twisted-pair bus circuit, which connects all of the vehicle computer systems.
- Fluid flow to the apply devices is directly controlled by the solenoids.
- Pressure switches give input to the transmission computer; they are all located within the solenoid assembly.
- Normally, the shift solenoids receive voltage through the ignition switch and are grounded through the PCM.
- The TCM is programmed to adjust its operating parameters in response to changes within the system, such as component wear. As component wear and shift overlap times increase, the TCM adjusts the line pressure to maintain proper shift timing calibrations. This is called adaptive learning.
- The pulse width modulated solenoid is a normally closed valve installed in the valve body. It controls the position of the TCC apply valve.
- If the TCM loses source voltage, the transmission will enter limp-in mode. The transmission will also enter into default if the computer senses a transmission failure. While in the default mode, the transmission will operate only in park, neutral, reverse, and one forward gear. This allows the vehicle to be operated, although its efficiency and performance are hurt.
- The basic shift logic of the computer allows the releasing apply device to slip slightly during the engagement of the engaging apply device.
- The EPC solenoid provides changes in pressure in response to engine load.
- Toyota, Ford, and Nissan hybrid systems rely on electric motors to determine the overall gear ratio in their CVTs.
- The two-mode hybrid system fits into a standard automatic transmission housing and is comprised of two planetary gearsets coupled to two electric motor/generators. This arrangement allows for two distinct modes of hybrid drive operation.
- If a computer's input signals are correct and its output signals are incorrect, the computer must be replaced.
- Input devices are critical to the operation of an EAT and should be checked with a scan tool, DMM, or lab scope.
- Solenoid valves can be checked by measuring their resistance or by applying a current to it and listening and feeling for its movement. They can also be checked with a lab scope or DMM.

REVIEW QUESTIONS

Short Answer

1. Although computers receive different information from a variety of sensors, the decisions for shifting are actually based on more than the inputs. What else are they based on?
2. What happens if the TCM determines that the signals from the TFT sensor are incorrect?
3. How can air pressure be used to check an electrical switch?
4. Most transmissions receive information through multiplexing. How does this work?
5. List five things that could cause incorrect shift times and poor shifting quality.
6. Most late-model transmission control systems have adaptive learning. What does this mean?
7. What inputs are of prime importance to a computer in deciding when to shift gears?
8. What are the advantages of using electronic controls rather than relying on conventional hydraulic controls in a transmission?
9. Voltage generation devices are typically used to monitor ___ ___.

True or False

1. *True or False?* On most late-model EAT systems, separate procedures must be followed to retrieve the DTCs from the transmission control system and the TCC system.
2. *True or False?* The neutral safety switch and reverse lamp switch are typically part of a digital transmission range sensor.

Multiple Choice

1. Which of the following is *not* a voltage-generating type sensor?
   a. Vehicle speed sensor
   b. OSS
   c. MAP
   d. ISS
2. A glitch appears in the waveform of a vehicle speed sensor. Which of the following is *not* a probable cause of the problem?
   a. A loose connector
   b. A damaged wire
   c. A poorly mounted sensor
   d. A damaged magnet in the sensor
3. In a Toyota hybrid CVT, which of the following parts effectively controls the overall gear ratio of the transaxle?
   a. MG1
   b. MG2
   c. Reduction unit
   d. Transaxle damper
4. Which of the following would probably not be caused by a plugged filter screen at a solenoid?
   a. Erratic shifting
   b. No shift conditions
   c. A solenoid that will not energize
   d. Wrong gear starts

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that some systems use a special modulated shift control solenoid. Technician B says that some systems use a special modulated converter clutch control solenoid. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Technician A says that shift solenoids direct fluid flow to and away from the apply devices in the transmission. Technician B says that shift solenoids are used to mechanically apply a friction brake or multiple-disc clutch assembly. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. Technician A says that throttle position is an important input in most electronic shift control systems. Technician B says that vehicle speed is an important input for most electronic shift control systems. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. Technician A says that a faulty TP sensor can cause delayed shifts. Technician B says that delayed shifts can be caused by an open shift solenoid. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. Technician A says that some shift solenoids can be activated by providing a ground for the solenoid. Technician B says that some shift solenoids can be activated by applying hydraulic pressure to their valve. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. An electronically controlled transmission has erratic shifting: Technician A says that a poor PCM ground will cause this problem. Technician B says that erasing the TCM memory may cause erratic shifting. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. While discussing transmission adaptive learning: Technician A says that the transmission learns to respond according to the current condition of the engine and transmission. Technician B says that the TCM learns to respond to the driver's driving habits. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. While discussing valve body assemblies in late-model transmissions: Technician A says that the valve body is no longer needed in some electronically controlled transmissions. Technician B says that an EPC solenoid maintains constant fluid pressure through the valve body regardless of the vehicle's operating condition. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. A transmission has delayed upshifts under all operating conditions: Technician A says that low mainline pressure can cause this. Technician B says that a faulty TFT sensor can cause this. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. While diagnosing the cause of TCC shudder: Technician A checks the fluid pressure sent to the clutch. Technician B says that because the shudder occurs only after the clutch is engaged, the problem is the engine, transmission, or another component of the driveline. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER

43

AUTOMATIC TRANSMISSION AND TRANSAXLE SERVICE

OBJECTIVES

- Diagnose unusual fluid usage, level, and condition problems.
- Replace automatic transmission fluid and filters.
- Diagnose noise and vibration problems.
- Diagnose hydraulic control systems.
- Perform oil pressure tests and determine needed repairs.
- Inspect and adjust external linkages.
- Describe the basic steps for overhauling a transmission.

Because of the many similarities between a transmission and a transaxle, most diagnostic and service procedures are similar. Therefore, all references to a transmission apply equally to a transaxle unless otherwise noted. Whenever you are diagnosing or repairing a transaxle or transmission, make sure you refer first to the appropriate service information before you begin.

Transmissions are strong and typically trouble-free units that require little maintenance. Normal maintenance usually includes fluid checks, scheduled linkage adjustments, and oil and filter changes.

Identification

Always make sure you know exactly which transmission you are working on. This ensures you are following the correct procedures and specifications and are installing the correct parts. Proper identification can be difficult because transmissions cannot be

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2006	**Make:** Dodge	**Model:** Stratus	**Mileage:** 155,366	**RO:** 17117
Concern:	Customer states vehicle shakes and vibrates when shifting into higher gears.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

FIGURE 43–1 Make sure you properly identify the transmission before servicing it.

FIGURE 43–2 Typical location of a transmission dipstick in a transaxle.

accurately identified by the way they look. The only exception to this is the shape of the oil pan, which can sometimes be used for identification. However, this is not foolproof.

The only positive way to identify a transmission is by its identification numbers. Transmission identification numbers are found on stickers on the transmission, stamped numbers in the case, or on a metal tag held by a bolt **(Figure 43–1)**. Also, all vehicles have a vehicle certification label that gives transmission information in a space marked TR. Use the service information to decipher the identification number. Most identification numbers include the model, manufacturer, and build date. Most late-model transmissions have labels with bar codes that can be scanned for transmission identification.

Basic Service

GO TO Chapter 8 for additional details on checking the fluid level in an automatic transmission.

For most transmissions, the fluid level and condition should be checked on a regular basis. Checking the fluid is also one of the initial steps to take while diagnosing a transmission concern.

When checking the fluid level, make sure the vehicle is on a level surface. Check the level and condition of the fluid. If the transmission has a dipstick, locate it **(Figure 43–2)**, remove it and wipe all dirt off the protective disc and the dipstick handle.

On most automobiles, the ATF level can be checked accurately only when the transmission is at operating temperature, the transmission is in a specific gear, and the engine is running. It is important to determine the correct operating temperature and conditions to get an accurate fluid check. Fluid temperature specs can range from less than 100° F (37.7° C) to nearly 200° F (93.3° C). According to one manufacturer, under-or overfilling by as little as a half a quart (473 mL) can cause shifting concerns. Remove the dipstick and wipe it clean with a lint-free white cloth or paper towel. Reinsert the dipstick, remove it again, and note the reading. Markings on a dipstick indicate ADD levels and on some models indicate FULL levels for cool, warm, or hot fluid.

Low fluid levels can cause a variety of problems. Air can be drawn into the oil pump's inlet circuit and mix with the fluid. This will result in aerated fluid, which causes slow pressure buildup, and low pressures, which cause slippage between shifts. Air in the pressure regulator valve will cause a buzzing noise when the valve tries to regulate pump pressure. If the fluid level is low, the problem could be external fluid leaks. Check the transmission case, oil pan, and cooler lines for signs of leaks.

Excessively high fluid levels can also cause **aeration**. As the planetary gears rotate in high fluid levels, air can be forced into the fluid. Aerated fluid can foam, overheat, and oxidize. All of these problems can interfere with normal valve, clutch, and servo operation. Foaming may be evident by fluid leakage from the transmission's vent.

FIGURE 43–3 Examples of the different fluid used in today's transmissions.

Examine the fluid carefully. The normal color of ATF is red. If the fluid has a dark brownish or blackish color and/or a burned odor, the fluid has been overheated. A milky color indicates that engine coolant has been leaking into the transmission's cooler in the radiator. If there is any question about the condition of the fluid, drain out a sample for closer inspection. If fluid needs to be added to the transmission, make sure it is the type recommended by the manufacturer **(Figure 43–3)**. Before adding fluid, check for any TSBs regarding updated fluid specifications. Although not very common, sometimes a manufacturer will make a change in the type of fluid that should be used.

Synthetic ATF is normally a darker red than petroleum- based fluid. Synthetic fluids tend to look and smell burnt after normal use; therefore, the appearance and smell of these fluids is not a good indicator of the fluid's condition.

After checking the ATF level and color, wipe the dipstick on absorbent white paper and look at the stain left by the fluid. Dark particles are normally band and/or clutch material, whereas silvery metal particles are normally caused by the wearing of the transmission's metal parts. If the dipstick cannot be wiped clean, it is probably covered with varnish, which results from fluid oxidation. Varnish will cause the spool valves to stick, causing shifting malfunction. Varnish or other heavy deposits indicate the need to change the transmission's fluid and filter.

Contaminated fluid can sometimes be felt better than be seen. Place a few drops of fluid between two fingers and rub them together. If the fluid feels dirty or gritty, it is contaminated with burned friction material.

Transmissions without a Dipstick Many late-model transmissions do not have a dipstick, and the fluid level is checked in a way similar to a manual transmission. Photo Sequence 37 covers the typical procedure for checking the transmission fluid level on transmissions without a dipstick. The dipstick and filler tube were removed from these transmissions to prevent overfilling. Research has found that many transmission failures were caused by overfilling and/or using the wrong fluid. Without a dipstick, it is difficult to check the fluid level and condition. These transmissions have a vent/fill cap typically located on the side of the transmission. Some also have a drain plug in the bottom of the pan. In addition, these transmissions are fitted with a fluid level sensor that will inform the driver when the fluid level is dangerously low.

Fluid Changes

The transmission's fluid and filter should be changed whenever there is an indication of oxidation or contamination. Periodic fluid and filter changes, as well as fluid flushes are part of the preventive program for most vehicles. The mileage interval recommended depends on the type of transmission.

Change the fluid only when the transmission is at normal operating temperatures. Photo Sequence 38 shows a typical procedure for changing a transmission's fluid and filter. On most transmissions, you must remove the oil pan to drain the fluid. A filter or screen is normally attached to the bottom of the valve body. Filters are made of paper or fabric and held in place by screws, clips, or bolts, or by the pressure on the pickup tube seal **(Figure 43–4)**. Filters should be replaced, not cleaned.

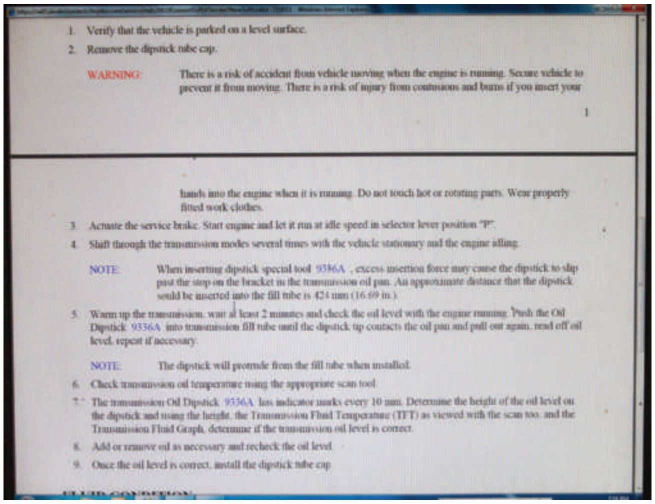
Some transmissions do not have a filter in the pan. Rather, they are fitted with a spin-on filter **(Figure 43–5)**. This filter looks like an engine filter. They are serviced in the same way as an engine oil filter. Some transmissions have both types of filters and both are serviced at the same time. Other transmissions may have an inline filter in the fluid lines leading to the cooler **(Figure 43–6)**.

SHOP TALK

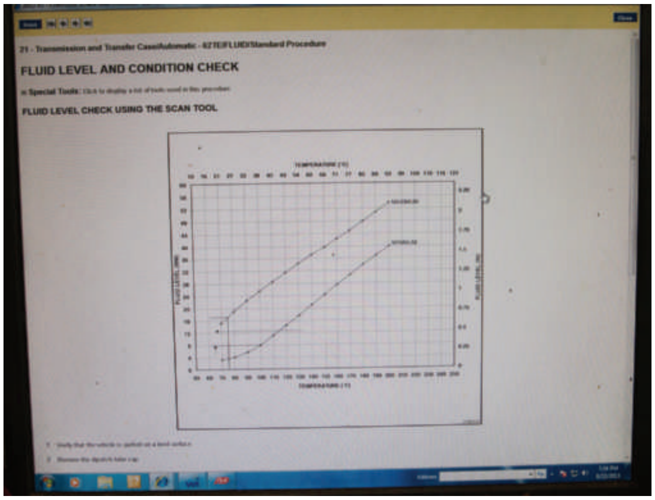
Make sure you always install the correct fluid in a transmission. Often the manufacturer recommends a special fluid for special applications. This is especially true of CVTs. Not only can the wrong fluid result in poor shifting; it can damage the transmission.

Checking Transmission Fluid Level on a Vehicle without a Dipstick

P37-1 Examine the transmission and determine how the fluid level is checked. If there is not a dipstick, often a service tag will indicate that special procedures are required.

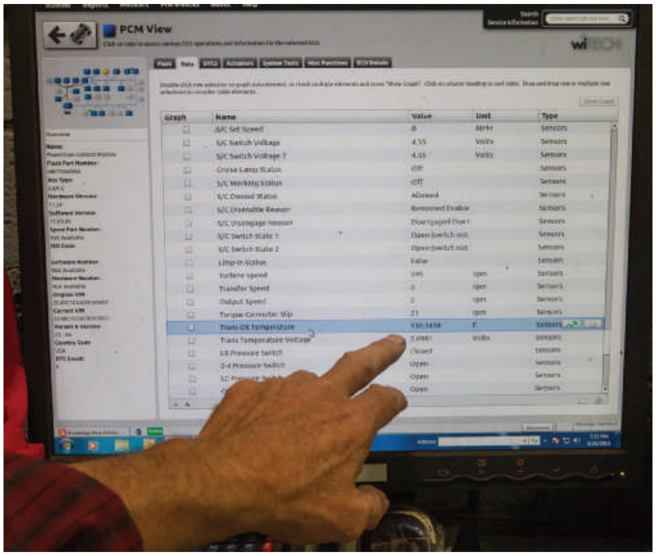


P37-2 Using the service information, determine how to check the transmission fluid level.



P37-3 Many vehicles require that the fluid level be checked with the fluid within a specific temperature range. This is to ensure that the fluid level is accurately determined as the fluid level reading changes as the fluid heats up.

P37-4 For this vehicle, a scan tool and a transmission fluid level tool are required to accurately determine the fluid level.



P37-5 To check transmission fluid temperature, connect a scan tool and locate the transmission fluid temperature PID. Once the fluid is within the correct range, continue with checking the fluid level.

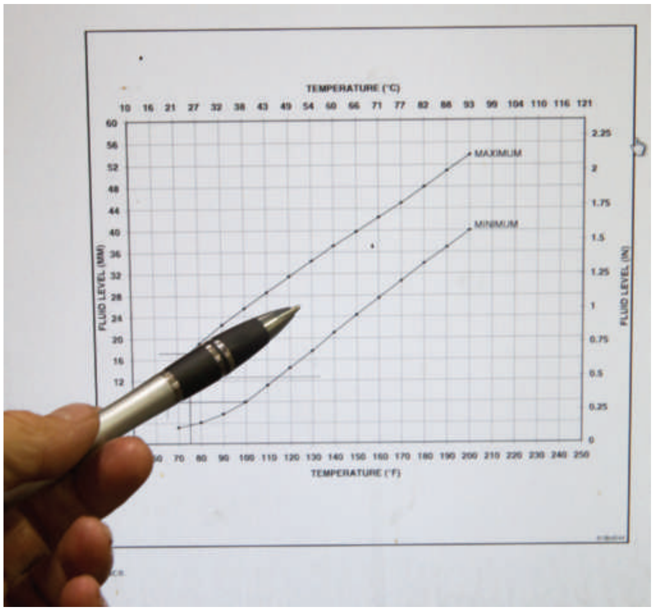
PHOTO SEQUENCE 37

Checking Transmission Fluid Level on a Vehicle without a Dipstick *(continued)*

P37-6 Locate the fluid check plug in the transmission. Remove the plug using the appropriate tools.

P37-7 Install the fluid tool into the transmission.

P37-8 Remove the tool and note the fluid level on the tool.



P37-9 Using the temperature range chart, the fluid level as measured at 128° F (52° C) indicates the fluid level is acceptable.

FIGURE 43–4 Transmission fluid filters are attached to the transmission case by screws, bolts, retaining clips, and/or by the pickup tube.

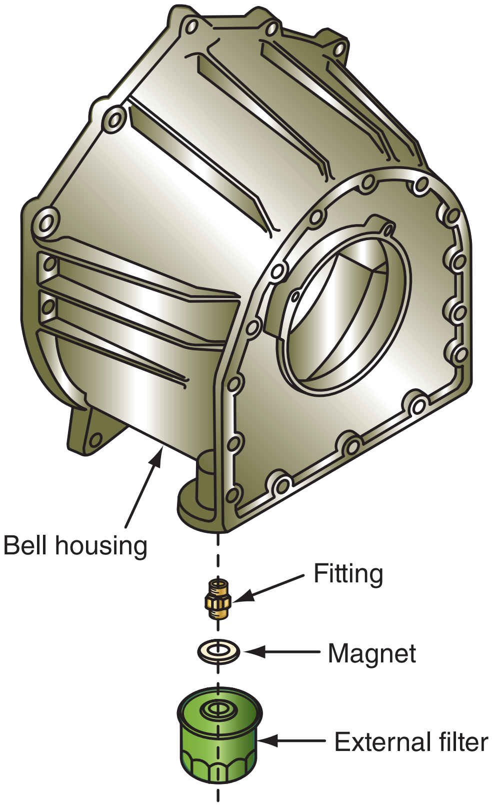


FIGURE 43–5 An engine oil filter-style transmission filter.

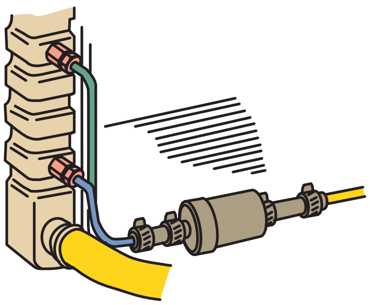


FIGURE 43–6 An inline filter for a fluid cooler.

Check the bottom of the pan for deposits and metal particles. Slight contamination, such as blackish deposits from clutches and bands, is normal. Other contaminants should be of concern. Clean the oil pan and its magnet **(Figure 43–7)**.

Remove the filter and inspect it. Use a magnet to determine if metal particles are steel or aluminum. Steel particles will be attracted to the magnet and indicate severe internal transmission wear or damage. If the metal particles are aluminum, they may be part of the torque converter stator. Some torque converters use phenolic plastic stators; therefore, aluminum particles found in these transmissions must be from the transmission itself.

Remove any traces of the old pan gasket on the case and oil pan. Then install a new filter and gasket and tighten the retaining bolts to the specified torque. If the filter is sealed with an O-ring, make sure it is properly installed. Reinstall the pan using the gasket or sealant recommended by the manufacturer. Tighten the bolts to the specified torque. The required torque is often given in inch-pounds. You can easily break the bolts or damage something if you tighten the bolts to foot-pounds.

Pour a little less than the required amount of fluid into the transmission through the filler tube or fill point. Start the engine and allow it to idle for at least 1 minute. Then, with the parking and service brakes applied, move the gear selector lever momentarily to each position, ending in park. Recheck the fluid level and add a sufficient amount of fluid to bring the level to about 1/8th inch below the FULL or MAX mark.

Bring the transmission up to normal operating temperature. Then recheck the fluid level and correct it if necessary. Make sure the dipstick is fully seated into the dipstick tube opening. This will prevent dirt from entering the transmission.

Parking Pawl

Any time you have the oil pan off, you should inspect all of the exposed parts, especially the parking pawl

SHOP TALK

Always check the service information for the correct conditions for checking fluid level. Although most manufacturers recommend checking it with the gear selector in the park position, some must be checked with the selector in neutral. In those transmissions, the fluid does not flow to the cooler when the transmission is in park.

PHOTO SEQUENCE 38

Changing Automatic Transmission Fluid and Filter

P38-1 Raise the vehicle to a good working height and safely positioned on the lift.

P38-2 Place a large-diameter oil drain pan under the transmission pan.

P38-3 Loosen all of the pan bolts except three at one end. This will allow some fluid to drain out.

P38-4 Support the pan with one hand and remove the remaining bolts to remove the pan. Pour the fluid in the pan into the drain pan.

P38-5 Inspect the residue in the pan for indications of transmission problems. Then remove the old pan gasket and wipe the pan clean with a lint-free rag.

P38-6 Unbolt the filter from the transmission.

P38-7 Compare the replacement gasket and filter with the old ones to make sure the replacements are the right ones for this application.

P38-8 Install the new filter and tighten the attaching bolts to specifications. Then lay the new gasket over the sealing surface of the pan.

P38-9 Install the pan onto the transmission. Install and tighten the bolts to specifications. Then lower the vehicle and pour new fluid into the transmission. Run the engine to circulate the new fluid, then turn it off and raise the vehicle. Check for fluid leaks.

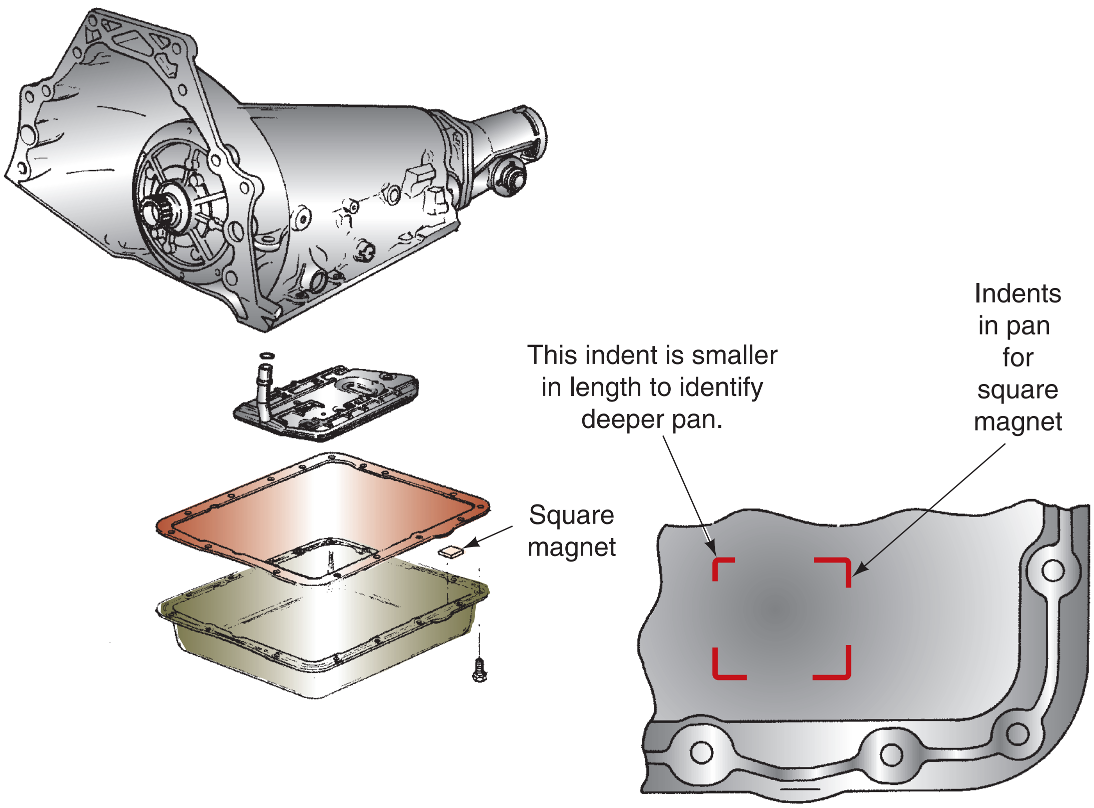


FIGURE 43-7 The magnet in the oil pan should be cleaned and the material it gathered should be analyzed.

assembly. This component is typically not hydraulically activated; rather, the gearshift linkage moves the pawl into position to lock the output shaft of the transmission. Unless the customer's complaint indicates a problem with the parking mechanism, no test will detect a problem here.

Check the pawl assembly for excessive wear and other damage. Also, check to see how firmly the pawl is in place when the gear selector is shifted into the park mode. If the pawl can be moved out easily, it should be repaired or replaced.

Basic Diagnostics

Automatic transmission problems are commonly caused by poor engine performance, problems in the hydraulic system, abuse resulting in overheating, mechanical malfunctions, electronic failures, and/or improper adjustments.

Engine performance can affect torque converter clutch operation. If the engine is running too poorly to maintain a constant speed, the converter clutch will engage and disengage at higher speeds. The customer complaint may be that the vehicle vibrates.

If the vehicle has an engine performance problem, the cause should be found and corrected before any conclusions on the transmission are made. A quick way to identify if the engine is causing shifting problems is to connect a vacuum gauge to the engine and take a reading while the engine is running. The gauge should be connected to intake manifold vacuum. A normal vacuum gauge reading is steady at about 17 in. Hg (431.8 mm Hg). The rougher the engine runs, the more the gauge readings will fluctuate.

Visual Inspection

Diagnosis of transmission problems should continue with conducting a thorough visual inspection, checking the various linkage adjustments, retrieving all DTCs, and checking basic engine operation. Also, check the voltage of the battery as improper voltage can affect the performance of the transmission.

Fluid Leaks

Check all drivetrain parts for looseness and leaks. If the transmission fluid was low or there was no fluid, raise the vehicle and carefully inspect the transmission for signs of leakage. Leaks are often caused by defective gaskets or seals. Common sources of leaks are the oil pan seal, rear cover and final drive

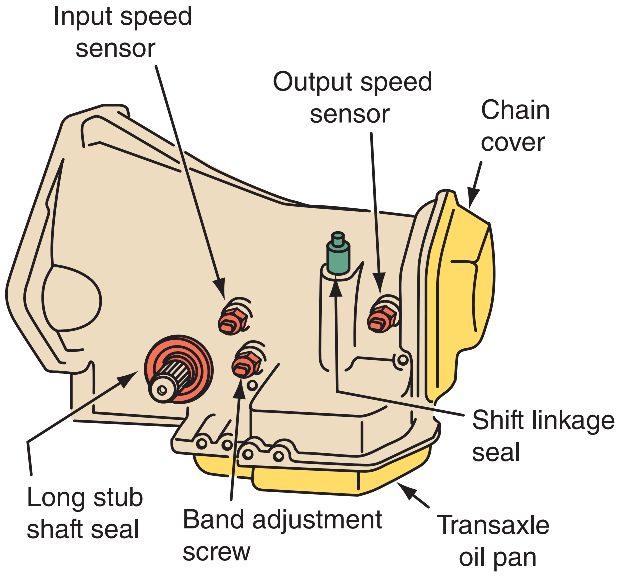


FIGURE 43–8 Possible sources of fluid leaks on this transaxle.

cover (on transaxles), extension housing, speedometer gear assembly, and electrical switches mounted into the housing **(Figure 43–8)**. The housing may have a porosity problem, allowing fluid to seep through the metal. Case porosity may be repaired with an epoxy sealer.

Oil Pan A common source of fluid leakage is between the oil pan and the transmission housing. If fluid is present around the rim of the pan, retorquing the pan bolts may correct the problem. If it does not correct the problem, the pan must be removed and a new gasket installed. Make sure the sealing surface of the pan is flat and capable of providing a seal before reinstalling it.

Torque Converter Torque converter problems can be caused by a leaking converter **(Figure 43–9)**. This type of problem may be the cause of customer complaints of slippage and a lack of power. To check the converter for leaks, remove the converter access cover and examine the area around the torque converter shell. An engine oil leak may be falsely diagnosed as a converter leak. The color of engine oil is different from that of transmission fluid and may help identify the true source of the leak. However, if the oil or fluid has absorbed much dirt, both will look the same. An engine leak typically leaves an oil film on the front of the converter shell, whereas a converter leak will cause the entire shell to be wet. If the transmission's oil pump seal is leaking, only the back side of the shell will be wet. If the converter is leaking or damaged, it should be replaced.

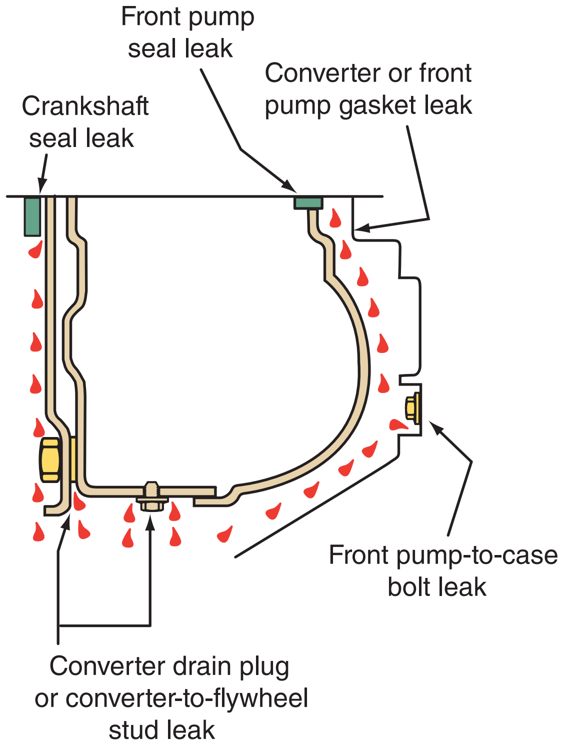


FIGURE 43–9 By determining the direction of fluid travel, the cause of a fluid leak around the torque converter can be identified.

Inspect the converter shell for swelling and signs of bluing. Both indicate that the converter has been too hot. Restrictions in the transmission cooler circuit and malfunctioning pressure valves can lead to an overheated converter.

Extension Housing An oil leak stemming from the mating surfaces of the extension housing and the transmission case may be caused by loose bolts. To correct this problem, tighten the bolts to the specified torque. Also, check for signs of leakage at the rear of the extension housing. Fluid leaks from the seal of the extension housing can be corrected with the transmission in the car. Often, the cause for the leakage is a worn extension housing bushing, which supports the sliding yoke of the drive shaft. When the drive shaft is installed, the clearance between the sliding yoke and the bushing should be minimal. If the clearance is satisfactory, a new oil seal will correct the leak. If the clearance is excessive, the repair requires that a new seal and a new bushing be installed.

Speed Sensor The vehicle's speedometer can be purely electronic, which requires no mechanical hookup to the transmission, or it can be driven, via a cable, off the output shaft. If the transmission is

equipped with a VSS, the bore and sensor can be a source of leaks. The sensor is retained in the bore with a retaining nut or bolt. An oil leak at the speedometer cable or VSS can be corrected by replacing the O-ring seal. Always lubricate the O-ring and sensor prior to installation.

Electrical Connections

Check all electrical connections to the transmission. Faulty connectors or wires can cause harsh or delayed and missed shifts. On transaxles, the connectors can normally be inspected through the engine compartment, whereas they can only be seen from under the vehicle on longitudinally mounted transmissions. To check the connectors, release the locking tabs and disconnect them, one at a time, from the transmission. Carefully examine them for signs of corrosion, distortion, moisture, and transmission fluid **(Figure 43–10)**. Carefully check the weather seals on all connectors. A connector or wiring harness may deteriorate if ATF reaches it. Also, check the connector at the transmission. Using a small mirror and flashlight may help you get a good look at the inside of the connectors. Inspect the entire transmission wiring harness for tears and other damage. Road debris can damage the wiring and connectors mounted underneath the vehicle.

Because the operation of the engine and transmission are integrated through the control computer, a faulty engine sensor or connector may affect the operation of the engine and the transmission. The various sensors and their locations can be identified by referring to the appropriate service information.

FIGURE 43–10 Carefully disconnect all connectors and inspect them.

The engine control sensors that are the most likely to cause shifting problems are the TP, MAP, and VSS.

Checking Transmission and Transaxle Mounts

The engine and transmission mounts on FWD cars are important to the operation of the transaxle. Any engine movement may change the effective length of the shift and throttle cables or wiring harnesses and therefore may affect the engagement of the gears. Delayed or missed shifts may result from linkage changes as the engine pivots on its mounts.

Visually inspect the mounts for looseness and cracks. With a pry bar, pull up and push down on the transaxle case while watching the mount **(Figure 43–11)**. If there is movement between the metal plate and its attaching point on the frame, tighten the attaching bolts.

Then, from the driver's seat, apply the foot brake, set the parking brake, and start the engine. Put the transmission into a forward gear and gradually increase the engine speed to about 1,500 to 2,000 rpm. Watch the torque reaction of the engine on its mounts. Repeat the check in reverse. If the engine's reaction to the torque appears to be excessive, broken or worn drivetrain mounts may be the cause.

If it is necessary to replace the transaxle mount, make sure you follow the manufacturer's recommendations for maintaining the alignment of the driveline. Failure to do so may result in poor gear shifting, vibrations, and/or broken cables. Some manufacturers recommend that a holding fixture or special bolt be used to keep the unit in its proper location.

FIGURE 43–11 All transmission and engine mounts should be carefully checked for cracks and damage.

Transmission Cooler and Line Inspection

Transmission coolers are a possible source of fluid leaks. The efficiency of the coolers is also critical to the operation and longevity of the transmission. Follow these steps when inspecting the transmission cooler and associated lines and fittings:

1. Check the engine's cooling system. The transmission cooler cannot be efficient if the engine's cooling system is defective. Repair all engine cooling system problems before continuing to check the transmission cooler.
2. Inspect the fluid lines and fittings between the cooler and transmission. Check these for looseness, damage, signs of leakage, and wear. Replace any damaged lines and fittings.
3. Inspect the engine's coolant for traces of transmission fluid. If ATF is present in the coolant, the transmission cooler leaks.
4. Check the transmission's fluid for signs of engine coolant. Water or coolant will cause the fluid to appear milky with a pink tint. This milky appearance is also an indication that the transmission cooler leaks and is allowing engine coolant to enter into the transmission fluid.

The cooler can be checked for leaks by disconnecting and plugging the transmission to cooler lines at the radiator. Then remove the radiator cap to relieve any pressure in the system. Tightly plug one of the ATF line fittings at the radiator. Using the shop air supply with a pressure regulator, apply 50 to 70 psi (3.52 to 4.92 kg/cm^2) of air pressure into the cooler at the other cooler line fitting **(Figure 43–12)**. Look into the radiator. If bubbles are observed, the cooler leaks.

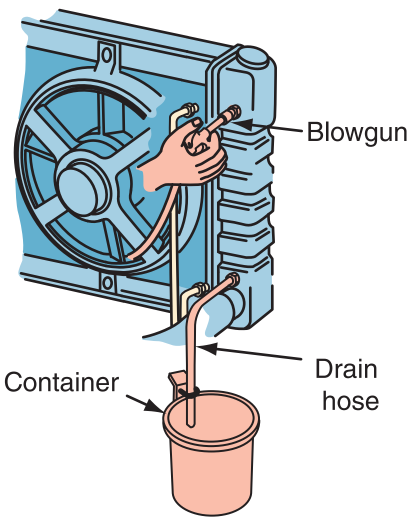


FIGURE 43–12 Shop air can be used to check a transmission for leaks and restrictions.

Road Testing the Vehicle

Critical to proper diagnosis of an automatic transmission is a road test. If the vehicle has an EAT, connect a scan tool with recording capabilities, if possible, before taking the drive. Also, find the appropriate chart that shows the activity of the various solenoids for the transmission **(Figure 43–13)**. Knowing their activity will help you determine if one or more of them are causing a shifting problem.

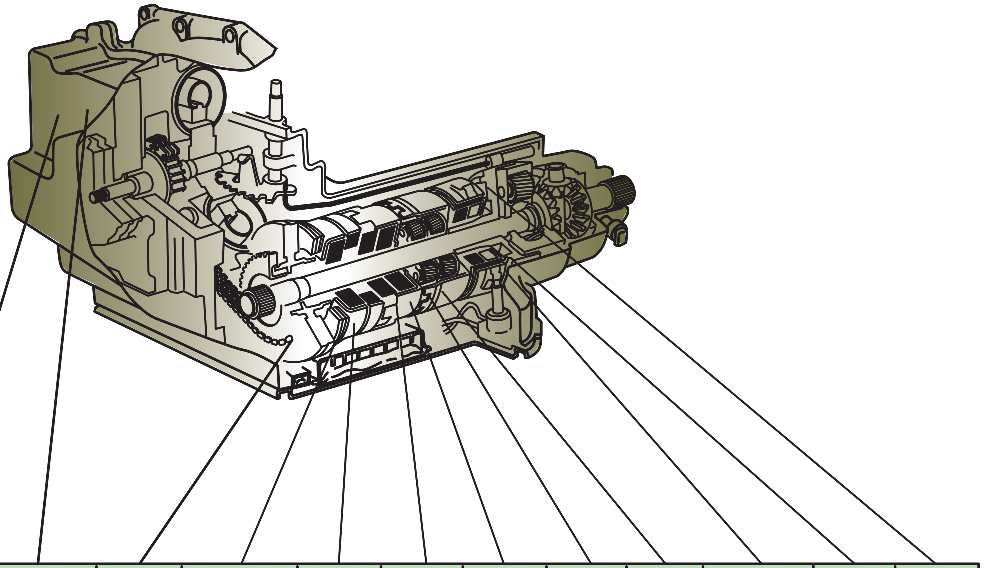
All transmission concerns should be verified attempting to duplicate the customer's concern. Knowing the exact conditions that cause the symptom will allow you to accurately diagnose the cause. Diagnosis becomes easy if you think about what is happening in the transmission when the problem occurs. If there is a shifting problem, think about the parts that are being engaged and disengaged.

Also, before beginning your road test, find and duplicate, from service information, the chart that shows the band and clutch application for different gear selector positions. Using these charts will greatly simplify your diagnosis of automatic transmission problems. It is also wise to have a notebook or piece of paper to jot down notes about the operation of the transmission.

Begin the road test with a drive at normal speeds to warm the engine and transmission. If a problem appears only when starting and/or when the engine and transmission are cold, record this symptom on the chart or in your notebook.

During the road test, the transmission should be operated in all possible modes and its operation noted. Check for proper gear engagement as the selector lever is moved to each gear position, including park. There should be no hesitation or roughness as the gears are engaging. Check for proper operation in all forward ranges, especially the upshifts and converter clutch engagement during light throttle operation. These shifts should be smooth and positive and occur at the correct speeds. These same shifts should feel firmer under medium to heavy throttle pressures. Transmissions equipped with a torque converter clutch should be brought to the specified apply speed and their engagement noted. Again, record the operation of the transmission in these different modes in your notebook or on the diagnostic chart. Also, the various computer inputs should be monitored and the readings recorded.

Force the transmission to kick down and pay attention to the quality of this shift. Manual downshifts should also be made at a variety of speeds.



Range	Gear	A solenoid	B solenoid	4th clutch	Reverse band	2nd clutch	3rd clutch	3rd roller clutch	Input clutch	Input sprag	Forward band	1–2 roller clutch	2–1 band
P – N		On	On						*	*			
D	1st	On	On						Appl	Hold	Appl	Hold	
	2nd	Off	On			Appl			*	Orun	Appl	Hold	
	3rd	Off	Off			Appl	Appl	Hold			Appl		
	4th	On	Off	Appl		Appl	*	Orun			Appl		
D	3rd	@Off	@Off			Appl	Appl	Hold	Appl	Hold	Appl		
	2nd	@Off	@On			Appl			*	Orun	Appl	Hold	
	1st	@On	@On						Appl	Hold	Appl	Hold	
2	2nd	@Off	@On			Appl			*	Orun	Appl	Hold	Appl
	1st	@On	@On						Appl	Hold	Appl	Hold	Appl
1	1st	@On	@On				Appl	Hold	Appl	Hold	Appl	Hold	Appl
R	Rev	On	On		Appl				Appl	Hold			

*Applied but not effective

On - Solenoid energized

Off - Solenoid de-energized

@The solenoid's state follows a shift pattern which depends upon vehicle speed and throttle opening. It does not depend upon the selected gear.

FIGURE 43-13 A solenoid and clutch application chart for a typical electronic transmission.

The reaction of the transmission should be noted, as should all abnormal noises, and the gears and speeds at which they occur.

After the road test, check the transmission for signs of leakage. Any new leaks and their probable cause should be noted. Then compare your written notes from the road test to the information given in the service information to identify the cause of the malfunction. This information usually has a diagnostic chart to aid you in this process.

> **SHOP TALK**
>
> **Always refer to the service information to identify the particulars of the transmission you are diagnosing. Also check for any technical service bulletins that may be related to the customer's complaint.**

Diagnosis of Noise and Vibration Problems

Many noise and vibration problems that appear to be transmission related may be caused by problems in the engine, drive shaft, U-joints or CV joints, wheel bearings, wheel/tire imbalance, or other conditions. Problems in those areas can lead customers and, unfortunately, some technicians, to mistakenly

suspect that the problems are caused by the transmission or torque converter. The entire driveline should be checked before assuming that the noise is transmission related.

Common transmission noise and vibrations, and their typical cause, are shown in **(Figure 43–14)**. As can be seen, they can be caused by faulty bearings, damaged gears, worn or damaged clutches and bands, or a bad oil pump as well as contaminated fluid or improper fluid levels.

Most vibration problems are caused by an unbalanced torque converter assembly, a loosely mounted torque converter, a loose or cracked flexplate, torque converter, or a faulty output shaft. The key to determining the cause of the vibration is to pay particular attention to the vibration in relationship to engine and vehicle speed. If the vibration changes with a change in engine speed, the cause of the problem is probably the torque converter. If the vibration changes with vehicle speed, the cause is probably the output shaft or the driveline connected to it. The latter can be a bad extension housing bushing or universal joint, which could become worse at higher speeds.

To determine if the problem is caused by the transmission or the driveline, put the transmission in gear and apply the foot brakes. If the noise is no longer evident, the problem can be in the driveline or the output of the transmission. If the noise is still present, the problem must be in the transmission or torque converter.

Some lab scopes have the ability to measure vibrations, analyze the data, and plot the vibration characteristics on the scope. This ability can be very

Problem	Probable cause(s)
Ratcheting noise	The return spring for the parking pawl is damaged, weak, or misassembled
Engine speed sensitive whine	Torque converter is faulty Faulty pump
Popping noise	Pump cavitation—bubbles in the ATF Damaged fluid filter or filter seal
Buzz or high-frequency rattle whine or growl	Cooling system problem Stretched drive chain Broken teeth on drive and/or driven sprockets Nicked or scored drive and/or driven sprocket bearing surfaces Pitted or damaged bearing surfaces
Final drive hum	Worn final drive gear assembly Worn or pitted differential gears Damaged or worn differential gear thrust washers
Noise in forward gears	Worn or damaged final drive gears
Noise in specific gears	Worn or damaged components pertaining to that gear
Vibration	Torque converter is out of balance Torque converter is faulty Misaligned transmission or engine Output shaft bushing is worn or damaged Input shaft is out of balance The input shaft bushing is worn or damaged

FIGURE 43–14 A basic symptom-based diagnostic chart.

useful when trying to isolate the cause of a driveline vibration.

Noise problems are also best diagnosed by paying a great deal of attention to the speed and the conditions at which the noise occurs. If the noise is engine speed related and is present in all gears, including park and neutral, the oil pump is the most probable source because it rotates whenever the engine is running. However, if the noise is engine speed related and is present in all gears except park and neutral, the most probable sources of the noise are those parts that rotate in all gears, such as the drive chain, the input shaft, and the torque converter.

Noises that only occur when a particular gear is operating must be related to those parts responsible for providing that gear, such as a brake or clutch. Often the exact cause of noise and vibration problems can only be identified through a careful inspection of a disassembled transmission.

Checking the Torque Converter

Many transmission problems are related to the operation of the torque converter. Normally, torque converter problems will cause abnormal noises, poor acceleration in all gears, normal acceleration but poor high-speed performance, or transmission overheating.

If the vehicle lacks power during acceleration, it has a restricted exhaust or the torque converter's one-way stator clutch is slipping. To determine which of these problems is causing the power loss, test for a restricted exhaust first. Other possible causes of this problem include a restricted air or fuel filter and a defective fuel pump.

If there is no evidence of a restricted exhaust, it can be assumed that the torque converter's stator clutch is slipping and not allowing any torque multiplication to take place in the converter. To correct this problem, the torque converter should be replaced.

If the engine's speed flares up during acceleration in drive and does not have normal acceleration, the clutches or bands in the transmission are slipping. This symptom is similar to the slipping of a clutch in a manual transmission. Often this problem is mistakenly blamed on the torque converter.

Complaints of thumping or grinding noises are often thought to be caused by the torque converter (T/C), when they are actually caused by bad thrust washers or damaged gears and bearings in the transmission. Nontransmission problems, such as bad CV joints and wheel bearings, also cause these noises.

A faulty engine damper can feel like a bad T/C, allowing vibrations that seem to be related to the torque converter. These vibrations can be caused by an out of balance torque converter. If the T/C is not properly balanced, the vibration will increase at higher speeds and while the transmission is in gear.

Checking the TCC

During the road test, check to see if the TCC engages and disengages. Engagement should be smooth and free of abnormal vibrations and noise. If the clutch prematurely engages or is not being applied by full pressure, a shudder or vibration results from the rapid grabbing and slipping of the clutch. If the shudder is only noticeable during clutch engagement, the problem is typically the converter. When the shudder is evident after the engagement of the clutch; the engine, transmission, or another component of the driveline may be the cause.

A shudder when the TCC is being engaged or disengaged can be caused by an out-of-round torque converter or contaminated clutch frictional material. An out-of-round converter prevents full clutch engagement.

If the clutch does not engage, check the TCC solenoid circuit for power and excessive voltage drops. The solenoids should drop very close to source voltage. If the solenoid is electrically sound, suspect clutch material, dirt, or other material plugging the solenoid valve passages. If blockage is found, attempt to flush the valve with clean ATF. If the solenoid has a filter assembly **(Figure 43–15)**,

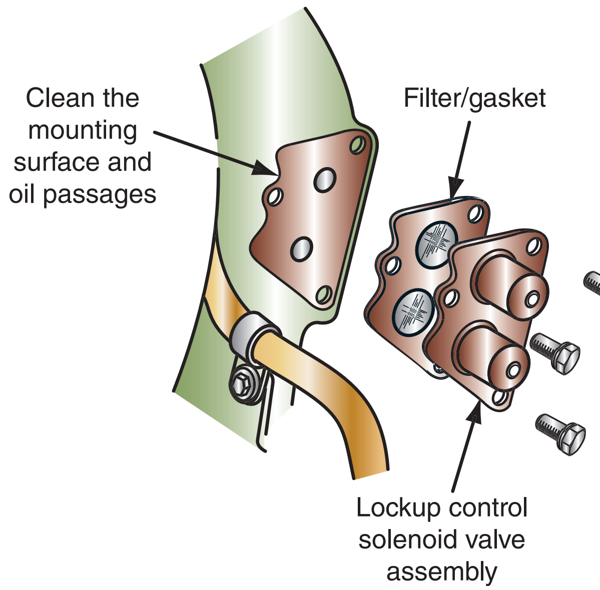


FIGURE 43–15 Some torque converter clutches have a replaceable filter.

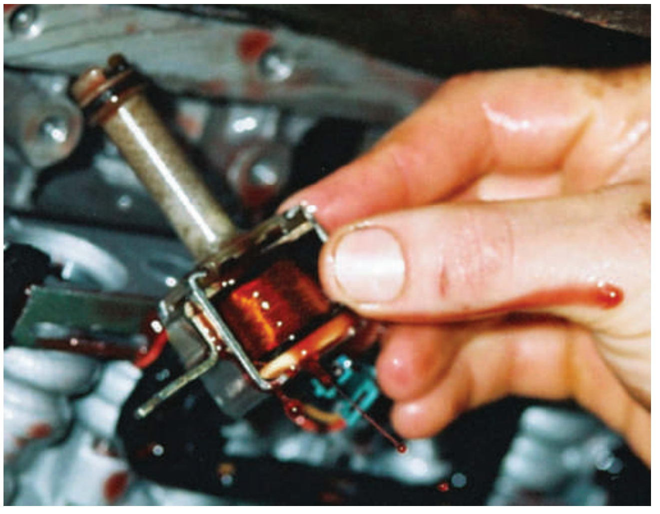


FIGURE 43-16 A TCC solenoid.

replace the filter after cleaning the fluid passages. If the blockage cannot be removed, replace the solenoid **(Figure 43–16)**.

The TCC also may not apply because of fluid leaking from the converter or past its seals, or a severely worn TCC disc or friction material has fallen off the clutch disc.

If the TCC stays applied and tends to stall the engine at a stop, the problem may be a damaged piston plate or the plate is stuck to the T/C cover. These problems can be caused by overheating the converter. Look at the converter for signs of heat to verify this problem. This problem can also be caused by the lack of end clearance inside the converter. In either case, the T/C should be replaced.

If the concern with the TCC is electrical, all related inputs and outputs should be tested with the appropriate meter. A scan tool should be used to retrieve all DTCs **(Figure 43–17)**. The scan tool should also be used to monitor the serial data while the vehicle is taken on a road test.

Most systems have the provision for operating outputs from the scan tool. This feature allows you to engage and disengage the TCC so its action can be felt and heard.

Stall Test

To test the torque converter, many technicians perform a stall test. The stall test checks the holding capacity of the converter's stator overrunning clutch assembly as well as the clutches and bands in the transmission. Some manufacturers do not

SHOP TALK

Stall testing places extreme stress on the transmission and should only be conducted if recommended by the manufacturer.

DTC	Description	Condition	Symptom
P0741	TCC slippage detected	The PCM noticed an excessive amount of slippage during normal operation.	TCC slippage, erratic operation, or no TCC operation. Flashing transmission MIL.
P0743	TCC solenoid circuit failure during on-board diagnostic	The TCC solenoid circuit does not provide the specified voltage drop across the solenoid. The circuit is open or shorted or the PCM driver failed during the diagnostic test.	With a short circuit, the engine will stall in second gear at low idle speeds with brake applied. With an open circuit, the TCC will not engage. This may cause the MIL to flash.
P0740	TCC electrical failure	The TCC solenoid circuit does not provide the specified voltage drop across the solenoid. The circuit is open or shorted or the PCM driver failed during the diagnostic test.	With a short circuit, the engine will stall in second gear at low idle speeds with brake applied. With an open circuit, the TCC will not engage. This may cause the MIL to flash.
P1740	TCC malfunction	A mechanical failure of the solenoid was detected.	If the solenoid is stuck in the ON position, the engine will stall in second gear at low idle speeds with brake applied. If the solenoid stays in the OFF position, the TCC will not engage. This may cause the MIL to flash.
P1742	TCC solenoid failed on	The TCC solenoid has failed, which was caused by an electric, mechanical, or hydraulic problem.	The transmission will exhibit harsh shifts.
P2758	TCC solenoid circuit failure, stuck ON	The TCC solenoid circuit does not provide the specified voltage drop across the solenoid. The circuit is open or shorted or the PCM driver failed during the diagnostic test.	The TCC will never engage and there will be no adaptive or self learning strategies.

FIGURE 43-17 A sample of some TCC-related DTCs.

Caution! If a stall test is not correctly conducted, the converter and/or transmission can be damaged.

recommend the stall test. Rather, diagnosis should be based on the symptoms of the problem.

To conduct a stall test, connect a tachometer to the engine and position it so that it can be easily read from the driver's seat. Set the parking brake, raise the hood, and place blocks in front of the vehicle's non-driving tires. Conduct the test outdoors, if possible, especially if it is a cold day. If the test is conducted indoors, place a large fan in front of the vehicle to keep the engine cool. With the engine running, press and hold the brake pedal. Then move the gear selector to the drive position and press the throttle pedal to the floor. Hold the throttle down for 2 seconds then note the tachometer reading and immediately let off the throttle pedal and allow the engine to idle. Compare the measured stall speed to specifications.

Warning! Make sure no one is around the engine or the front of the vehicle while a stall test is being conducted. A lot of stress is put on the engine, transmission, and brakes during the test. If something lets go, somebody can get seriously hurt.

Caution! To prevent serious damage to the transmission, follow these guidelines while conducting a stall test:

1. Never conduct a stall test if there is an engine problem.
2. Check the fluid levels in the engine and transmission before conducting the test.
3. Ensure that the engine is at normal operating temperature during the test.
4. Never hold the throttle wide open for more than 5 seconds during the test.
5. Do not perform the test in more than two gear ranges without driving the vehicle a few miles to allow the engine and transmission to cool down.
6. After the test, allow the engine to idle for a few minutes to cool the transmission fluid before shutting off the ignition.

The engine will reach a specific speed if the torque converter and transmission are functioning properly. If the tachometer indicates a speed above or below specifications, a possible problem exists in the transmission or torque converter. If a torque converter is suspected as being faulty, it should be removed and the one-way clutch checked on the bench.

A restricted exhaust or slipping stator clutch is indicated if the stall speed is below the specifications. If the stator's one-way clutch is not holding, ATF leaving the turbine of the converter works against the rotation of the impeller and slows down the engine. Both of these problems cause poor acceleration. If the stall speed is only slightly below normal, the engine is probably not producing enough power and should be diagnosed and repaired.

If the vehicle has poor acceleration but had good results from the stall test, suspect a seized one-way clutch. Excessively hot ATF in the transmission is a good indication that the clutch is seized. However, other problems can cause these same symptoms; therefore, be careful during your diagnosis.

If the stall speed is above specifications, the bands or clutches in the transmission may be slipping and not holding properly.

A stall test will generate a lot of noise, most of which is normal. If you hear any metallic noises during the test, however, diagnose the source of these noises. Operate the vehicle at low speeds on a hoist with the drive wheels free to rotate. If the noises are still present, the source of the noises is probably the torque converter.

TC-Related Cooler Problems

Vehicles equipped with a TCC may stall when the transmission is shifted into reverse gear. The cause of this problem may be plugged transmission cooler lines, or the cooler itself. Fluid normally flows from the torque converter through the transmission cooler. If the cooler passages are blocked, fluid is unable to exhaust from the torque converter and the TCC's piston remains engaged. When the clutch is engaged, there is no vortex flow in the converter and therefore little torque multiplication takes place in the converter.

To verify that the transmission cooler is plugged, disconnect the cooler return line from the radiator or cooler. Connect a short piece of hose to the outlet of the cooler and allow the other end of the hose to rest inside an empty container. Start the engine and measure the amount of fluid that flows into the container after twenty seconds. Normally, 1 quart of

fluid should flow into the container. If less than that filled the container, a plugged cooler is indicated.

If the cooler is plugged, disconnect the cooler lines at the transmission and the radiator. Blow air through the cooler, one end at a time, then through the cooler lines. The air will clear large pieces of debris from the cooler. Always use low air pressure, no more than 50 psi (3.5 kg/cm^2). Higher pressures may damage the cooler. If there is little airflow through the cooler, the radiator or external cooler must be removed and flushed or replaced.

Diagnosing Hydraulic and Vacuum Control Systems

The best way to identify the exact cause of the problem is to use the results of the road test, logic, and the oil circuit charts for the transmission being worked on. Before doing this, however, always check all sources for information about the symptom first. Also, make sure to check the basics: trouble codes in the computer, fluid level and condition, leaks, and mechanical and electrical connections.

Using the oil circuits available in the service information, you can identify which valves and apply devices should be operating in each particular gear selector position. Through a process of elimination, you can identify the most probable cause of the problem.

In most cases, the transmission or transaxle is removed to repair or replace the items causing the problem. However, some transmissions allow for a limited amount of service to the apply devices and control valves.

Mechanical and/or vacuum controls can also contribute to shifting problems. The condition and adjustment of the various linkages and cables should be checked whenever there is a shifting problem. If all checks indicate that the problem is either an apply device or in the valving, an air pressure test can help identify the exact problem. Air pressure tests are also performed during disassembly to locate leaking seals and during reassembly to check the operation of the clutches and servos.

Pressure Tests

If you cannot identify the cause of a transmission problem from your inspection or road test, a pressure test should be conducted. This test measures the fluid pressure of the different transmission circuits during the various operating gears and gear selector positions **(Figure 43–18)**. The number of hydraulic circuits that can be tested varies with the different makes and models of transmissions. However, most transmissions are equipped with pressure taps, which allow the pressure test equipment to be connected to the transmission's hydraulic circuits **(Figure 43–19).**

Before conducting a pressure test on an electronic automatic transmission, check and correct all trouble codes retrieved from the system. Also make sure the transmission fluid level and condition are okay and that the shift linkage is in good order and properly adjusted.

The test is best conducted with three pressure gauges, but two will work. Two of the gauges should read up to 400 psi (28 kg/cm^2) and the other to 100 psi (7 kg/cm^2). The two 400 psi (28 kg/cm^2) gauges are usually used to check mainline and an individual circuit, such as mainline and direct or forward circuits. If a circuit is 15 psi (1 kg/cm^2) lower than mainline pressure when they are both tested at exactly the same time, a leak is indicated. A 100 psi (7 kg/cm^2) gauge may be used be used on TV and governor circuits.

The pressure gauges are connected to the pressure taps in the transmission housing and routed so that the gauges can be seen by the driver. The vehicle is then road tested and the gauge readings observed during the following operational modes: slow idle, fast idle, and WOT. Depending on the vehicle, pressure tests may be able to be performed through the scan tool **(Figure 43–20)**. With pressure gauges connected, use the scan tool to increase and decrease line pressure and compare to specifications. Perform the test several times to be sure to achieve accurate readings.

During the road test, observe the starting pressures and the steadiness of the increases that occur with slight increases in load. The pressure drops as the transmission shifts from one gear to another also should be noted. The pressure should not drop more than 15 psi (1 kg/cm^2) between shifts.

Any pressure reading not within the specifications indicates a problem **(Figure 43–21)**. Typically, when the fluid pressures are low, there is an internal leak, clogged filter, low oil pump output, or faulty pressure regulator valve. If the pressure increased at the wrong time or the pressure was not high enough, sticking valves or leaking seals are indicated. If the pressure drop between shifts was greater than approximately 15 psi (1 kg/cm^2), an internal leak at a servo or clutch seal is indicated. Always check the manufacturer's specifications for maximum drop off.

Gear selector position	Actual gear	PRESSURE TAPS					
		Underdrive clutch	Overdrive clutch	Reverse clutch	Torque converter clutch off	2/4 Clutch	Low/reverse clutch
Park* 0 mph	Park	0–2	0–5	0–2	60–110	0–2	115–145
Reverse* 0 mph	Reverse	0–2	0–7	165–235	50–100	0–2	165–235
Neutral* 0 mph	Neutral	0–2	0–5	0–2	60–110	0–2	115–145
L# 20 mph	First	110–145	0–5	0–2	60–110	0–2	115–145
3# 30 mph	Second	110–145	0–5	0–2	60–110	115–145	0–2
3# 45 mph	Direct	75–95	75–95	0–2	60–90	0–2	0–2
OD# 30 mph	Overdrive	0–2	75–95	0–2	60–90	75–95	0–2
OD# 50 mph	Overdrive with TCC	0–2	75–95	0–2	0–5	75–95	0–2

*Engine speed at 1,500 rpm.

#CAUTION: Both front wheels must be turning at the same speed.

FIGURE 43–18 A typical oil pressure chart for an engine running at approximately 1,500 rpm.

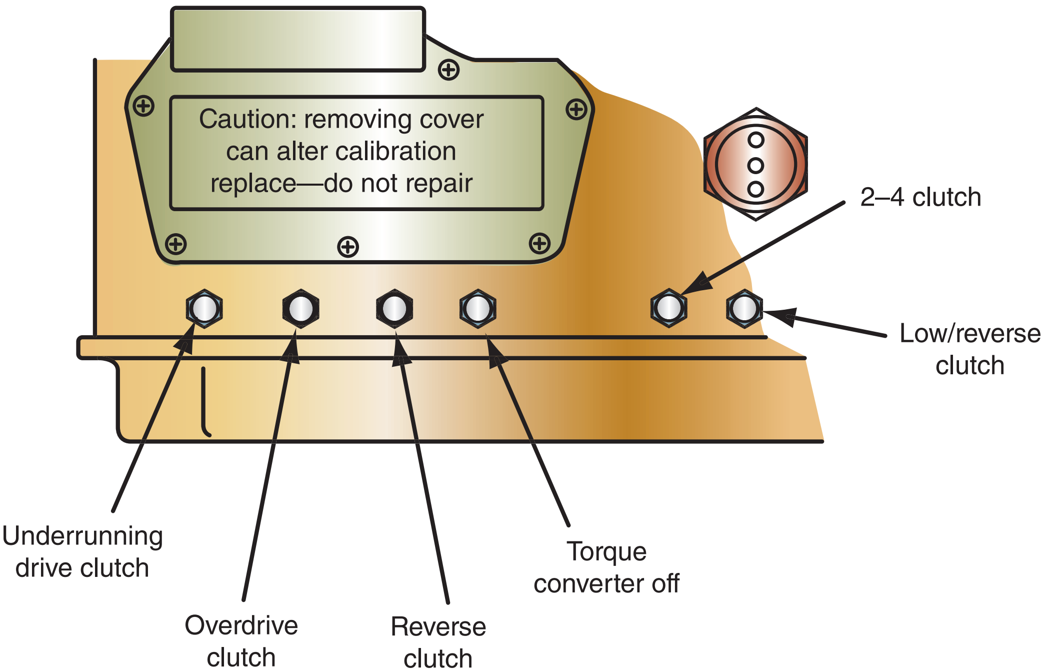


FIGURE 43–19 Pressure taps on the outside of a typical transaxle.

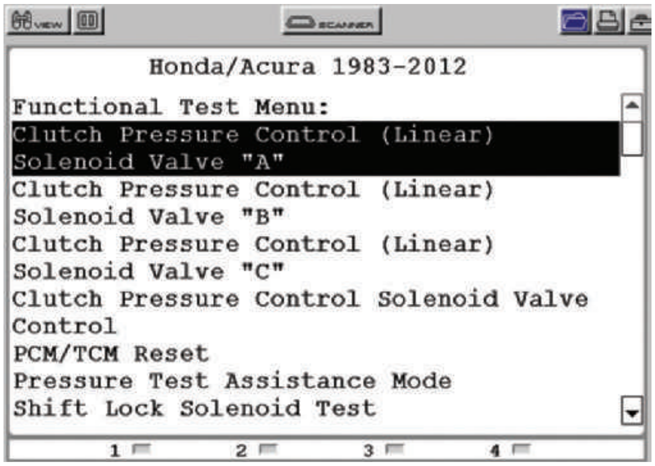


FIGURE 43-20 Solenoid testing with a scan tool.

On transmissions equipped with an electronic pressure control (EPC) solenoid, if the line pressure is not within specifications, the EPC pressure needs to be checked. To do this, connect the pressure gauge to the EPC tap. Start the engine and check EPC pressure, then compare it to specifications. If the pressure is not within specifications **(Figure 43–22)**, follow the procedures for testing the EPC. If the pressure is okay, there is a mainline pressure problem.

If the pressure tests suggest a governor or governor drive problem, it should be removed, disassembled, cleaned, and inspected. However, electronically controlled transmissions do not rely on the hydraulic signals from a governor; rather, they rely on the electrical signals from speed and load sensors. These send a signal to the TCM when gears should be shifted.

Some transmissions require that the transmission be removed to service the governor. In other transmissions, it can be serviced by removing the extension housing or oil pan, or by detaching an external retaining clamp and then removing the unit.

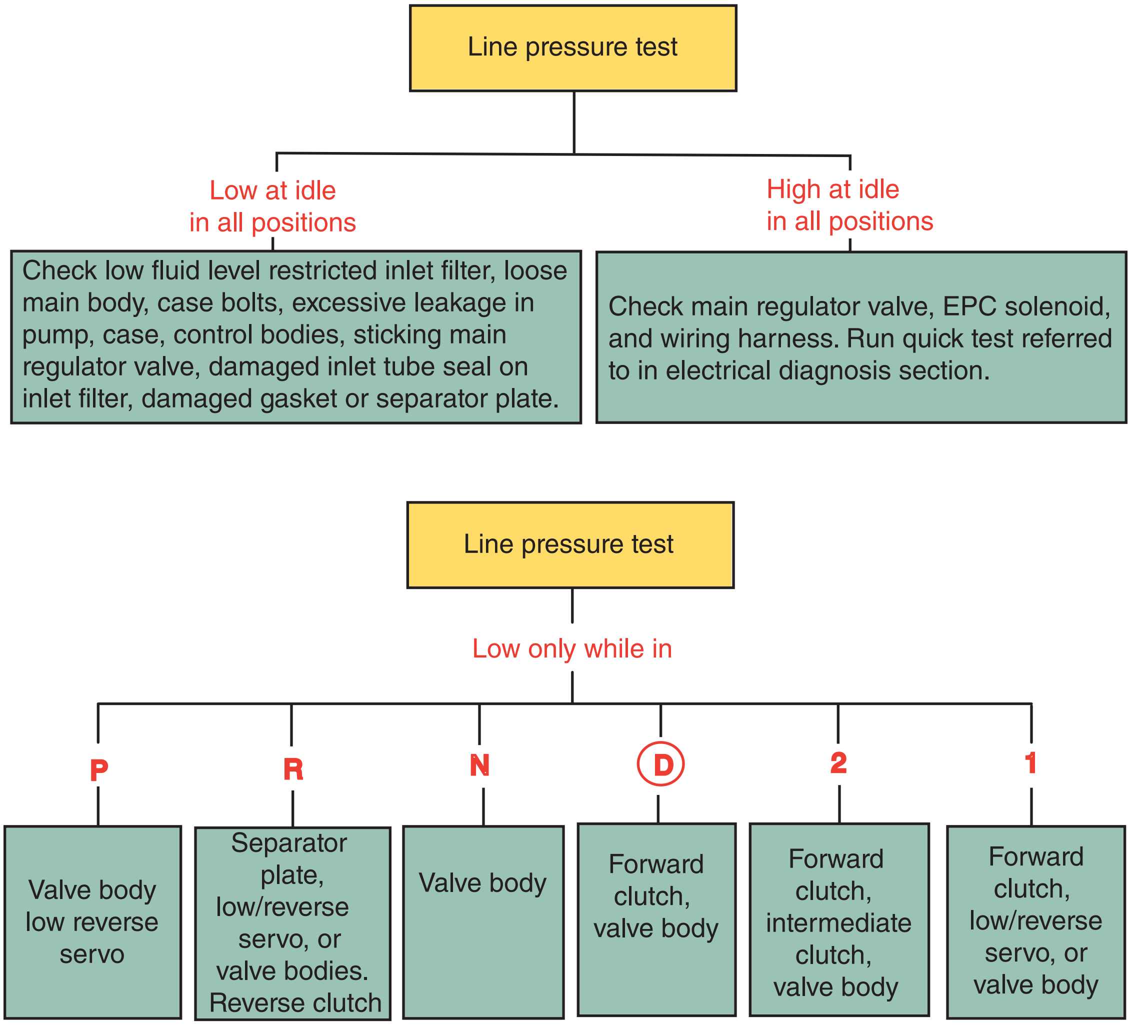


FIGURE 43-21 A troubleshooting chart for abnormal line pressure.

Transmission pressure with TP at 1.5 volts and vehicle speed above 8 km/h (5 mph)					
Gear	EPC tap	Line pressure tap	Forward clutch tap	Intermediate clutch tap	Direct clutch tap
1	276–345 kPa (40–50 psi)	689–814 kPa (100–118 psi)	620–745 kPa (90–108 psi)	641–779 kPa (93–113 psi)	0–34 kPa (0–5 psi)
2	310–345 kPa (45–50 psi)	731–869 kPa (106–126 psi)	662–800 kPa (96–116 psi)	689–827 kPa (100–120 psi)	655–800 kPa (95–116 psi)
3	341–310 kPa (35–45 psi)	620–758 kPa (90–110 psi)	0–34 kPa (0–5 psi)	586–724 kPa (85–105 psi)	551–689 kPa (80–100 psi)

FIGURE 43–22 A pressure chart for a transmission equipped with an EPC solenoid.

Common Problems

The following problems and their causes are given as examples. The actual causes of these types of problems vary with the different models of transmissions. Refer to the appropriate Band and Clutch Application Chart while diagnosing shifting problems. Doing so allows you to identify the cause of the shifting problems through the process of elimination.

Normally, if the shift for all forward gears is delayed, the clutch that is applied in all forward gears may be slipping. Likewise, if the slipping occurs in one or more gears but not all, suspect the clutch that is applied only during those gear ranges.

It is important to remember that delayed shifts or slippage may also be caused by leaking hydraulic circuits or sticking spool valves in the valve body. Since the application of bands and clutches is controlled by the hydraulic system, improper pressures will cause shifting problems. Other components of the transmission can also contribute to shifting problems. For example, on transmissions equipped with a vacuum modulator, if upshifts do not occur at the specified speeds or do not occur at all, the modulator may be faulty or the vacuum supply line may be leaking.

Valve Body

If the pressure problem was associated with the valve body, a thorough disassembly, cleaning in fresh solvent, careful inspection, and the freeing and polishing of the valves may correct the problem. Disconnect the lever and detent assemblies attached to the valve body, and then remove the valve body screws. Before lowering the valve body and separating the assembly, hold the assembly with the valve body on the bottom and the transfer and separator plates on top. Holding the assembly in this way reduces the chances of dropping the steel balls located in the valve body. Lower the valve body and note where these steel balls are located in the valve body **(Figure 43–23)**, then remove them and set them aside along with the various screws.

After all of the valves and springs **(Figure 43–24)** have been removed from the valve body, soak the

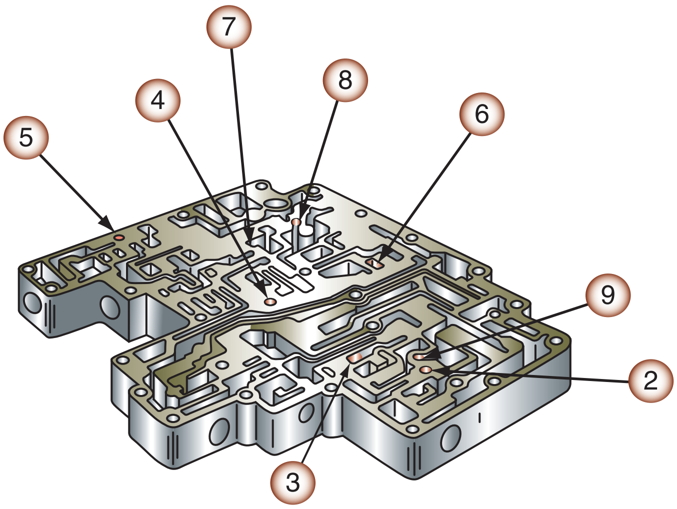


FIGURE 43–23 Location of the check balls in a typical valve body.

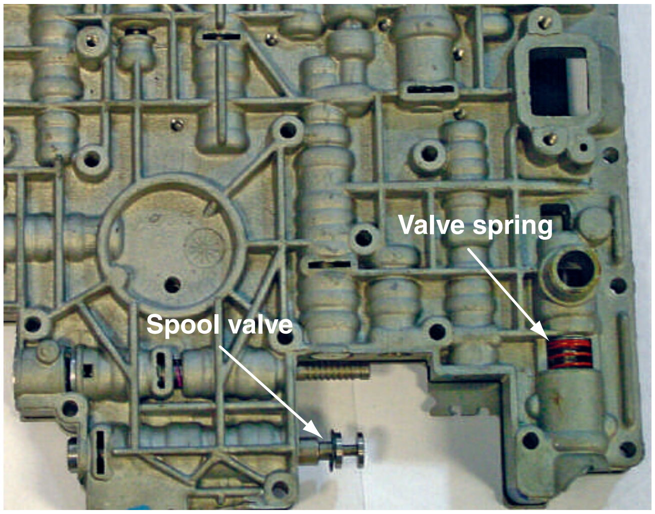


FIGURE 43–24 Examples of a spool valve and return spring in a valve body.

FIGURE 43–25 To remove the servo in some transmissions, the retaining snapring must be removed.

valve body, separator, and transfer plates in mineral spirits for a few minutes. Thoroughly clean all parts and make sure all passages within the valve body are clear and free of debris. Carefully blow-dry each part individually with dry compressed air. Never wipe the parts of a valve body with a wiping rag or paper towel. Lint from either will collect in the valve body passages and cause shifting problems. As the parts of the valve body are dried, place them in a clean container.

Examine each valve for nicks, burrs, and scratches. Check that each valve properly fits into its respective bore. If a valve cannot be cleaned enough to move freely in its bore, the valve body is normally replaced. Individual valve body parts are available, as well as bore reamers. Care must be taken when rebuilding valve bodies.

During reassembly of the valve body, lube the valves with fresh ATF. Check the valve body gasket (if used) to make sure it is the correct one by laying it over the separator plate and holding it up to the light. No oil holes should be blocked. Then install the bolts to hold valve body sections together and the valve body to the case. Tighten the bolts to the torque specifications to prevent valve body warpage and possible leakover.

Servo Assemblies

On some transmissions, the servo assemblies are serviceable with the transmission in the vehicle **(Figure 43–25)**. Others require the complete disassembly of the transmission. Internal leaks at the servo or clutch seal will cause excessive pressure drops during gear changes.

When removing the servo, check both the inner and outer parts of the seal for wet oil that means leakage. When removing the seal, inspect the sealing surface, or lips, before washing **(Figure 43–26)**. Look for unusual wear, warping, cuts and gouges, or particles embedded in the seal.

The servo piston, spring, piston rod, and guide should be cleaned and dried. Then check the sealing rings to make sure they are able to turn freely in the groove of the piston ring. These seal rings are not typically replaced unless they are damaged, so carefully inspect them. Check the servo piston for cracks, burrs, scores, and wear. Inspect the servo cylinder for scores or other damage. Move the piston rod through the piston rod guide and check for freedom of movement. If all of the parts are in good condition, the servo assembly can be reassembled.

FIGURE 43–26 When removing the servo assembly, carefully inspect all parts.

Lubricate the sealing ring with ATF and carefully install it on the piston rod. Lubricate and install the piston rod guide with its snapring into the servo piston. Then, install the servo piston assembly, return spring, and piston guide into the servo cylinder. Some servos are fitted with rubber lip seals that should be replaced. Lubricate and install the new lip seal. On lip seals, make sure the spring is seated around the lip and that the lip is not damaged.

Band Adjustment

On some transmissions, slippage during shifting can be corrected by adjusting the holding bands. To help identify if a band adjustment will correct the problem, refer to the written results of your road test. Compare your results with the Clutch and Band Application Chart in the service information. If slippage occurs when there is a gear change that requires the holding by a band, the problem may be corrected by tightening the band.

On some vehicles, the bands can be adjusted externally with a torque wrench. On others, the transmission fluid must be drained and the oil pan removed. Locate the band-adjusting nut **(Figure 43–27)**, then clean off all dirt on and around the nut. Now, loosen the band-adjusting bolt locknut and back it off approximately five turns. Use a calibrated pound-inch torque wrench to tighten the adjusting bolt to the specified torque. Then back off the adjusting screw the specified number of turns and tighten the adjusting bolt locknut while holding the adjusting stem stationary. Reinstall the oil pan with a new gasket and refill the transmission with fluid. If the transmission problem still exists, an oil pressure test or transmission teardown must be done.

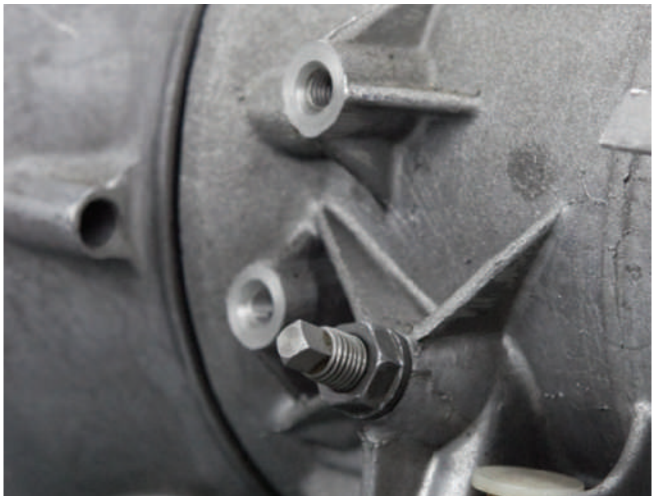


FIGURE 43–27 An example of the location of an external band adjusting screw.

Warning! Do not excessively back off the adjusting stem as the anchor block may fall out of place. It will then be necessary to remove and disassemble the transmission to fit it back in place.

Linkages

Many transmission problems are caused by improper adjustment of the linkages. Older transmissions have either a cable or a rod-type gear selector linkage and also have throttle valve linkage or an electric switch connected to the throttle to control forced downshifts.

Transmission Range Switch

The transmission range (TR) switch or sensor sends gear shifter location to the TCM and PCM. A faulty switch can cause the transmission to not upshift, not stay in gear, delay gear engagement, and allow the engine to start in positions other than park and neutral.

To check the TR sensor, connect a scan tool and prepare it to read the transmission data. Move the gear selector through its various positions and see if the scan tool is displaying the selected location. Depending on the type of sensor, you may need a digital multimeter (DMM) to check the resistance through each position of the switch. Always refer to the manufacturer's service procedures for proper testing information.

The TR sensor will not work properly if the gear shift linkage is damaged or out of adjustment.

Gear Selector Linkage

Many transmissions have a shift cable. The cable connects the gear shifter to the transmission's shift lever. The shift lever is connected to the manual shift valve. This valve directs fluid through the valve body according to the position of the shift lever.

Some automatic transmissions have no linkage, rather the gear shift works as an input device for the TCM or PCM.

A worn or misadjusted gear selection linkage will affect transmission operation. The transmission's manual shift valve must completely engage the selected gear **(Figure 43–28)**. Partial manual shift valve engagement will not allow the proper amount of fluid pressure to reach the rest of the valve body. If the linkage is misadjusted, poor gear engagement,

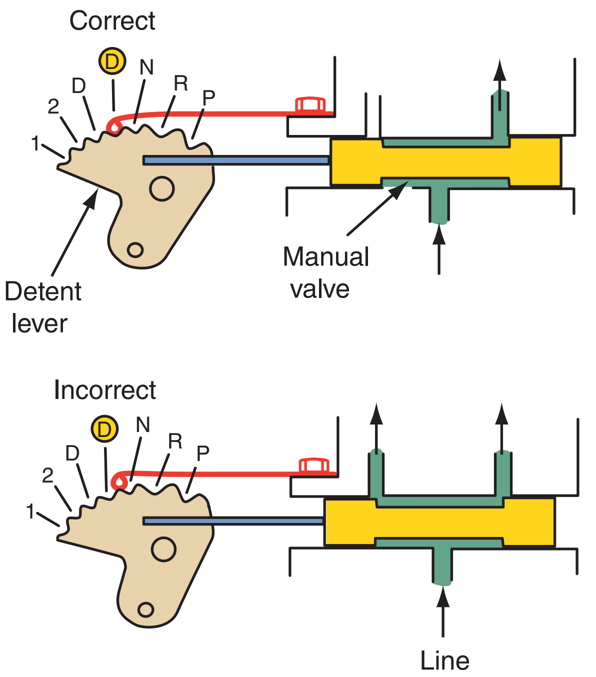


FIGURE 43-28 Incorrect linkage adjustments may cause the manual shift valve to be positioned improperly in its bore and cause slipping during gear changes.

slipping, and excessive wear can result. The gear selector linkage should be adjusted so the manual shift valve detent position in the transmission matches the selector level detent and position indicator.

To check the adjustment of the linkage, move the shift lever from park to the lowest drive gear. Detents should be felt at each of these positions. If the detent cannot be felt, the linkage needs to be adjusted. While moving the shift lever, pay attention to the gear position indicator. Although the indicator will move with an adjustment of the linkage, the pointer may need to be adjusted so that it shows the exact gear after the linkage has been adjusted.

Replacing, Rebuilding, and Installing a Transmission

Obviously, in order to rebuild or service a transmission, it must be removed. The procedure for this is very similar to removing a manual transmission or transaxle. The exact procedure for removing a transmission will vary with each year, make, and model of vehicle. Always refer to the service information for the correct procedure.

GO TO Chapter 39 for details on removing and installing a transmission.

Before removing the transmission, remove the torque converter access cover. Check for loose torque converter bolts. Then rotate the engine and watch the movement of the T/C. If it wobbles, this may be caused by a damaged flexplate or converter.

Place an index mark on the converter and the flexplate to ensure the two will be properly mated during installation. Using a flywheel turning tool, rotate the flywheel until some of the converter-to-flexplate bolts are exposed. Loosen and remove the bolts. Once the bolts are removed, slide the converter back into the transmission.

Once the vehicle is in position, disconnect all transmission linkages connected to the engine. Also remove the ATF dipstick. Plug the cooler line fittings on the housing and the lines. Then proceed to remove the transmission.

Inspecting the Torque Converter

After the transmission has been removed:

- Inspect the flexplate for evidence of cracking or other damage.
- Check the condition of the starter ring gear teeth and make sure the gear is firmly attached to the flexplate.
- Inspect the drive studs or lugs used to attach the converter to the flexplate.
- Check the shoulder area around the lugs and studs for cracked welds or other damage.
- Inspect the converter attaching bolts or nuts and replace them if they are damaged.
- Check the T/C for ballooning; this is caused by excessive pressure. If the converter is ballooned, it should be replaced and the cause of the high pressure corrected.
- Check the converter's balance weights to make sure they are still firmly attached to the unit.

Caution! Always begin by disconnecting the battery ground cable. This is a safety-related precaution to help avoid any electrical surprises when removing starters or wiring harnesses. It is also possible to send voltage spikes, which may kill the PCM if wiring is disconnected when the battery is still connected.

- Check the pilot of the converter for wear and other damage.
- Check the area around the pilot for cracks.
- Check the drive hub of the torque converter for wear and other damage **(Figure 43–29)**.
- Check for excessive runout of the flexplate and the converter's hub with a dial indicator.

In general, a torque converter should be replaced if there is fluid leakage from its seams or welds, loose drive studs, worn drive stud shoulders, stripped drive stud threads, heavily grooved hub, or excessive hub runout. The following additional tests of the T/C can be conducted to determine its condition:

- Stator one-way clutch check
- Internal interference check
- End play check
- Converter leakage tests

Summary of T/C Checks

These conditions suggest that the converter should be replaced:

- If there is a stator clutch failure.
- If there is internal interference.
- If the transmission's front pump is badly damaged.
- If the converter hub is severely damaged or scored.
- If there are signs of external fluid leaks.
- If the drive studs or lugs are damaged or loose.
- If there are signs of overheating.
- If heavy amounts of metal were found in the fluid.
- If any damage is evident that the converter is no longer balanced.

Although some specialty shops will rebuild a converter, nearly all technicians replace the converter when any of the above exists. This is especially true of converters with a clutch. Rebuilding a converter is not a normal task for an automobile technician. This procedure requires special equipment and knowledge, do not attempt to repair a faulty converter.

FIGURE 43–29 Check the oil pump and input shaft mating areas of the torque converter.

Transmission Overhaul

The exact procedure for overhauling a transmission depends solely on the specific transmission as well as the problems that the transmission may have. Always refer to the service information for the procedures for a specific transmission/ transaxle.

The following guidelines will help you service any transmission:

- After the unit has been removed from the vehicle, secure it in a suitable holding fixture.
- Remove the torque converter if it has not been already removed.
- Check and record the end play of the input shaft, before unbolting and removing the oil pan and gasket **(Figure 43–30)**.
- Remove the oil pan, oil filter, and all components readily accessible at this point.
- If the transaxle is fitted with a drive chain, inspect it for side play and stretch **(Figure 43–31)**.
- If the unit is a transaxle, remove the differential assembly.

GO TO Chapter 39 for information on checking and servicing final drive units in a transaxle.

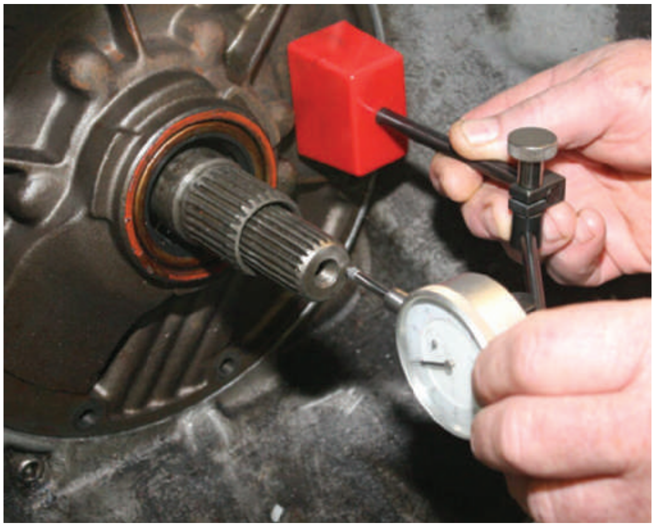


FIGURE 43–30 Before and after taking apart a transmission, check the end play of the input shaft.

FIGURE 43–31 While removing the drive chain from a transaxle, make sure you check it for damage and stretch.

- Before removing and disassembling the oil pump, mark the gears with machinist bluing ink or paint first. This ensures proper reassembly.
- Measure the clearances within the oil pump.
- Some oil pumps have a wear plate. The plate should be carefully inspected for damage and distortion. The plate should not be scored, nicked, or have grooves cut into it. The thickness of the plate at the wear area should be measured and compared to specifications.
- The bushing of the oil pump should be carefully checked and should be replaced if it is damaged or worn. The best way to determine if it is worn is to measure the inside diameter. If the measurement exceeds specifications, the bushing should be replaced.
- To replace the bushing, remove all gears from the pump's body. Support the body so both ends of the bushing's bore are away from the bench. Install the removal tool into the bore and press or drive the bushing out of the bore. Clean the bore and then press or drive the bushing into the bore.
- Check all pumps, valve bodies, and cases for warpage and ensure that they are flat filed to take off any high spots or burrs prior to reassembly.
- When removing the check balls and springs from the valve body, note their exact location and count them as they are removed.
- Check each spring for signs of distortion.
- Examine each valve for nicks, burrs, and scratches **(Figure 43–32)**.
- Check the oil passages in the upper and lower valve bodies for varnish deposits, scratches, or other damage that could restrict the movement of the valves. Make sure all fluid drain back openings are clear and have no varnish or dirt buildup.
- Band servos and accumulators are basically pistons with seals in a bore held in position by springs and retaining bolts or snaprings. Some pistons have cast iron seal rings that may not need replacement but rubber and elastomer seals should always be replaced.
- To disassemble an accumulator, depress the piston to remove the accumulator cover snapring. If the piston assembly is retained by a cover, unbolt the cover. Depending on the transmission, a special tool may be required to keep the spring compressed so the cover can be removed.
- Note the direction of the piston during the teardown, it is possible to install some pistons upside down. It is common for manufacturers to mate servo piston assemblies with accumulators. A servo is disassembled in a similar way as an accumulator. Some have two or more pistons and four or five fluid passages and fluid control orifices or check balls inside them. Make sure you do not mix the parts. Also note the exact location of the check balls.
- Inspect the outside area of the servo/accumulator seal. If it is wet, determine if the oil is leaking out or if it is merely a lubricating film of oil. Check both the inner and outer parts of the seal for wet oil which means leakage. When removing the seal, inspect the sealing surface or lips. Look for unusual wear, warping, cuts and gouges, or particles embedded in the seal.
- The accumulator or servo's piston, spring, piston rod, and guide should be cleaned and dried. Check the piston for cracks, burrs, scores, and

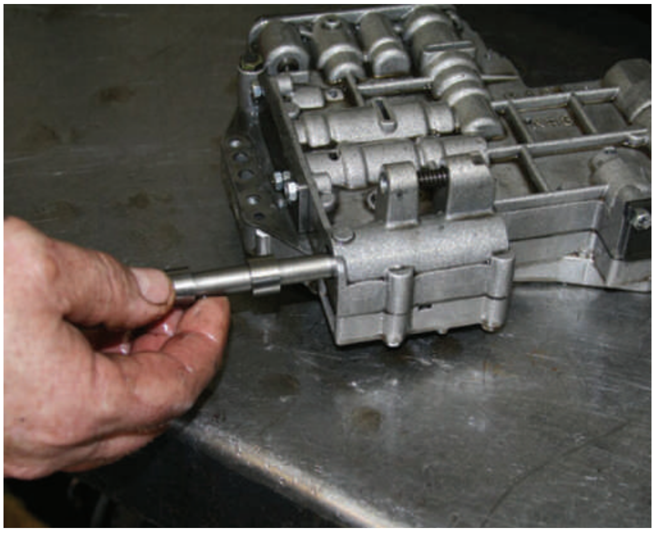


FIGURE 43–32 When removing vales from the valve body, check them for damage.

wear. The seal groove should be free of nicks or any imperfection that might pinch or bind the seal. Clean up any problems with a small file. The piston ring should rotate freely in its groove. If it does not, clean and inspect the grooves. Replace the piston ring during reassembly.

- Check the condition of the servo/accumulator pins. Look for signs of wear and damage. Also, check the fit of the pins and pistons in the case. The bores in the case should not allow the pins and pistons to wobble. If they do, they are worn or the bores in the case are worn.
- Inspect the servo or accumulator spring for cracks. Also, check the area where the spring rests against the case or piston. The spring may wear a groove; make sure the piston or case material has not worn too thin.
- Inspect the servo cylinder and other parts for wear, scores or other damage. Move the piston rod through the piston rod guide and check for freedom of movement. Replace all other components as necessary, and then reassemble the servo assembly.
- When removing and disassembling a multiple-disc assembly, use the correct puller and spring compressor. Measure the assembled clutch pack clearance. If the clearance is not correct, replace the pressure plate or snap ring that holds the pack in place to correct the clearance.
- Inspect the planetary gears for wear and signs of damage or discoloration. Make sure the planetary pinions spin freely but are not loose on the shaft. Measure planetary gear end play with feeler gauges and compare to specifications.
- Keep every part absolutely clean and air dry all parts. Only use lint-free rags to wipe parts off; lint can collect and damage the transmission.
- Check all of the threaded holes and related bolts and screws for damaged threads.
- Check the end play of each shaft as it is being assembled.
- Make sure that the correct size thrust washers are used throughout the transmission **(Figure 43–33)**.
- Soak all friction materials in clean ATF for at least 30 minutes prior to installing them.
- Coat the thrust washers, bearings, and bushings with transgel before putting them into position if specified by the service information.
- Typically to remove and install a one-way clutch, its retainer needs to be removed. Rotate the clutch clockwise until it lines up with the roller clutch cam ramps. Then remove the roller clutch from the inside of the roller clutch cam.

FIGURE 43–33 Make sure all thrust washers and bearings are the correct thickness before assembling the transmission.

- One-way clutches should be inspected for wear or damage, spline damage, surface finish damage, and damaged retainers and grooves. All smooth surfaces should be checked for any imperfections.
- All rollers and races that show any type of damage or surface irregularities should be replaced. Check the folded springs for cracks, broken ends, or flattening out. Replace all distorted or otherwise damaged springs.
- When reassembling a roller clutch, make sure the rollers and springs are facing the correct direction. If they are reversed the clutch will not lock in either direction.
- To reassemble the roller clutch assembly, press the clutch assembly onto the housing.
- Once the one-way clutches are ready for installation, verify that they overrun in the proper direction. Most one-way clutches have some marking that indicates which direction the clutch should be set. During installation, use a new retaining snapring.
- Solid sealing rings are commonly used in transmissions. These rings are made of a Teflon-based material and are never reused. To remove them, pry them out of their groove and carefully cut through the seal. Installing a new seal requires two tools: an installation tool and a resizing tool. To install a Teflon seal, warm the new seal in hot water to soften the material; this will make installation easier. Lubricate the new seal and tool. Slide the seal over the tool and seat it into its groove on

the hub or shaft. Inspect all bushings that may be inserted into the planetary gearsets. These are commonly found in sun gears. Measure the inside diameter and compare that dimension to specifications. If the diameter exceeds those specifications, replace the gear assembly.

- When tightening any fastener that directly or indirectly involves a rotating shaft, rotate the shaft during and after tightening to ensure that the part does not bind.
- Always use new gaskets and seals throughout the transmission.
- Make sure the differential and final drive unit is properly set up before installing it into the transaxle.
- Make sure that all electrical wiring to the solenoids and sensors **(Figure 43–34)** are connected and that all the harness clamps hold the wiring where it should.
- Air test the entire transmission **(Figure 43–35)** before installing the oil filter and oil pan.
- Install a new oil filter and pan gasket. Tighten the oil pan bolts to specifications.
- Always flush out the transmission cooling system before using a rebuilt or new transmission. The cooling system is a good place for debris to collect. Some manufacturers require replacement of the cooler rather than flushing it.

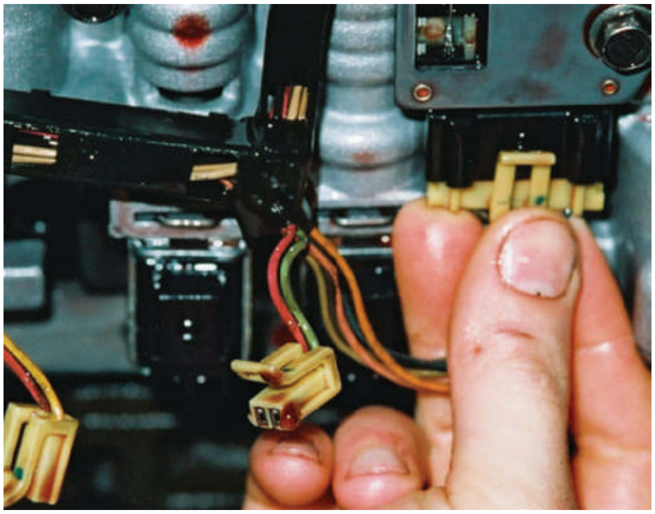


FIGURE 43–34 Make sure all of the electrical connectors are in place and are tight.

Installation

Transmission installation is generally the reverse of the removal procedure. A quick check of the following will greatly simplify your installation and reduce the chances of destroying something during installation.

- Make sure that the block alignment pins (dowels) are in their appropriate bores and are in good shape and that the alignment holes in the bell housing are not damaged.

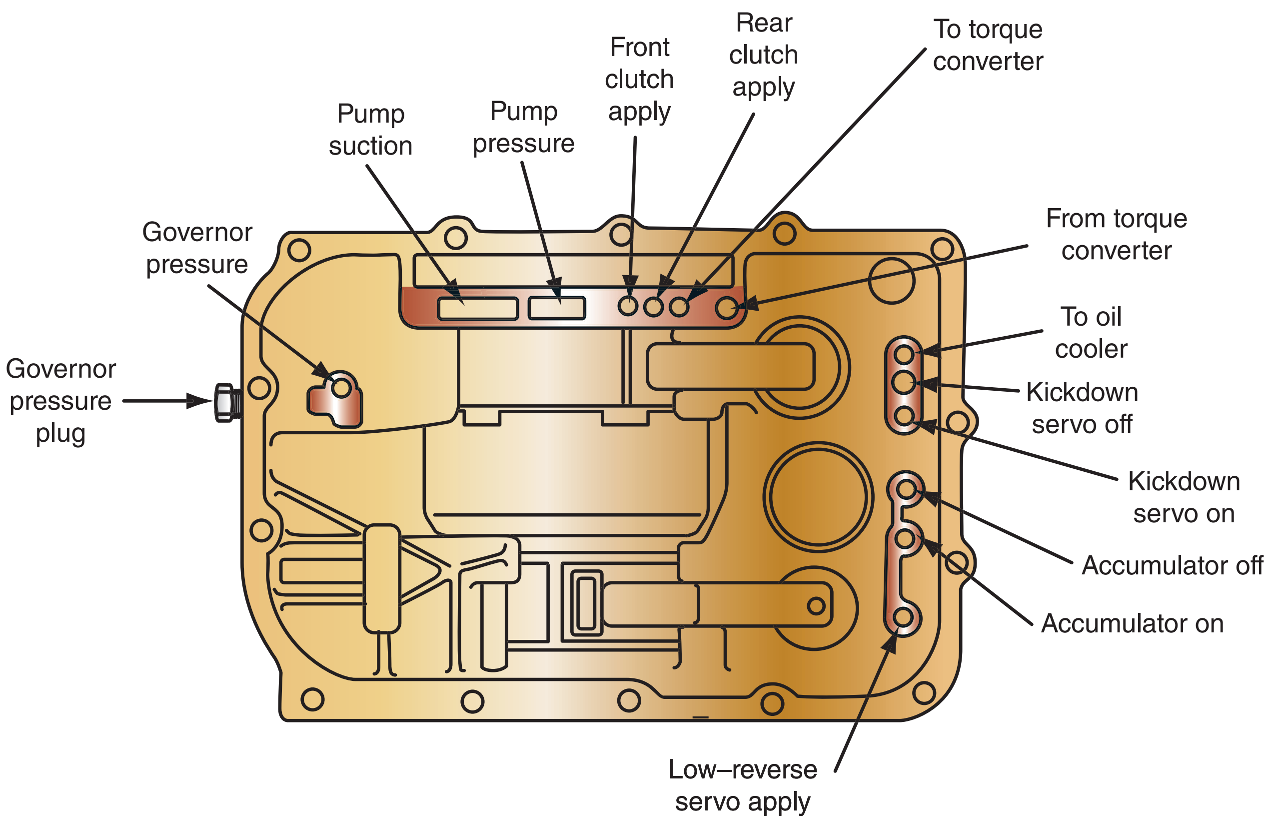


FIGURE 43–35 Air testing points in a typical transmission.

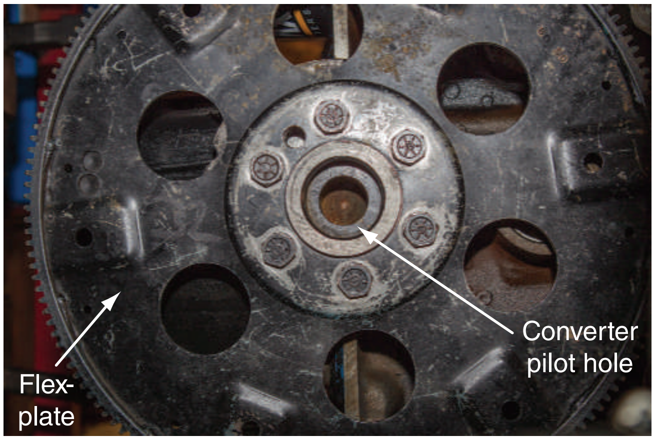


FIGURE 43–36 A pilot hole in a flex plate.

- Make sure that the pilot hole in the crankshaft is smooth and not out of round **(Figure 43–36)**. This will allow the converter to move in and out of the flexplate.
- Make sure that the pilot hub of the converter is smooth and that you cover it with a light coating of chassis lubricant to prevent chafing or rust.
- Make sure that the converter's drive hub is smooth and that you coat it with transgel or equivalent lubrication as specified.
- Secure all wiring harnesses out of the way to prevent their being pinched between the bell housing and engine block.
- Flush out the converter. It is recommended that clutch-type converters be replaced, because it is not possible to tell how much debris is in the unit.
- Always perform an end play check and check the overall height before reinstalling a torque converter or installing a fresh unit out of the box.
- Pour 1 quart of the recommended fluid into the converter before mounting the converter to the transmission. This will ensure that all parts in the converter have some lubrication before startup.

SHOP TALK

If the transmission is an EAT, check the service information before taking it on its initial road test. Most EATs require that a "Learning Procedure" be followed. This includes a variety of driving conditions. Because you need to road test and teach the transmission, you may as well do both at the same time.

A repaired transmission may require a shift adaptation relearn and a clutch learning procedure to be performed to make sure shift quality is correct. This can mean driving the vehicle with the transmission commanded to stay in certain gears using the manual gear selector or a scan tool and keeping the engine and transmission between specified speeds. Always refer to the manufacturer's service information for the correct procedures.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2006	**Make:** Dodge	**Model:** Stratus	**Mileage:** 155,366	**RO:** 17117
Concern:	Customer states vehicle shakes and vibrates when shifting into higher gears.			
After confirming the shaking during a test drive, the technician determines the vibration occurs when the TCC is trying to apply. He connects pressure gauges to the transmission and performs another test drive and finds the TCC circuit pressure is within specs.				
Cause:	Torque converter shudder present during lock up clutch application. Circuit pressure within specs.			
Correction:	Replaced torque converter due to faulty clutch.			

KEY TERM

Aeration

SUMMARY

- The ATF level should be checked at regular mileage and time intervals. Typically, when the fluid is checked, the vehicle should be level and running and the transmission should be at operating temperature.
- Both low fluid levels and high fluid levels can cause aeration of the fluid, which, in turn, can cause a number of transmission problems.
- Uncontaminated ATF is red in color and has no dark or metallic particles suspended in it.
- The fluid should be changed when the engine and transmission or transaxle are at normal operating temperatures. After draining the fluid, the pan should be inspected and the filter replaced.
- If ATF is leaking from the pump seal, the transmission must be removed from the vehicle so the seal can be replaced. Other worn or defective gaskets or seals can be replaced without removing the transmission. Case porosity may be repaired using an epoxy-type sealer.
- Slippage during shifting can indicate the need for band adjustment.
- Improper shift points can be caused by a malfunction in the governor or governor drive gear system or a misadjusted throttle linkage.
- The road test gives the technician the opportunity to check the transaxle or transmission operation for slipping, harshness, incorrect upshift speeds, and incorrect downshift.
- Accurate diagnosis depends on knowing what planetary controls are applied in a particular gear range.
- A pressure test checks hydraulic pressures in the transmission by using gauges attached to the transmission. Pressure readings reveal possible problems in the oil pump, governor, and throttle circuits.
- Proper adjustment of the gear selector or manual linkage is important to have the manual valve fluid inlet and outlets properly aligned in the valve body. If the manual valve does not align with the inlet and outlets, line pressure could be lost to an open circuit.

REVIEW QUESTIONS

Short Answer

1. What is the most probable cause of a low fluid level?
2. What does milky colored ATF indicate?
3. What do varnish or gum deposits on the dipstick indicate?
4. Typically during a pressure test, the pressure should not drop more than ___ psi between shifts.
5. List five reasons for replacing a torque converter.
6. Explain why oil circuit diagrams are invaluable tools for diagnosing a transmission problem.
7. Explain how a plugged fluid cooler can cause a vehicle to stall when reverse is selected.
8. What is checked during a stall test?
9. If a transmission does not have a dipstick, how do you check the level of the fluid?
10. What should you do if a valve does not move freely in its bore in the valve body?

Multiple Choice

1. Which of the following is the most likely cause for a shudder during the engagement of a lock-up torque converter?
   a. A bad converter
   b. Worn or damaged CV or U-joints
   c. A worn front planetary gearset
   d. Loose flexplate
2. When should the ATF level be checked on most vehicles?
   a. When the transmission is cool
   b. When the engine is at operating temperature and the engine is off
   c. When the transmission is at operating temperature and the engine is on
   d. It does not matter
3. Pressure readings reveal possible problems in which of the following?
   a. Oil pump
   b. Governor
   c. Apply circuits
   d. All of the above

4. Which of the following is a probable cause for a converter's stall speed being below specifications?
   a. Restricted exhaust
   b. Slipping transmission clutches
   c. Slipping transmission bands
   d. Worn planetary gearset
5. When rebuilding an automatic transmission, which of the following is *not* true?
   a. All pumps, valve bodies, and cases should be checked for warpage and should be flat filed to take off any high spots or burrs prior to reassembly.
   b. Only use lint-free rags to wipe parts off.
   c. Lubricate all thrust washers, bearings, and bushings before installing them.
   d. Soak all friction materials in clean engine oil prior to installing them.

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that a prerequisite to accurate road-testing analysis is knowing what planetary controls are applied in a particular gear range. Technician B says that all slipping conditions can be traced to a leaking hydraulic circuit. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. While discussing proper band adjustment procedures: Technician A says that on some vehicles the bands can be adjusted externally with a torque wrench. Technician B says that a calibrated inch-pound torque wrench is normally used to tighten the band adjusting bolt to a specified torque. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. Technician A says that if the shift for all forward gears is delayed, a slipping forward clutch is normally indicated. Technician B says that a bad forward clutch is indicated when there is a slip when the transmission shifts into any forward gear. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. Technician A says that the only positive way to identify the exact design of the transmission is by the shape of its oil pan. Technician B says that identification numbers only identify the manufacturer and assembly date of the transmission. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. Technician A says that delayed shifting can be caused by worn planetary gearset members. Technician B says that delayed shifts or slippage may be caused by leaking hydraulic circuits or sticking spool valves in the valve body. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. While checking the condition of a car's ATF: Technician A says that if the fluid has a dark brownish or blackish color and/or a burned odor, the fluid has been overheated. Technician B says that if the fluid has a milky color, this indicates that engine coolant has been leaking into the transmission's cooler. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. While discussing the results of an oil pressure test: Technician A says that when the fluid pressures are high, internal leaks, a clogged filter, low oil pump output, or a faulty pressure regulator valve are indicated. Technician B says that if the fluid pressure increased at the wrong time, an internal leak at the servo or clutch seal is indicated. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

8. While discussing a pressure test: Technician A says that a pressure drop of more than 15 psi during a shift indicates a possible leak. Technician B says that any pressure drop between shifts indicates a problem. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B
9. While checking the engine and transmission mounts on a FWD car: Technician A says that any engine movement may change the effective length of the shift and throttle cables and therefore may affect the engagement of the gears. Technician B says that delayed or missed shifts are caused by hydraulic problems, not linkage or control problems. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B
10. While discussing the cause of aerated fluid in a transmission: Technician A says that this can be caused by too much ATF in the transmission. Technician B says that this can be caused by too little ATF in the transmission. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

FOUR- AND ALL-WHEEL DRIVE

CHAPTER 44

OBJECTIVES

- Name the major components of a conventional four-wheel drive system.
- Name the components of a transfer case.
- State the difference between the transfer, open, and limited slip differentials.
- State the major purpose and operation of locking/unlocking hubs.
- Understand the difference between four- and all-wheel drive.
- Know the purpose of a viscous clutch in all-wheel drive.

With the popularity of 4WD and AWD SUVs, pickup trucks, and crossover vehicles **(Figure 44–1)**, the need for technicians who can diagnose and service four-wheel drive systems has increased drastically. Although all-wheel drive passenger cars are available, most prospective buyers for all-wheel and four-wheel drive vehicles are opting for cross-over vehicles, SUVs, and pickups.

Four-wheel drive (4WD) and **all-wheel drive (AWD)** systems can dramatically increase a vehicle's traction and handling ability in rain, snow, and off-road driving. Considering that the vehicle's only contact with the road is the small areas of the tires, driving and handling are improved when the work load is evenly spread out to four tires rather than two. However, it is important to note that most of these systems do not allow actual 4WD under most driving conditions. Driving all four wheels when traction is very low, such as on ice,

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2014	**Make:** Honda	**Model:** Pilot	**Mileage:** 47,077	**RO:** 17141
Concern:	Customer states there's noise coming from the rear of the vehicle while driving.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

FIGURE 44–1 A late-model crossover.

FIGURE 44–2 This Jeep is equipped for serious off-the-road adventures.

requires the ability to lock the differentials or wheel hubs. What most systems do is allow for torque to be routed to the both the front and rear axles, which improves traction.

The increased traction also makes it possible to apply greater amounts of energy through the drive system. Vehicles with 4WD and AWD can maintain control while transmitting levels of power that would cause two wheels to spin either on takeoff or while rounding a curve. The improved traction of 4WD and AWD systems allows the use of tires that are narrower than those used on similar 2WD vehicles. These narrow tires tend to cut through snow and water rather than hydroplane over them. Of course, wider and larger tires are often used in off-the-road adventures **(Figure 44–2)**.

Both 4WD and AWD systems add cost and weight to a vehicle. A typical AWD system adds approximately 170 pounds to a passenger car. The additional weight in larger 4WD trucks can be as much as 400 pounds or more. The systems also add to the initial cost of the vehicle. They also require special services and maintenance, and use more fuel, making the cost of operating a 4WD or AWD vehicle higher than operating a 2WD vehicle. For many, these disadvantages are heavily outweighed by the traction and performance these systems offer.

CUSTOMER CARE

Advise your customers that wear on 4WD systems is much greater than that on a 2WD transaxle or transmission, especially if drivers leave the four-wheel drive engaged on dry pavement. Some car makers warn that abuse of the system is not covered under the warranty.

Types of Drives

Because of the many names manufacturers give their drive systems, it is often difficult to clearly define the difference between 4WD and AWD. And both have the ability to send torque to all four wheels. However, today's AWD systems decide when to send torque to the front or rear axles, or both. 4WD systems can only lock the front and rear axles together, as a result each axle is always turning at the same speed. For the purposes of this text, the term four-wheel drive or 4WD is used to describe systems with a transfer case. Car-based systems that do not use a transfer case are discussed in the all-wheel drive (AWD) section. A **transfer case** splits the power from the transmission between the front and rear axles **(Figure 44–3)**. For clarity, the primary difference between an AWD and a 4WD is that the transfer case in a 4WD vehicle offers two speed ratios or gear ranges in four-wheel drive: typically called four-high and four-low. These systems are mostly found in pickups and large SUVs. An AWD vehicle does not offer this. AWD vehicles are usually

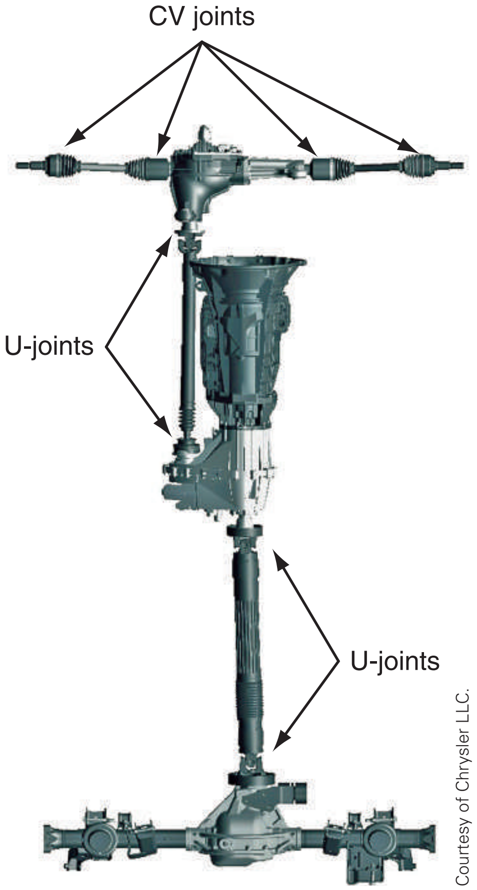


FIGURE 44–3 A typical arrangement of 4WD components.

smaller SUVs or passenger cars **(Figure 44–4)** and were developed for a front-wheel-drive based vehicle **(Figure 44–5)**.

FIGURE 44–4 A late-model AWD passenger car.

4WD vehicles do not drive all of the wheels all of the time. They use an open differential at the front and rear drive axles, and, in some cases, the center differential. An open differential splits the engine's torque output between the front and rear axles. The gear ratio of the front and rear axles can allow the axles to rotate at different speeds. However, the amount of torque transferred to the axles cannot be altered; therefore the torque will always move to the wheel or axle that has the least resistance. This means it is possible for a vehicle to become stuck with one wheel spinning while the others remain still. This happens when the axles and center differentials transmit torque to the wheels with the lowest traction.

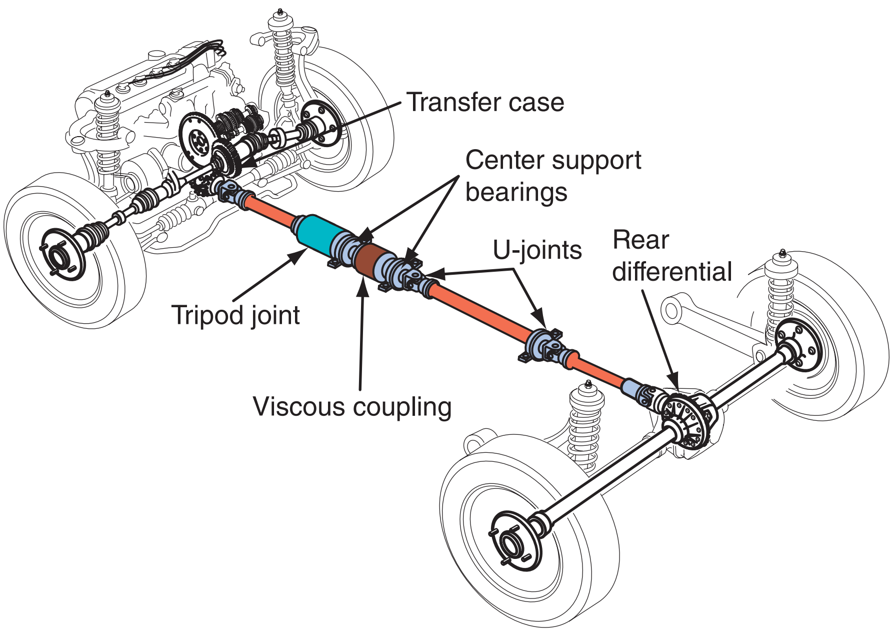


FIGURE 44–5 The layout of an AWD vehicle based on a FWD vehicle.

FIGURE 44–6 A locking hub from a 4WD truck.

Part-Time 4WD

Driving all four tires, all of the time, creates unwanted drag and binding in the drivetrain while driving on dry pavement. Limited slip (LSD) and locking differentials, locking hubs **(Figure 44–6)**, or couplings with torque management capability increase the ability to transfer and vary torque to all four wheels.

Part-time 4WD is designed to be used off-road. These systems provide a mechanical connection between the front and rear drive shafts when the transfer case is shifted into 4WD. Part-time systems are found on pickups and larger SUVs. These are RWD vehicles fitted with a two-speed transfer case and axle connects/disconnects. These 4WD systems operate in 2WD until the driver manually selects 4WD.

When 4WD is selected, more traction is available to allow the vehicle to either carry heavier loads and/or to travel in adverse terrain conditions. The system was designed just for those purposes and not for use on dry or smooth pavement. When operating in 4WD, the front and rear drive axles rotate with the same torque and there is no allowance for axle speed differences. When in 4WD and turning on dry surfaces, the tires scrub against the road surface since no difference in axle speed is available; as a result, the vehicle does not handle well. However, when the vehicle is cornering on a slippery surface, the tires easily skid or spin across the surface to allow for the required axle speed differences.

It must be kept in mind that the distances the tires must travel are different when the vehicle is making a turn **(Figure 44–7)**. The outside front wheel will travel further than the outside rear wheel and the result is called **driveline windup**. This is the main reason for new AWD transfer case designs using clutch packs or viscous couplings to permit full time use on dry pavement. Driveline windup can cause

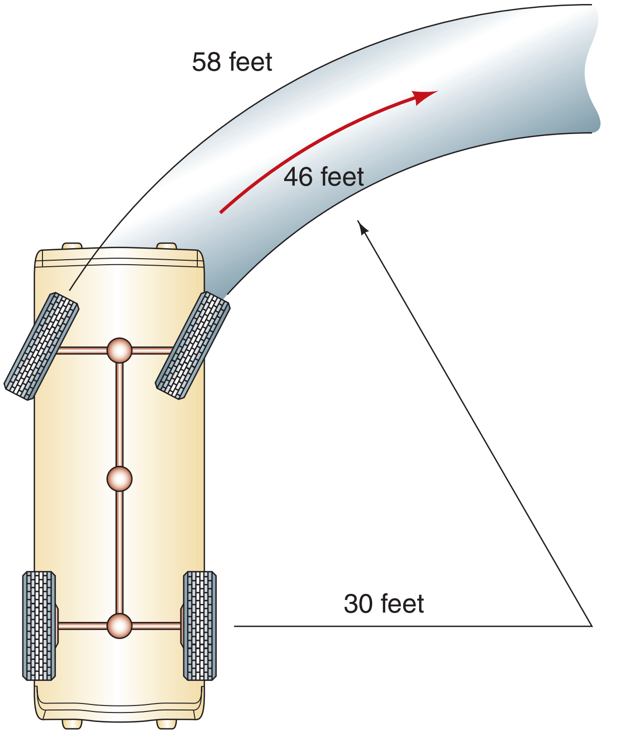


FIGURE 44–7 The distance the wheels travel while a vehicle is making a turn.

handling problems, particularly when rounding turns on dry pavement.

The drive shafts from the transfer case connect to differentials at the front and rear drive axles **(Figure 44–8)**. Universal joints are used to connect the drive shafts to the differential and the transfer

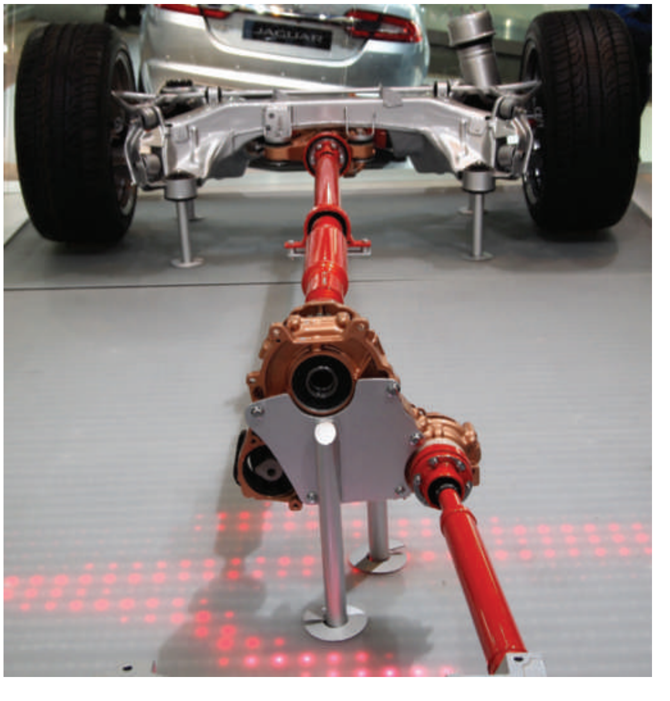


FIGURE 44–8 A transfer case and driveshafts.

(A)

(B)

FIGURE 44-9 (A) A live front axle. (B) A front wheel drive shaft for a 4WD truck.

case. The drive axles are either connected directly to the hub of the wheels or are connected to the hubs by U-joints. Universal joints are also normally used to connect the front axles to the wheel hubs on heavy-duty trucks **(Figure 44–9A)**. Light-duty vehicles generally use half shafts and CV joints in their front drive axle assembly **(Figure 44–9B)**.

Nearly all part-time 4WD systems have a transfer case that not only allows for 2WD or 4WD, but also offers two different speed ratios: high and low. This feature allows the driver to control how engine torque will be distributed to the drive wheels. The selector switch **(Figure 44–10)** or mechanical shifter **(Figure 44–11)** that controls the transfer case normally has 2WD, 4WD high, and 4WD low positions. The shift control either physically moves a gear in the transfer case or activates an electrically operated solenoid or clutch pack to send torque to the front axle. Nearly all newer vehicles use electronic 4WD controls, many of which also

FIGURE 44-10 A 4WD-mode selector switch.

FIGURE 44-11 A manual 4WD gear shifter.

provide for various modes of operation, such as in sand and snow **(Figure 44–12)**. Also, most mechanical shifters offer a neutral position that is used as a stopping point before 4WD low can be selected. Other

FIGURE 44-12 A terrain selector for a 4WD vehicle.

transfer cases are a single speed and only allow the driver to select between 2WD and 4WD modes.

When 2WD is selected, only the rear drive axle is engaged and this setting is used for all dry-road driving. Most vehicles use an open or limited-slip rear differential and some have the ability to lock the rear if needed. 4WD high transfers engine power to both axles, without affecting the amount of torque sent to the drive wheels. This gear selection provides 4WD traction on surfaces covered with ice or packed snow. 4WD low places the transfer case in a gear reduction configuration. The gear reduction may be 2:1, 4:1 or higher and provides great torque multiplication to the drive wheels. This high torque multiplication drastically decreases the speed of the vehicle. The sole purpose of this gear is to provide more traction force at the drive wheels to overcome rough terrain, including rocks, snow, gravel, or steep inclines.

Shifting

Some 4WD vehicles use a vacuum motor or mechanical linkage to move a splined sleeve to connect or disconnect the front drive axle **(Figure 44–13)**. With this system, locking hubs are not needed. When 2WD is selected, one axle is disconnected from the front differential. As a result, all engine torque moves to the side of the differential with the axle disconnected. This is due to normal differential action. When the vehicle is shifted into 4WD, the shift collar connects the two sections of the axle shaft together.

Other axle disconnects are operated electrically. An electric motor can be used to connect and disconnect the axle **(Figure 44–14)**. This system allows for a smooth transition from two- to four-wheel drive. General Motors uses a system whereby selecting 4WD on the selector switch energizes a heating element in the axle disconnect. The heating element heats a gas causing the plunger to operate the shift mechanism.

Most late-model vehicles with a mechanical or electronic 4WD control allow the driver to switch between 2WD and 4WD while the vehicle is moving or "on the fly." These systems work with the vehicle's PCM and integrated wheel ends (IWE) solenoids. The driver can typically switch between 2WD and 4WD at speeds up to 55 mph (88 km/h). However, switching from 4WD high to 4WD low requires that the vehicle be traveling at less than 3 mph (5 km/h) with the brake pedal pressed and the transmission in neutral. The transfer case is fitted with an electromagnetic clutch **(Figure 44–15)** that is used to synchronize the front driveline with the transmission's output. When

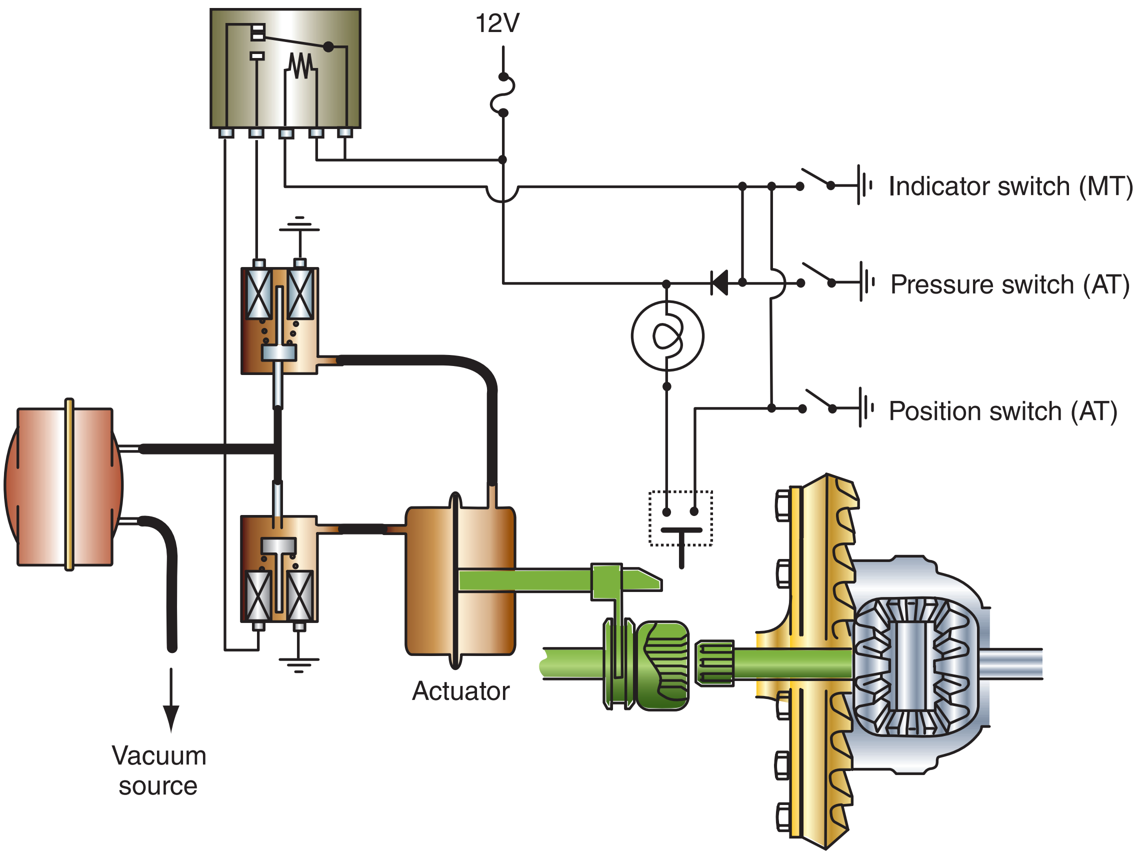


FIGURE 44–13 A vacuum operated axle disconnect system.

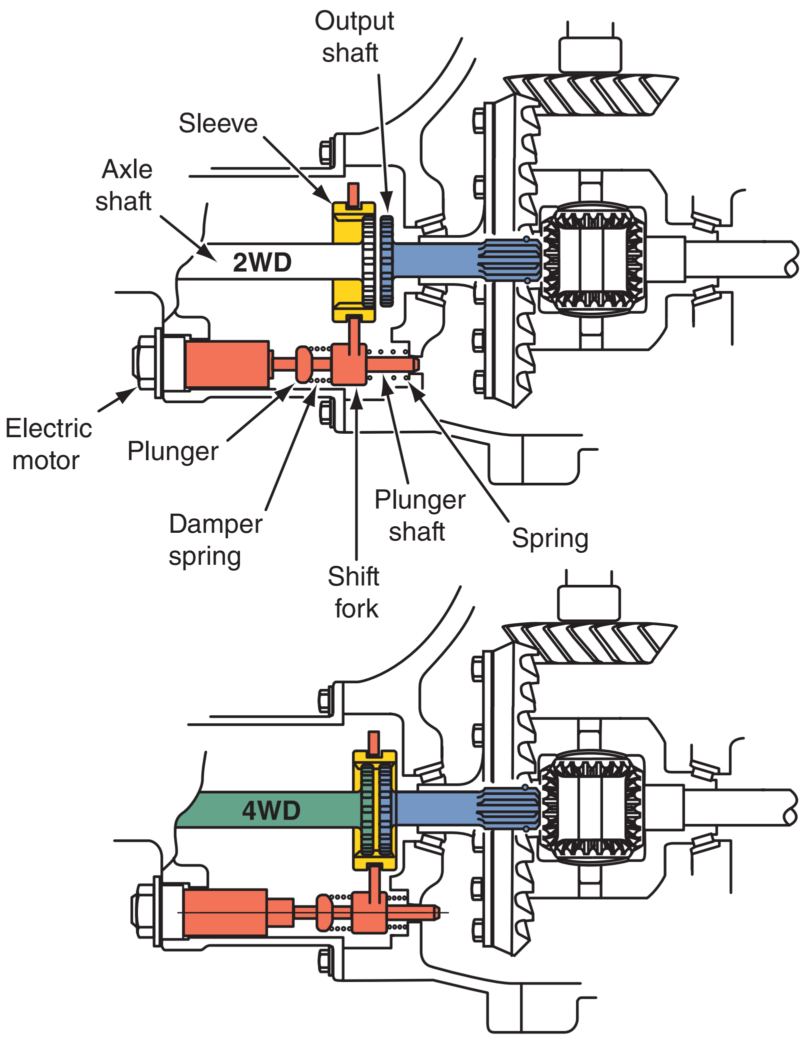


FIGURE 44–14 An electric motor disconnects the axles in this system.

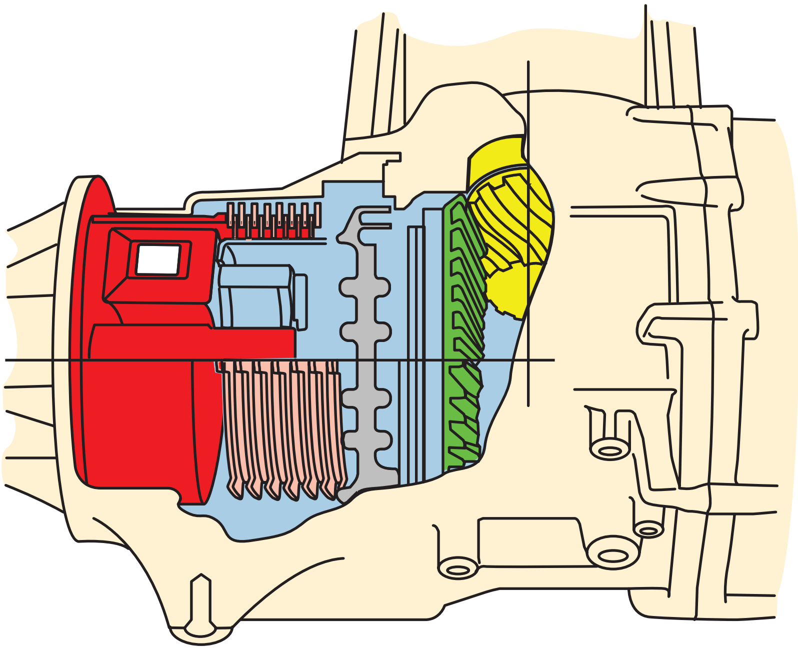


FIGURE 44–15 The clutch assembly in this transfer case is used to synchronize the front driveline with the transmission's output.

the manual shift lever is moved into 4WD, the electromagnetic clutch is energized. This causes a shifting collar to engage the transfer case's main shaft hub to the drive sprocket for the front drive shaft. The front axle integrated wheel ends (IWEs) are engaged, then the electromagnetic clutch is disengaged. In electronic shifter transfer cases, the clutch ultimately controls a shift motor.

FWD-Based Systems Some FWD vehicles fitted for 4WD use a compact transfer case bolted to the transaxle. A drive shaft then carries the power to the rear differential. The driver can switch from 2WD to 4WD by pressing a switch that activates a solenoid vacuum valve or electric motor.

All-Wheel Drive

All-wheel drive cars and trucks differ from heavier-duty 4WD trucks and SUVs in several other ways. First, there is no separate transfer case; any gearing needed to transfer power to the rear driveline is usually contained in the transaxle housing or small bolt-on extension housing **(Figure 44–16)**. The reason some cars are equipped with AWD is to improve their handling, although the ability to drive all four wheels does help during inclement weather conditions. Other vehicles use AWD to increase handling performance by applying torque to each wheel based on driving conditions.

An AWD system may transfer constant power to the front and rear axles or power may only transfer under slippery conditions. AWD systems usually incorporate a center or interaxle differential between the front and rear output shafts **(Figure 44–17)**.

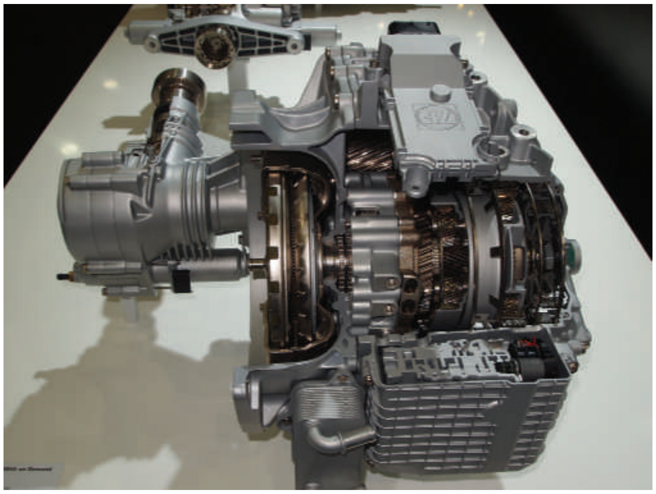


FIGURE 44–16 A nine-speed transaxle with bolt-on transfer case to provide AWD.

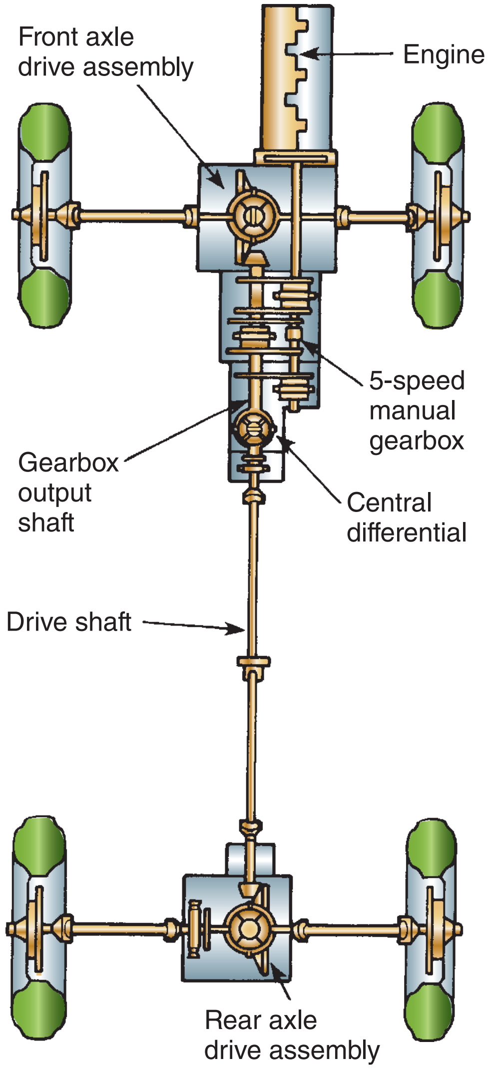


FIGURE 44–17 The placement of a center differential for a full-time 4WD system.

Full-time AWD can also be called "anytime 4WD" or AWD, although this is not entirely a correct designation. Like part-time 4WD, AWD provides a vehicle with more traction but it makes it more practical for everyday use, as it can be used full time on all surfaces including dry pavement. These systems cannot be selected out of AWD and output torque is spread equally to the drive wheels if the road conditions permit this. To prevent tire scrub during cornering, the system may have an additional differential incorporated into the transfer case or between the front and rear drive axles. The extra differential, called a center or interaxle differential, allows for a speed difference between the front and rear axles.

Full-Time AWD

Full-time AWD is similar to 4WD, in that it powers all four wheels at all times. However that 4 low setting

is not available. Since it does not have this low gear, vehicles with AWD are not designed for serious off-road excursions, but can be used on all other surfaces, including dry pavement.

Most passenger cars and smaller SUVs equipped with AWD are based on FWD designs. These modified FWD systems consist of a transaxle and differential to drive the front wheels, plus some type of mechanism for connecting the transaxle to a rear driveline. They do not have a separate transfer case; rather, a viscous clutch, center differential **(Figure 44–18)**, or electromagnetic transfer clutch is used to transfer power from the transaxle to a rear driveline and rear axle assembly.

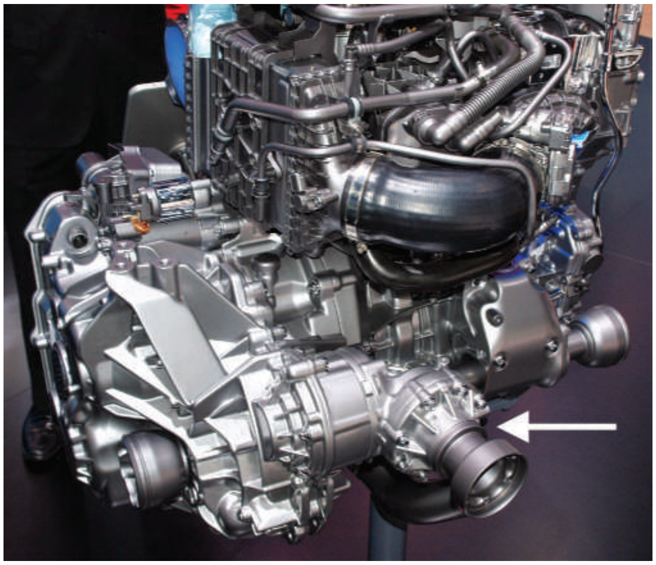


FIGURE 44-18 A center differential located at the transaxle.

Depending on the vehicle, all torque may be sent to the front wheels, but that can change with changing operating conditions. When the vehicle is moving straight on a level road, each wheel receives the same amount of torque. During a turn, the front wheels receive less torque; this prevents wheel slip. If one of the front wheels begins to slip, more torque is sent to the rear wheels. Other systems send a percentage of the torque to the front wheels and some to the rear all of the time. Many of these newer systems dynamically change the front/rear torque split and use brake-based torque vectoring to provide 4WD-like performance from the drivetrain.

These systems rely on a single-speed transfer case added to the transaxle and/or an interaxle differential to split power between the front and rear axles. The system responds to inputs from a variety of sensors. The primary input is wheel slip which is monitored by wheel-speed sensors connected to the CAN bus. When the system detects wheel slippage, the control module fully activates the clutch to send more torque to the front or rear wheels **(Figure 44–19)**. The control module monitors these inputs and adjusts the torque bias at the center, front, and/or rear differentials.

Automatic AWD

Vehicles equipped with automatic AWD may operate in 2WD most of the time and operate in AWD for only brief periods of time. Under normal conditions one axle gets 100 percent of the torque, and power to

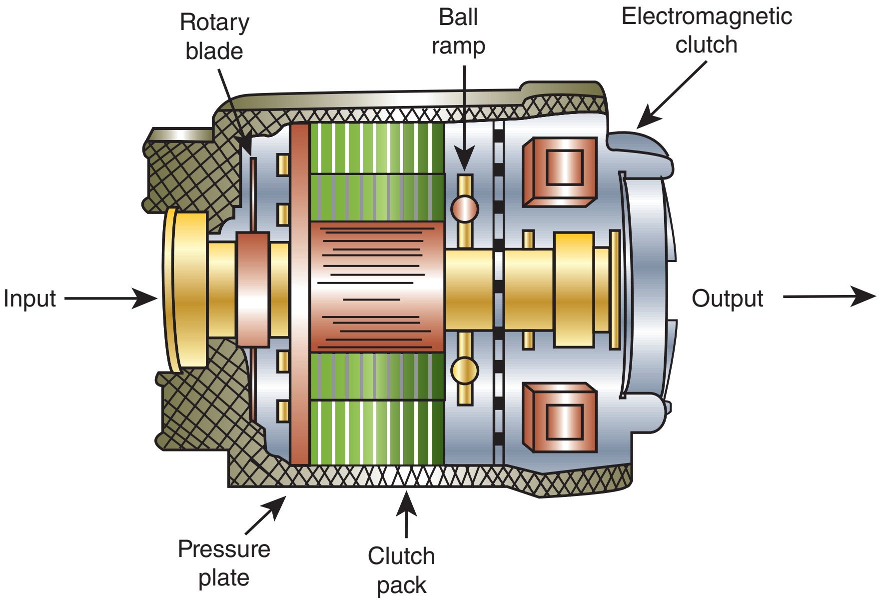


FIGURE 44-19 An electronically controlled clutch.

four wheels only occurs when the conditions make it desirable or necessary.

The PCM constantly monitors the speed of each wheel **(Figure 44–20)**. When an axle experiences some slippage, the control unit splits the power, accordingly, to the other axle. This power split can be accomplished hydraulically, mechanically, or electrically, depending on the system. As soon as the axle is no longer slipping and all four wheels are rotating at the same speed, all torque is sent to that axle.

Normally, to split the power between axles, a multiple disc clutch is used. This clutch serves as an interaxle differential and permits a speed difference between the front and rear drive axles. Sensors monitor front- and rear-axle speeds, engine speed, and load on the engine and driveline **(Figure 44–21)**. An electronic traction control unit (TCU) receives information from the sensors and controls a solenoid that operates on a duty cycle to control the fluid flow that engages the transfer clutch. The duty solenoid

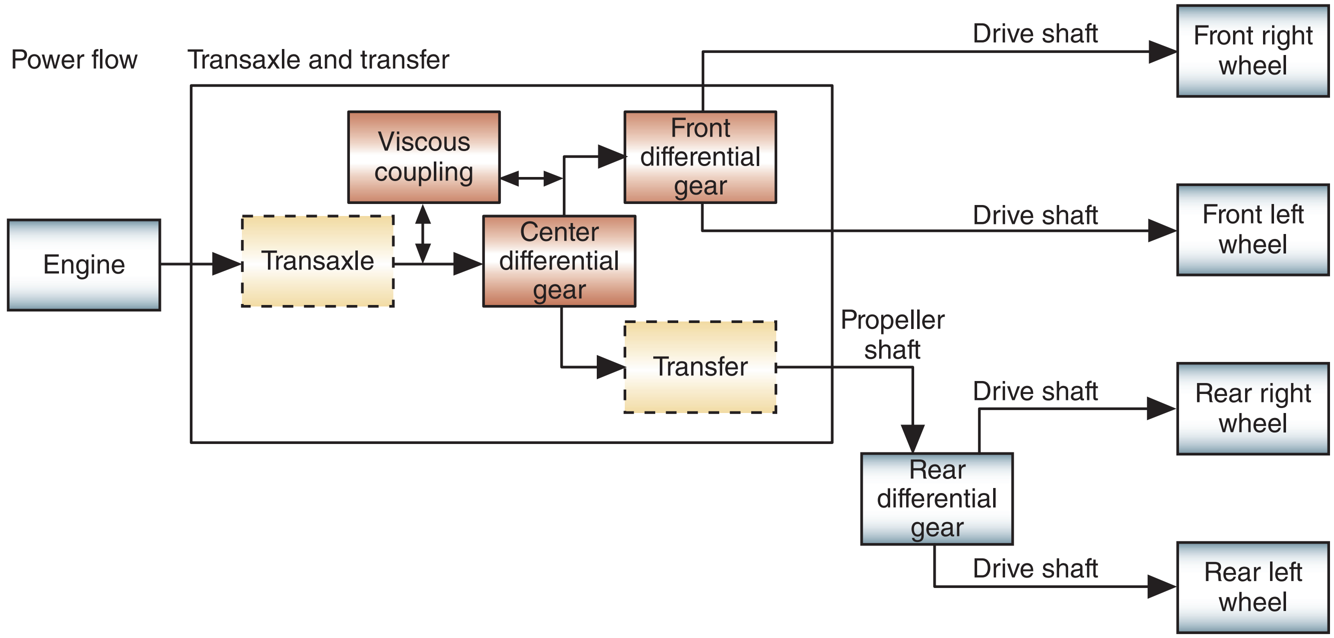


FIGURE 44-20 The power flow through a viscous clutch-type center differential.

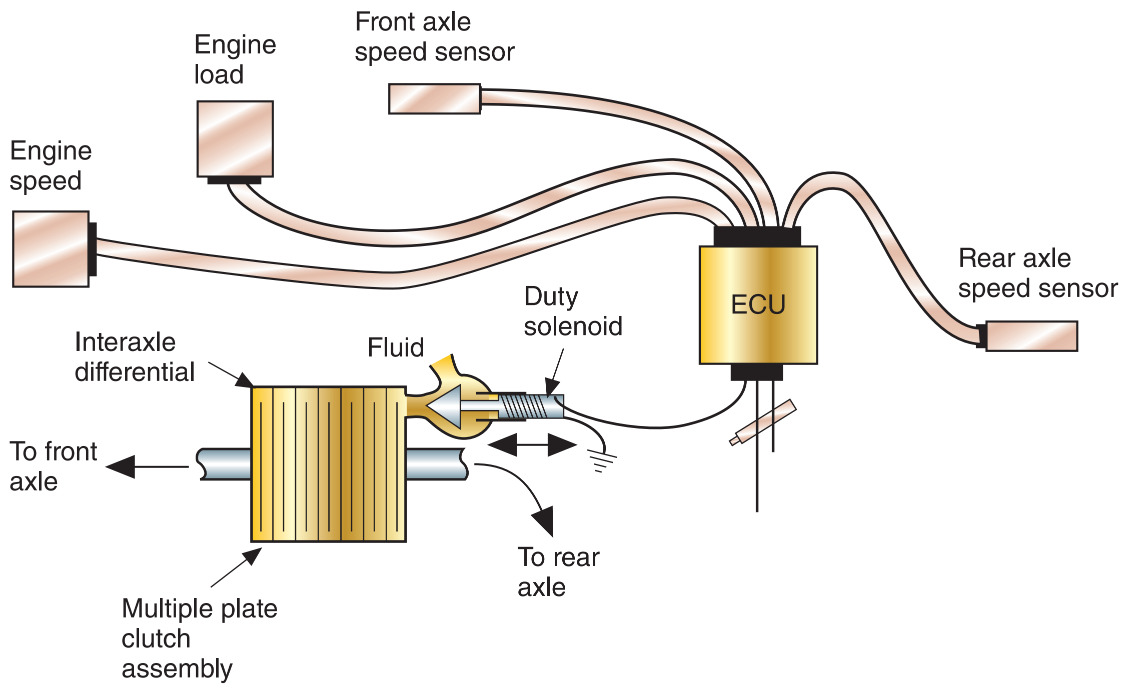


FIGURE 44-21 A simple schematic for an electronically controlled AWD system.

pulses, cycling on and off very rapidly, which develops a controlled slip condition. As a result, the transfer clutch operates like an interaxle differential and allows for a power split from 95 percent FWD and 5 percent RWD to 50 percent FWD and 50 percent RWD. This power split takes place so rapidly that the driver is unaware of the traction problem.

AWD Hybrids

On Toyota and Lexus hybrid SUVs, the front transaxle assembly has been modified to include a speed reduction unit. This unit is a planetary gearset coupled to the power-split planetary gearset. In addition, at the rear axle, an additional motor/generator (MGR) is placed in its own transaxle assembly to rotate the rear drive wheels. Unlike conventional 4WD vehicles, there is no physical connection between the front and rear axles **(Figure 44–22)**. The aluminum housing of the rear transaxle contains the motor/generator (MGR), a counter drive gear, counter driven gear, and a differential. The unit has three shafts: MGR and the counter drive gear are located on the main shaft (MGR drives the counter drive gear), the counter driven gear and the differential drive pinion gear are located on the second shaft, and the third shaft holds the differential.

Unlike the 4WD Toyotas, the Ford Escape hybrid does not have a separate motor to drive the rear wheels. Rather, these wheels are driven in a conventional way with a transfer case, rear drive shaft, and a rear axle assembly. This AWD system is fully automatic and has a computer-controlled clutch that engages the rear axle when traction and power at the rear are needed. The system relies on inputs from sensors located at each wheel and the accelerator pedal. The system calculates how much torque should be sent to the rear wheels. By monitoring these inputs, the control unit can predict and react to wheel slippage. It also can make adjustments to torque distribution when the vehicle is making a tight turn; this eliminates any driveline shudder that can occur when a 4WD vehicle is making a turn.

4WD Drivelines

The heart of conventional 4WD vehicles is the transfer case, which may be integrated into the transmission **(Figure 44–23)** or mounted to the back of the transmission **(Figure 44–24)**. A chain or gear drive within the case receives the power from the

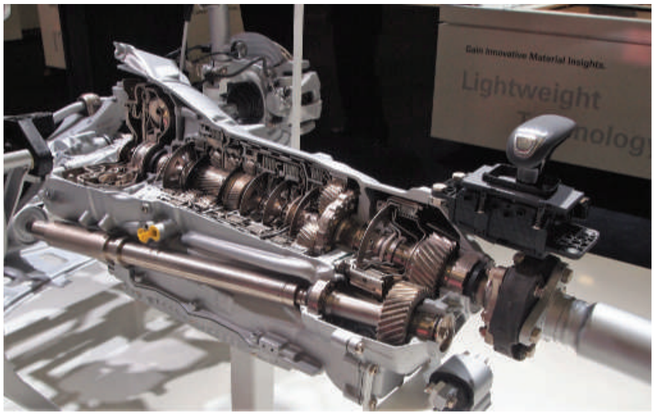


FIGURE 44–23 The transfer case is integrated with the transmission.

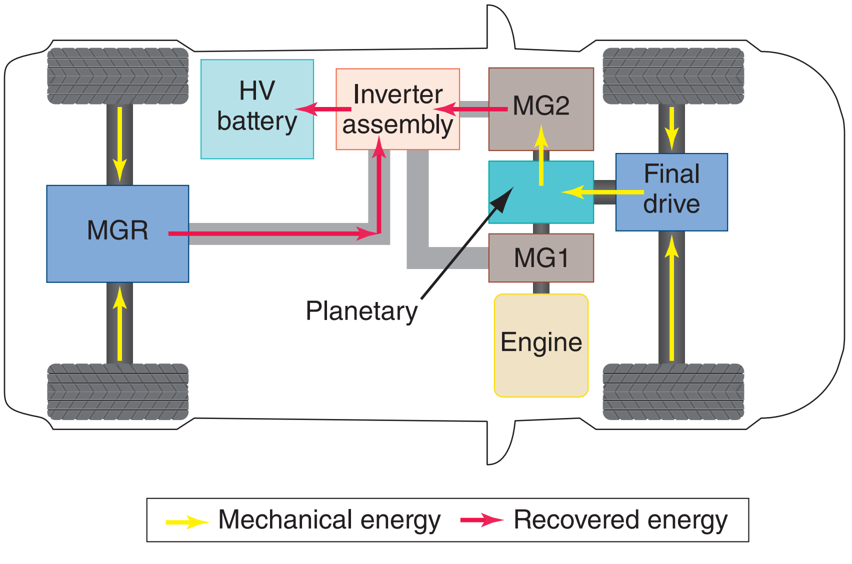


FIGURE 44–22 The basic layout for a hybrid vehicle equipped with an additional motor to drive the rear wheels.

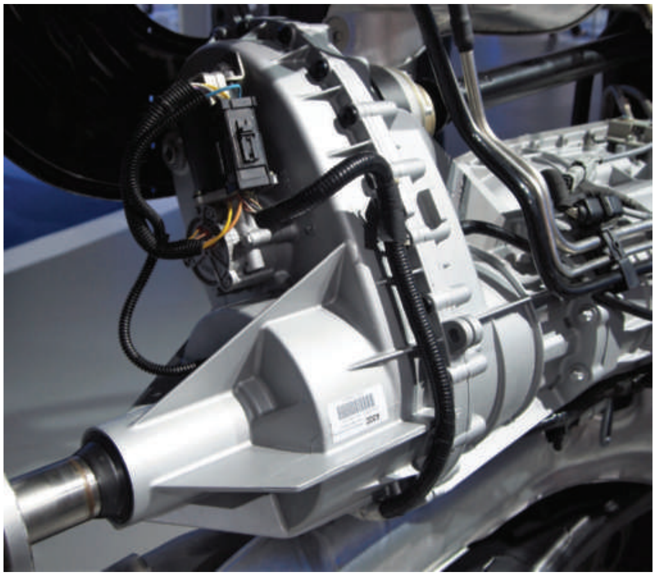


FIGURE 44–24 The transfer case is bolted to the rear of this transmission.

transmission and transfers it to the front and rear axles through two separate drive shafts.

The driveline from the transfer case shafts run to differentials at the front and rear axles. As on two-wheel drive vehicles, these axle differentials are used to compensate for road and driving conditions by adjusting the rpm to opposing wheels. For example, the outer wheel must roll faster than the inner wheel during a turn because it has more ground to cover. To permit this action, the differential cuts back the power delivered to the inner wheel and boosts the amount of power delivered to the outer wheel.

U-joints are used to couple the driveline shafts with the differentials and transfer cases on all these vehicles. U-joints can also be used on some vehicles to connect the rear axle and wheels. Normally, however, rear axles are simply bolted to the wheel hubs.

The coupling between front wheels and axles is normally done with U-joints or CV (constant velocity) joints. Generally, half axles or half shafts with CV joints are found on AWD passenger cars. They can also be found on a number of passenger vans and on mini pickups and trucks.

To provide independent front suspension, some vehicles have one half shaft and one solid axle for the front drive axle **(Figure 44–25)**. The half shaft is able to move independently of the solid axle, thereby giving the vehicle the ride characteristics desired from an independent front suspension.

Transfer Case

In a 4WD vehicle, as mentioned earlier, the transfer case delivers power to both the front and rear assemblies. Two drive shafts normally operate from the transfer case, one to each drive axle.

A transfer case **(Figure 44–26)** is constructed much like a transmission. Some transfer cases rely on a chain and sprockets and others use gears to rotate the driveshaft to the front or rear axle.

It uses shift forks to select the operating mode, plus splines, gears, shims, bearings, and other components found in manual and automatic transmissions. The outer case of the unit is made of cast iron, magnesium, or aluminum. It is filled with lubricant (oil) that cuts friction on all moving parts.

Power Transfer (Takeoff) Units

On AWD systems adapted from front-wheel drive systems, a separate front differential and driveline are not needed. The front wheels are driven by the transaxle differential of the base model. A power transfer (takeoff) unit (PTU) is added to the transaxle to transmit power to the rear wheels in four-wheel drive. This takeoff gearing is housed in or bolted to the transaxle housing **(Figure 44–26)**. It is simply a gearset, driven by the transaxle's final drive, that transfers the output torque at a 90-degree angle and rotates the rear driveshaft at the same speed as the front wheels.

Jeep Compass The current AWD Jeep Compass has electronic controls that decide when to engage the rear axle, via the PTU, by monitoring the outside temperature, wheel speed changes, windshield wiper use, and other inputs. On warm and dry days, the PTU, the rear ring and pinion, and the rear drive shaft are totally disconnected from the engine. When conditions indicate that there is a possibility of wheel spin, a clutch in the rear differential and a toothed dog clutch in the PTU turn on, this sends torque to the rear.

Locking Hubs

A transfer case can only disconnect power to one of the driveshafts, either to the front or rear. Although the driveshafts are disconnected from the engine,

CUSTOMER CARE

It is very important to remind your customers that the fluid level in a transfer case must be checked at recommended time intervals. (Check the owner's manual). Remind them to make sure only the correct fluid is used.

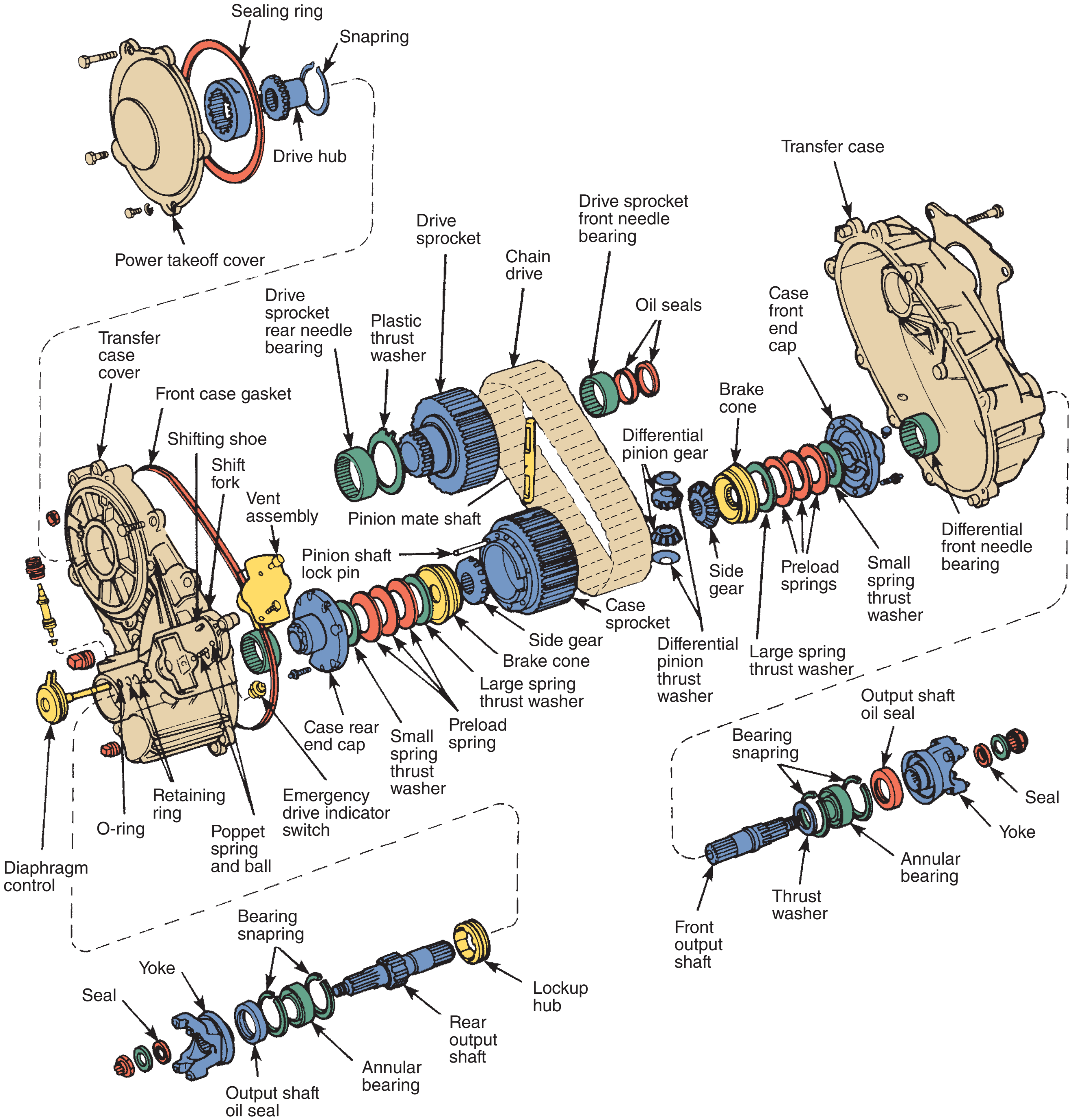


FIGURE 44–25 This transfer case receives the output from the transmission via a chain drive before power is sent to the rear wheels.

the wheels of the disconnected axle will still drive the driveshaft and the gears and axle shafts. This causes unnecessary wear on the system and wastes fuel. Some 4WD vehicles are equipped with wheel hubs that engage or disengage the axle shafts from the engine's power. These hubs can be manually operated gear and ratchet assemblies or automatically switched to lock or unlock the axles power flow.

On some 4WD vehicles, the front axles are engaged by locking wheel hubs. The hubs are designed to stop the rotation of the front axles and differential when 4WD is not selected. **Locking hubs** can be either manual or automatic. Newer systems have automatic hubs that engage when the driver switches into 4WD. Older vehicles had manual hubs that require the driver to turn a knob on the

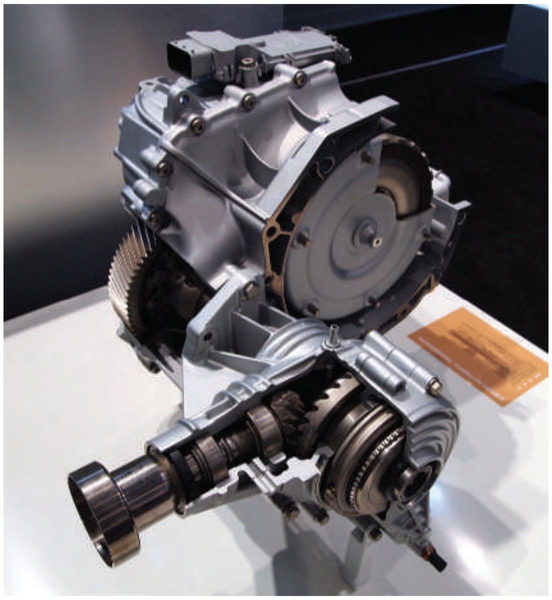


FIGURE 44–26 A PTU bolted to a transaxle.

front wheels. These hubs connect the front wheels to the front drive axles when they are in the locked position.

Manual locking hubs require that a lever or knob be turned by hand to the 2WD or 4WD position **(Figure 44–27)**. Automatic locking hubs can be locked by shifting to 4WD and moving forward slowly **(Figure 44–28)**. They are unlocked by slowly backing up the vehicle. On certain late-model 4WD systems, a front axle lock is used in place of individual locking hubs.

A locking hub is a type of clutch that engages or disengages the outer ends of the front axle shafts from the wheel hub. When the hub is in the locked position, the ring of the clutch is set onto the splines of the axle shaft. When the hub is in the unlocked position, spring pressure forces the clutch ring away from the axle shaft, thereby disconnecting the wheel hub and the axle.

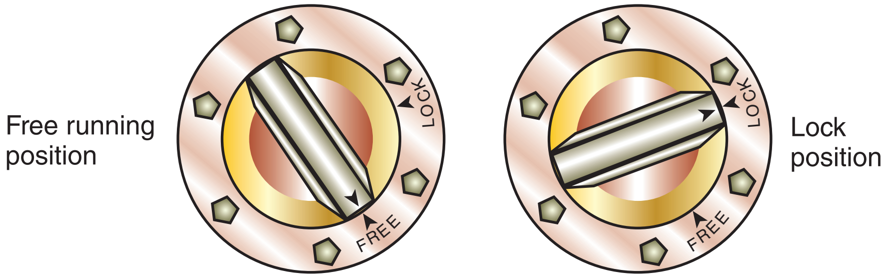


FIGURE 44–27 The knob positions for a manual locking hub.

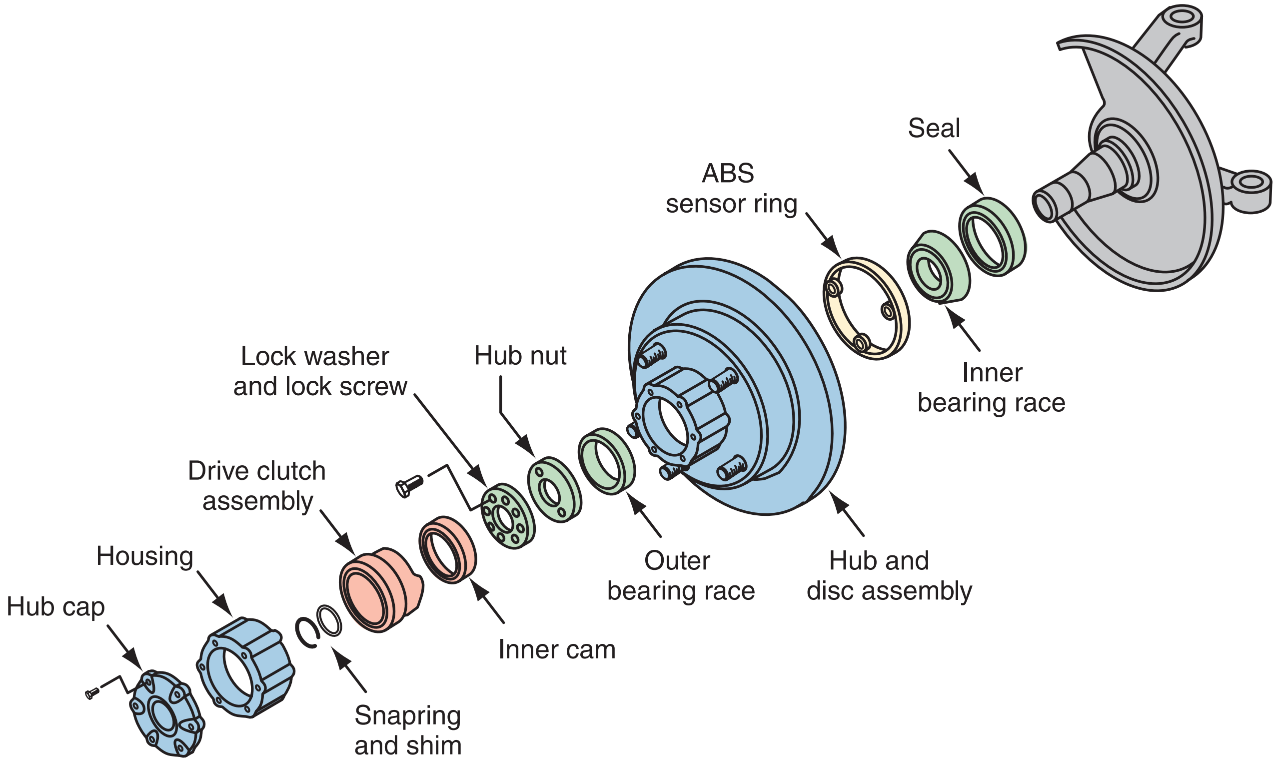


FIGURE 44–28 The parts of an automatic locking front hub.

Although automatic hubs are more convenient for the driver, they do have a disadvantage. Many self-locking hub designs are unlocked when the vehicle is moved in reverse. Therefore, if the vehicle is stuck and needs to back out of the trouble spot, only RWD will be available to move it. Other automatic hubs unlock immediately when 4WD is disengaged without the need to back up. On these systems, the hubs are automatically locked, regardless of the direction the vehicle is moving.

Locking hubs are not needed with full-time AWD. The wheels and hubs are always engaged with the axle shafts. The interaxle differential or transfer case prevents damage and undue wear of the parts of the powertrain.

Interaxle (Center) Differentials

AWD systems require a device that allows the front and rear axles to rotate at different speeds. These units work to eliminate driveline windup. The most common setup has an **interaxle (center) differential (Figure 44–29)**. The front and rear drivelines are connected by a drive shaft to the center differential. Just as a drive axle differential allows for different left and right drive axle shaft speeds, the center differential allows for different front and rear driveline shaft speeds **(Figure 44–30)**.

While the interaxle differential solves the problem of driveline windup during turns, it also lowers performance in poor traction conditions. This is because the interaxle differential will tend to deliver more power to the wheels with the least traction. The result is increased slippage, which is the exact opposite of what is desired.

To counteract this problem, some interaxle differentials are designed much like a limited slip differential. They use a multiple-disc clutch pack to maintain a predetermined amount of torque transfer before the differential action begins to take effect **(Figure 44–31)**.

Electromagnetic systems use an electromagnetic coil to engage a multiplate clutch to transfer torque to the rear axle. If the front wheels are turning faster than the rear, the PCM applies the clutch to drive the rear wheels. Some systems use a Torsen or Haldex unit in the center differential. A Torsen or *tor*que *sen*sing unit is a mechanical differential capable of transferring power from a wheel with little or no traction to the other wheel that has traction. Other systems such as the one shown in Figure 44–22 use a cone braking system rather than a clutch pack, but the end result is the same. Power is supplied to both axles regardless of the traction encountered.

Some systems also give the driver the option of locking the interaxle differential in certain operating

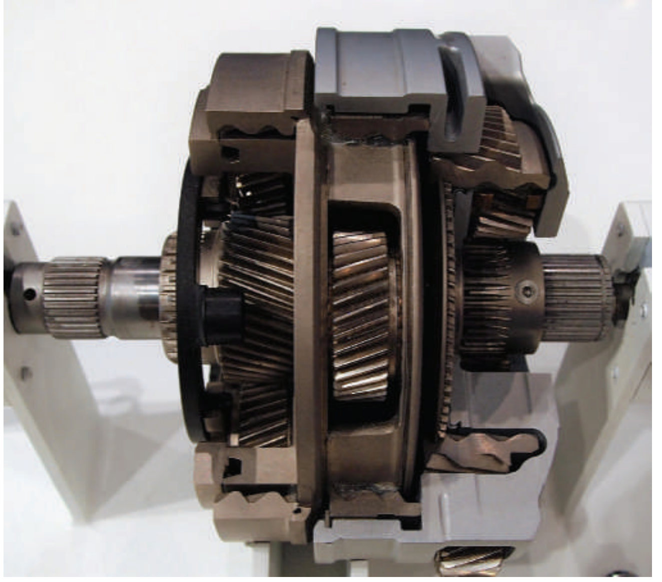


FIGURE 44–29 A center differential.

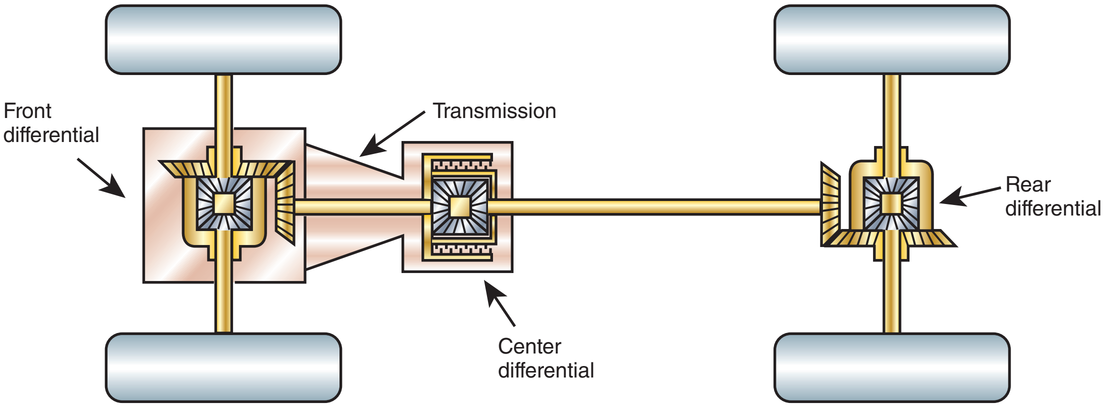


FIGURE 44–30 The center differential allows for different front and rear speeds.

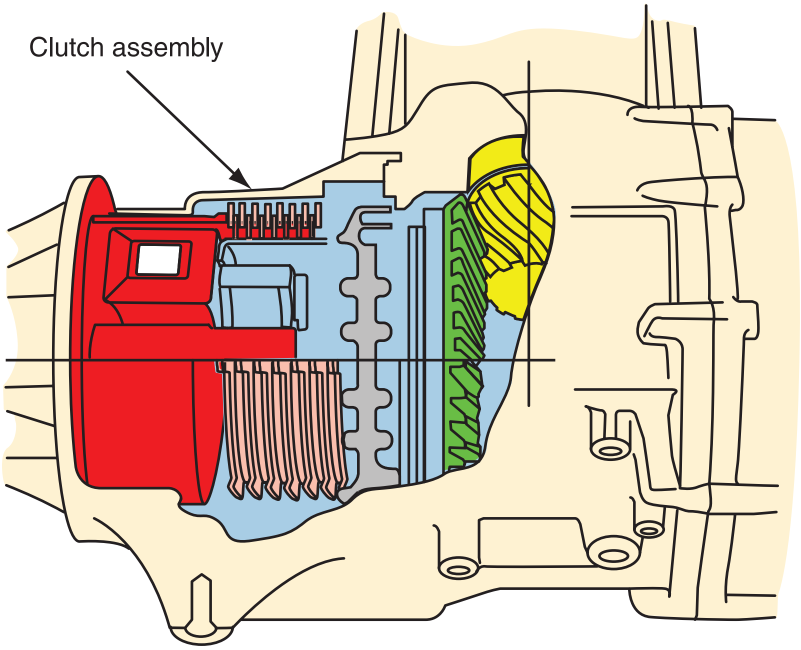


FIGURE 44–31 A mechanical clutch assembly for a center differential.

modes **(Figure 44–32)**. This eliminates the differential action altogether. However, the differential should only be locked while driving in slippery conditions and can only be activated at low speeds.

FIGURE 44–32 The center differential can be controlled by these selectors.

Audi's Quattro System

Early Audi Quattro systems relied on Torsen or viscous clutch center differentials, but newer models use an electronically controlled multiple-disc clutch to route the engine's torque. This new system is called Quattro with Ultra. It is capable of idling the rear axle's ring and pinion gears and driveshaft. Two clutches on the transmission's output shaft and a toothed dog clutch in the rear differential open to disengage the drag-inducing parts, enabling better fuel economy. Several environmental factors are considered by the ECM that controls the operation of this differential, which include outside temperature, yaw rate, steering angle, throttle position, and wheel speed.

Helical Center Differential

Helical center differentials, commonly called Torsen units, use tuned planetary gears with teeth cut in a helical spiral pattern that bind up or push against friction discs to limit wheel spin and alter torque distribution. They increase the torque from the engine to create more friction to enhance the locking action. The locking action is determined by the angle at which the gears are cut, steeper angles produce more locking force. When used as a center

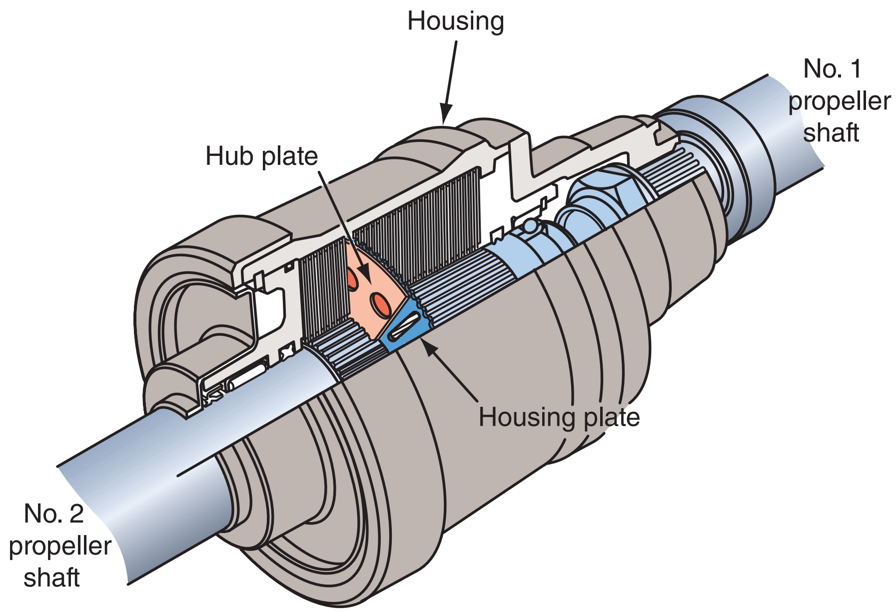


FIGURE 44–33 A viscous clutch is a sealed assembly with disc clutches submerged in a fluid.

differential, helical limited slip differentials are often designed to offer an unequal torque bias—an effect determined by the ratio between the gears to drive the front and rear axles.

Viscous Clutch

Some systems use a viscous clutch in the transfer case, outside the transfer case **(Figure 44–33)**, or as a separate unit to split the power to the front and rear axles. A **viscous clutch** is used to drive the axle with low tractive effort, taking the place of the interaxle differential. In existence for several years, the viscous clutch is installed to improve mobility under difficult driving conditions. Viscous clutches operate automatically while constantly transmitting power to the axle assembly as soon as it becomes necessary to improve driving wheel traction. This action is also known as biasing driving torque to the axle with tractive effort. The viscous clutch assembly is designed similarly to a multiple-disc clutch with alternating driven and driving plates **(Figure 44–34)**. The coupling functions as a speed sensitive limited slip unit.

The viscous clutch pack fits inside a drum that is completely sealed. The clutch pack is made up of alternating steel and friction plates. One set of steel plates is splined internally to the clutch assembly hub. The second set of clutch plates is splined externally to the clutch drum. The clutch housing is filled with a small amount of air and special silicone fluid with the purpose of transmitting force from the driving plates to the driven plates.

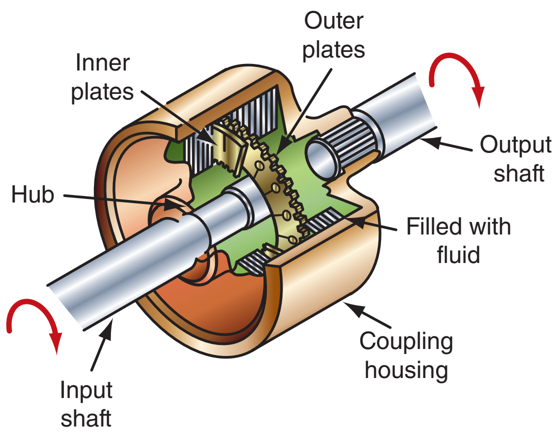


FIGURE 44–34 Inside a typical viscous clutch assembly.

When the front and rear differentials are at the same speed, the clutch pack rotates slowly and little or no torque is transferred through the coupling. As the speed difference increases, so does the amount of transferred torque. When a difference in speed of 8 percent exists between the input shaft driven by the driving axle with tractive effort, the clutch plates begin shearing (cutting) the special silicone fluid. The shearing action causes heat to build within the housing very rapidly, which results in the silicone fluid stiffening. The stiffening action causes a locking action between the clutch plates to take place within approximately 0.10 second. A locking action results from the stiff silicone fluid, making it very hard for the plates to shear. The stiff silicone fluid transfers power from the driving to the driven plates.

The driving shaft is then connected to the driven shaft through the clutch plates and stiff silicone fluid.

During normal driving, the coupling allows enough slippage for the front and rear wheels to travel at different speeds while turning corners. The viscous clutch has a self-regulating control. When the clutch assembly locks up, there is very little, if any, relative movement between the clutch plates. Because there is little relative movement, silicone fluid temperature drops, which reduces pressure within the clutch housing. As speed fluctuates between the driving and driven members, heat increases, causing the silicone fluid to stiffen. Speed differences between the driving and driven members regulate the amount of slip in a viscous clutch driveline. The viscous clutch takes the place of the interaxle differential, biasing driving torque to the normally undriven axle during difficult driving conditions.

Haldex Clutch

Some AWD vehicles are equipped with a **Haldex clutch (Figure 44–35)**, which serves as a center differential. This clutch unit distributes the drive force variably between two axles.

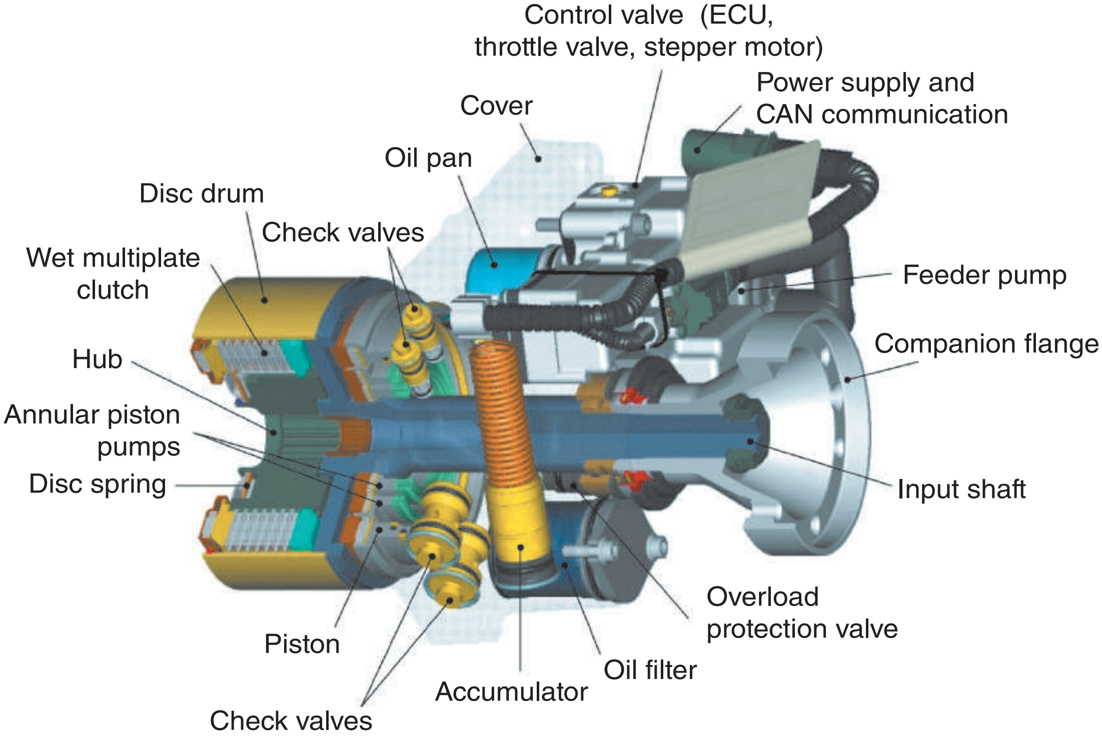
The Haldex unit has three main parts: the hydraulic pump driven by the slip between the axles or wheels, a wet multidisc clutch, and an electronically controlled valve. The unit is much like a hydraulic pump in which the housing and a piston are connected to one shaft and a piston actuator connected to the other **(Figure 44–36)**.

When a front wheel slips, the input shaft to the Haldex unit spins faster than its output shaft. This causes the pump to immediately generate oil flow. The oil flow and pressure engages the multidisc clutch to send power to the rear wheels. This happens extremely quickly because an electric pump and accumulator keep the circuit primed.

The oil from the pump flows to the clutch's piston to compress the clutch pack. The oil returns to the reservoir through a controllable valve, which adjusts the oil pressure and the force on the clutch pack. An electronic control module controls the valve.

In high slip conditions, a high pressure is delivered to the clutch pack. In tight curves or at high speeds, a much lower pressure is provided. When there is no difference in speed between the front and rear axles, the pump does not supply pressure to the clutch pack.

Volkswagen 4MOTION The Volkswagen 4MOTION AWD system uses a Haldex coupling as a center differential. The coupling is mounted in front and is part of the rear axle housing. The input shaft of the Haldex center differential is driven by a drive shaft from the transaxle. In a Haldex, the input shaft is totally separated from the output shaft, which is



Courtesy of Haldex Traction AB.

FIGURE 44–35 A Haldex clutch assembly.

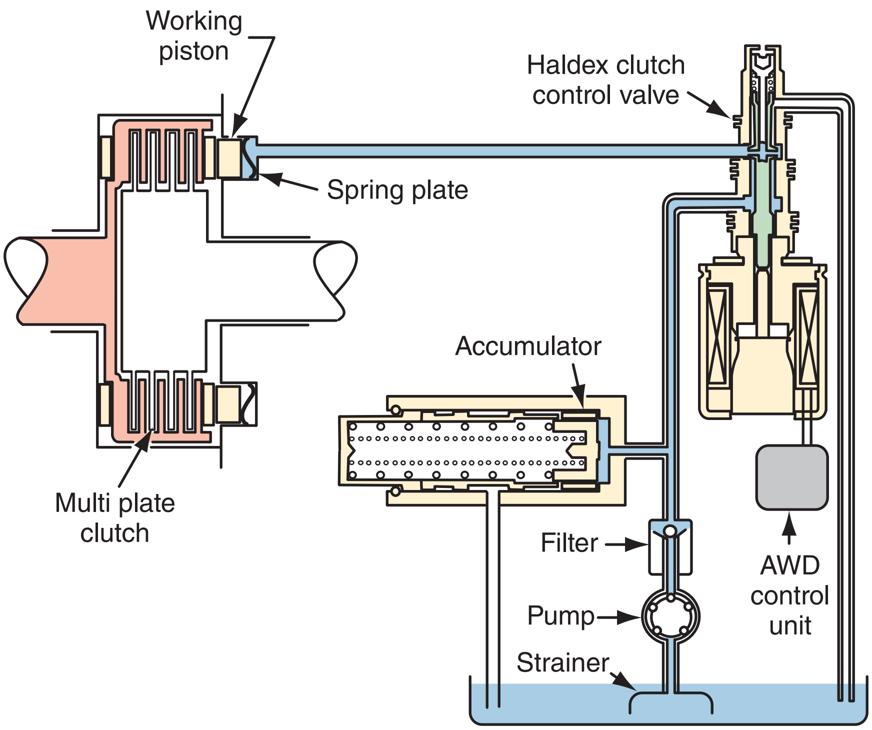


FIGURE 44–36 The hydraulic circuit for a typical Haldex clutch.

connected to the rear final drive gears. Therefore, power is only sent to the rear wheels when the Haldex clutch is engaged.

The Haldex unit is controlled by a PCM that receives inputs from a variety of sensors. This means the system can respond to other driving conditions and not just wheel slip. When there is no slip, understeer, or oversteer, the vehicle operates as a 2WD vehicle. It only distributes power to the rear axle when it is needed.

On-Demand Systems

Many late model SUVs and crossovers are equipped with "on-demand" AWD systems. These systems engage the front and rear axles on an as needed basis. They can also adjust the torque applied to the inner and outer wheel. There are many different designs of on-demand systems; most rely on a center differential to control the flow of torque. Some use an electric motor to power the front wheels and do not need a center differential. Others, such as the Toyota RAV4 Hybrid, have a motor that powers the rear wheels. The following are a few of the basic systems found on today's vehicles.

On-Demand Coupling On-demand systems primarily drive only one axle until the coupling engages the opposite side axle. It will gradually engage the axle as needed. Most of these systems rely on clutch packs or a tooth coupling called a dog gear. A clutch pack coupling increases the torque routed to the opposite axle by increasing the clamping force on the friction discs. The systems return to 2WD when there is no need for AWD. On-demand coupling systems are desirable because they can be programed to send torque to the opposite axle before it is actually need. Of course this action is based on the inputs from a variety of sensors.

On-Demand Twin Rear-Axle Couplings These systems are based on earlier systems that have a dedicated clutch for the left and right rear axles. The rear drive axle assembly has ring and pinion gears but does not have differential gearing. When the clutches are fully engaged, the system works like a typical 4WD system. With this system, torque-vectoring is easily achieved by changing one axle ratio. The Ford Focus RS uses this system, and the car has a rear wheel torque bias, which gives a considerable power push from the rear wheels. Whenever the rear clutch pack is engaged, the rear wheels receive more torque and try to rotate faster than the front wheels.

2017 Ford Focus RS This little hot rod from Ford has a 350 hp 2.3 liter turbocharged four-cylinder with 350 lb-ft of torque. Since the Focus is basically a FWD vehicle and that amount of power would probably shred its front tires, Ford developed a

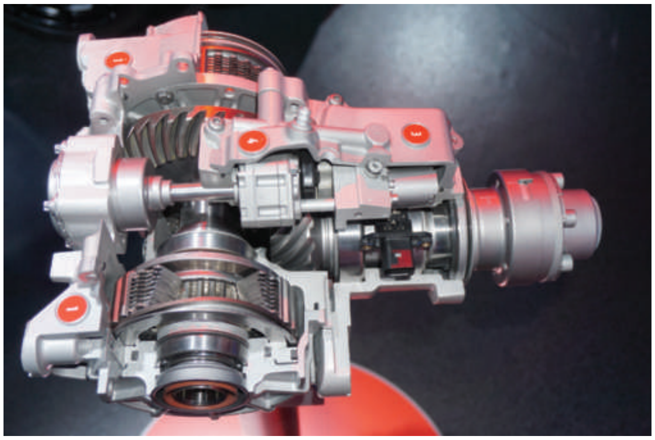


FIGURE 44-37 The Focus RS rear differential.

unique AWD system that can send up to 70 percent of the engine's torque to the rear wheels. This system utilizes a "Torque Vectoring Rear Drive Module" **(Figure 44–37)**, which consists of a differential and two clutches. These serve as rear axle couplings. The module can send all, some or none of the engine's torque to the left or right rear wheel. A computer calculates, based on a variety of inputs, how to limit wheel spin. It also helps the car by offering some differential action.

Active Twin Clutch AWD The GMC Arcadia with the All-Terrain package uses an active twin clutch AWD system. This system relies on a pair of electronically controlled clutches in place of the rear differential **(Figure 44–38)**. The system can partially or fully engage each rear wheel independently to maximize traction on slippery surfaces. It cannot overdrive the rear wheels, but it can deliver all of the rear axle's torque to the wheel with the traction.

Electronically Controlled Limited Slip Center Differential These units use electric and/or hydraulic actuators to engage a clutch that limits slip between the front and rear axles. They also have the ability to work independent of engine torque or friction at the wheels. Using inputs from a sensors and computer controls, these units offer a full range of operation from fully open to fully locked according to the needs. The systems can also be programed to predict when more slip is needed to prevent wheel slip before it occurs.

Torque Vectoring

Recently AWD vehicles have been equipped with electronically controlled torque vectoring systems. These are advanced traction and stability controls. They are capable of transferring torque, not only from front to rear, but also from side to side **(Figure 44–39)**. The benefits of these systems include improved overall handling, excellent cornering performance, and improved vehicle stability and safety.

A basic torque vectoring system can vary the torque between the front and rear wheels, in response to conditions. The system also monitors each wheel independently and will increase or decrease the amount of torque sent to each. To improve cornering, the system will automatically add torque to the outside rear wheel to allow the vehicle to turn quicker.

Through the vehicle's CAN system, the system monitors vehicle speed, individual wheel speeds, operating gear, braking force, steering angle, yaw rate, and other inputs.

Some AWD systems rely on a passive system in which the differential mechanically reacts to conditions to provide stability. Other current AWD systems

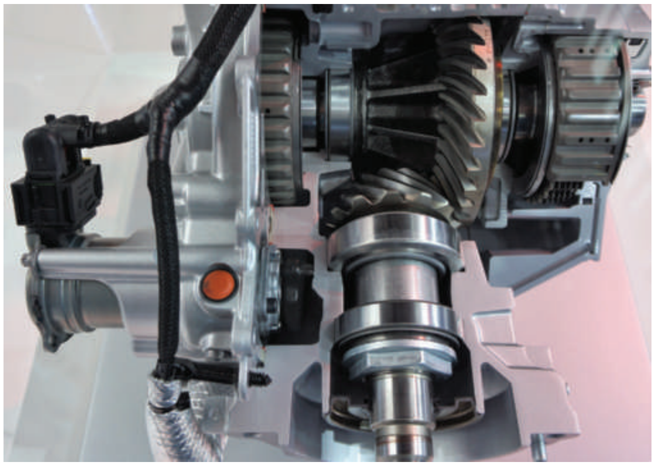


FIGURE 44-38 An electronically controlled rear differential.

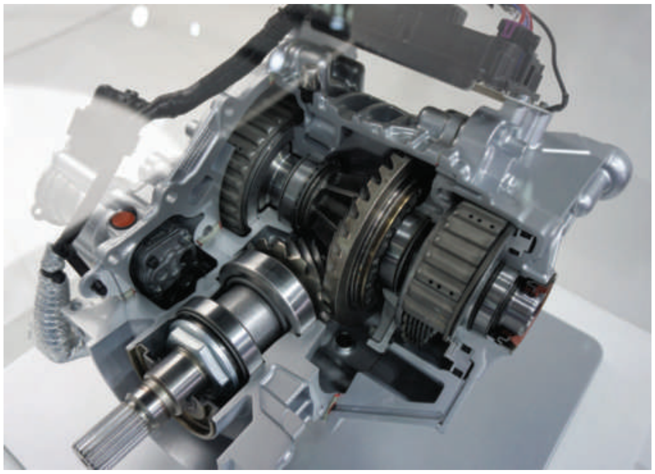


FIGURE 44-39 The Cadillac torque vectoring rear differential.

control wheel slip and stability by braking the wheel with little or no traction or by reducing the power from the engine. These are referred to as active brake systems. An AWD system with two open differentials, on very slippery surfaces, can get stuck as all the torque goes to the spinning tire. By applying the brake of the spinning tire, the system "locks" the differential, allowing torque to transfer to the opposite tire. True torque vectoring is achieved with special differentials that distribute power to the wheel or wheels that have traction; these are called active differential systems. Basic and true torque vectoring differentials can be found on some FWD vehicles.

GO TO Chapter 53 for more information on traction and stability control systems.

Active Differential Systems

Honda's Super Handling All-Wheel Drive (SH-AWD) is a full-time, fully automatic AWD traction and handling system with an active rear differential. The system does not have a center differential or a limited-slip differential at either axle.

The active differential is in the rear axle. It relies on planetary gears to increase the rotation speed, creating a speed difference between the input and output, and two electromagnetic clutches to transfer driving torque to the rear axles **(Figure 44–40)**. Each clutch is tied to an individual drive wheel and is electronically controlled. The system monitors many inputs that are available on the CAN bus to automatically add torque to the wheel with the most traction and the outside rear wheel during corners. Before the clutches are activated, wheel slip must be detected.

The system, which normally distributes torque 90 percent up front and 10 percent in the rear, can respond to conditions by allowing for a 50/50 split during acceleration or hard cornering. The system can then send some or all of that 50 percent going to the rear axle directly to the outside tire to make the vehicle bend into a corner more sharply.

Torque Vectoring Systems by ZF Late-model Audi Quattros and AWD BMWs are equipped with torque vectoring systems from ZF or Ricardo. Both of these systems are similar and rely on an active differential. These torque vectoring systems use wet clutches and planetary gearsets, in the front, center, and/or rear differentials **(Figure 44–41)**. They are controlled by electrical, electro-mechanical or electro-hydraulic systems.

One difference between the Audi system and BMW's is that Audi uses a wet clutch in the center differential that is mechanically controlled by the worm gears in its Torsen or crown gear differential. The rear differential has planetary gears connected to each drive axle that are controlled by motor-operated clutches to provide a difference in drive wheels'

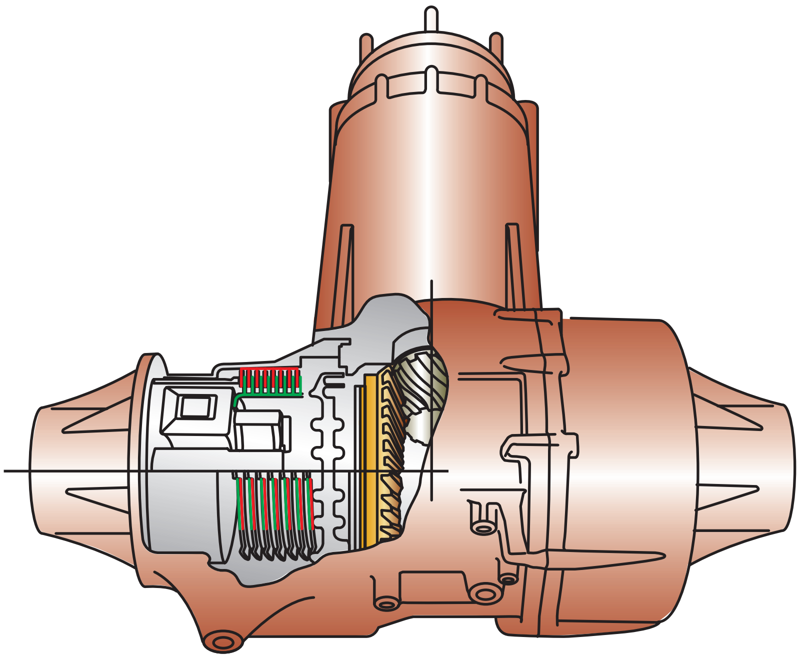
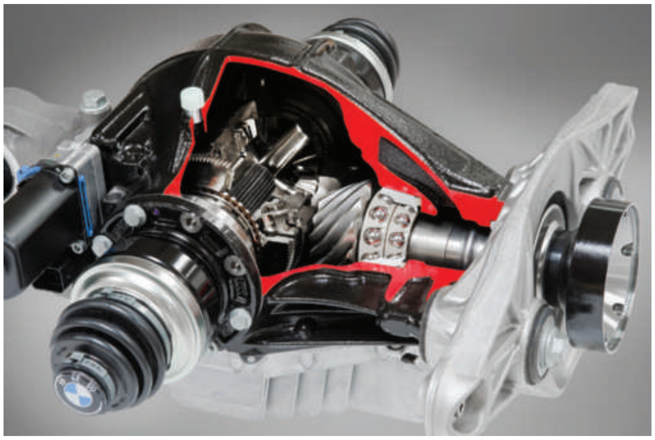


FIGURE 44–40 The differential and rear axle assembly for a Honda with SH-AWD.



Courtesy of BMW of North America, LLC.

FIGURE 44–41 The rear differential used with BMW's Active torque vectoring system.

rotational speed. Normally the front differential is open to allow for normal steering. The PCM controls the operation of the center and rear clutches of both systems. The system is tied to the stability control system, the active steering system, and the ABS. It helps steer the vehicle by sending torque to either of the rear wheels, which not only prevents wheel slip but also eliminates oversteer and understeer. When the possibility of understeer is detected, power to the front wheels is reduced. When oversteering is detected, more power is sent to the front wheels.

The systems are also designed to anticipate slippage by monitoring many inputs on the CAN bus and can provide yaw torque when the vehicle is cornering. The yaw torque forces the outside rear wheel to push forward while the inside rear wheel pulls back a bit. This is done by slightly altering the torque at the rear wheels. The overall effect is the same as the rear steering option offered on some vehicles.

Mitsubishi S-AWC Mitsubishi's Super All Wheel Control (S-AWC) is a full-time AWD system used in the Lancer Evolution. The system is integrated with the vehicle's active center differential (ACD), active yaw control (AYC), active stability control (ASC), and sports ABS components. This provides for regulation of torque and braking force at each wheel. The system is best described as an active differential (center and rear) with active braking at all wheels.

The ACD is an electronically controlled hydraulic multiplate clutch that limits the action of the center differential gears. The ACD regulates the torque split between the front and rear drive axles. The AYC acts like a limited slip differential by reducing rear-wheel slip to improve traction. It controls rear-wheel torque to limit the yaw of the vehicle to improve the vehicle's cornering performance. The ASC regulates engine power and the braking force at each wheel. This system improves vehicle stability and improves traction during acceleration. The system relies on two ECUs: one controls the ACD and AYC and the other controls ASC and ABS. The ECUs communicate to each other via the CAN bus.

Passive AWD Control Systems

Audi AWD vehicles carry the designation of "Quattro." Their basic system has evolved through the years. The early systems relied on Torsen-type differentials in the center and rear differentials. These systems are capable of varying the torque sent to any wheel of the vehicle. As time moved on, the basic system gained more electronic controls and is currently using a torque vectoring system by ZF.

Audi's Quattro permanent all-wheel drive system transfers torque from the front to the rear and side-to-side, as needed. The center differential compensates for the speed differences between the front and rear axles and distributes engine power between the front and rear wheels. The system automatically regulates the distribution of power within milliseconds. This action is based on engine speed and torque, wheel spreads, and longitudinal and lateral acceleration rates.

AWD Control Braking Systems

The Mercedes-Benz Torque Vectoring Brake system can apply braking to only the inside rear wheel during cornering. If the system detects understeer, it generates a quick burst of yaw torque. This allows the driver to have more control of the steering and the car can go through the corner with improved control.

This active brake torque vectoring system is integrated with Mercedes' stability control system and is always engaged. At the slightest hint of wheel slip, the system begins to brake that wheel or starts to decrease power to it.

Porsche Torque Vectoring (PTV) Although there are many AWD variations available, the 911 is unique in that it is rear-wheel drive with the engine mounted to the rear as well. A special assembly is used to transfer power from the rear to the front axle **(Figure 44–42)**. Torque vectoring is not currently available for the front and rear wheels.

The PTV system is a rear-wheel only active braking system first used in the 2010 Porsche 911 Turbo. The PTV can apply the brakes individually to stabilize and improve traction while the car is making a turn. The system relies on CAN inputs, such as steering

FIGURE 44–42 This Mitsubishi EVO is equipped with the S-AWC torque vectoring system.

angle, vehicle speed, throttle position, and yaw rate. PTV applies the brake on the inside rear wheel to minimize understeer while entering corners.

FWD Torque Vectoring

Ford introduced torque vectoring in its 2012 FWD Focus. Basically this torque vectoring system works like an electronic limited slip differential. The system relies on inputs from various sensors to apply an appropriate amount of brake force to the wheel with the least amount of traction.

Diagnosing 4WD and AWD Systems

Current 4WD and AWD systems are controlled by the PCM or a separate control module. Like all computer-monitored and computer-controlled systems, faults have to be identified by DTCs **(Figure 44–43).**

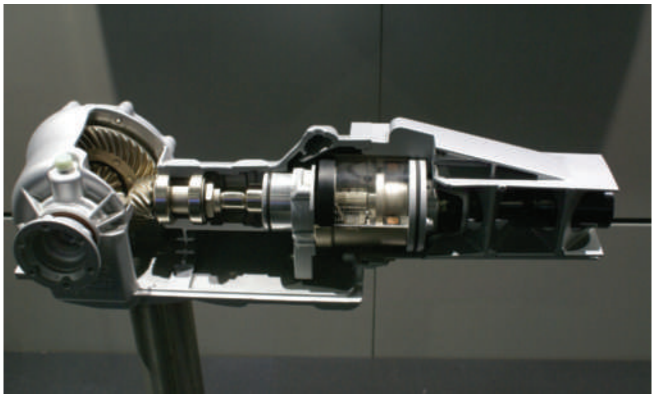


FIGURE 44–43 The assembly used to transfer engine power from the rear to the front axle in a Porsche 911.

PROCEDURE

To diagnose late-model 4WD systems, follow these steps:

STEP 1 Verify the customer's complaint.

STEP 2 Visually inspect for obvious signs of mechanical or electrical damage. Check the condition of the following (some systems will not have all of these):

- Half shafts
- Locking hubs
- Drive shaft and U-joints
- Shift lever and/or linkage
- Mode switch
- Shift motor
- Electromagnetic clutch
- Vacuum and fluid lines
- Axle disconnect units
- Matching tire sizes
- Transfer case
- Transfer case linkages
- System fuses
- Wiring harnesses and connectors

STEP 3 If the cause was not visually evident, connect the scan tool to the DLC.

STEP 4 Note the DTCs retrieved.

STEP 5 Clear the DTCs.

STEP 6 Conduct the self-test for the 4WD control module.

STEP 7 If the DTCs retrieved are related to the concern, interpret the codes and follow the specific pinpoint tests for those codes **(Figure 44–44)**.

STEP 8 If the DTCs are not related to the concern or there are no DTCs, go to the manufacturer's symptom chart **(Figure 44–45)**.

STEP 9 Identify and repair the cause of the problem.

STEP 10 Verify the repair.

Basic System Diagnosis

Computer-controlled 4WD systems are diagnosed just like other computer-controlled systems. Make sure the scan tool can communicate with the vehicle by completing the test provided by the scan tool. If

DTC	DESCRIPTION
B1317	Battery Voltage High
B1318	Battery Voltage Low
C1979	IWE Solenoid Circuit Failure
C1980	IWE Solenoid Short to Battery
P1812	4-Wheel Drive Mode Select Circuit Failure
P1815	4-Wheel Drive Mode Select Short Circuit to Ground
P1820	Transfer Case Clockwise Shift Relay Coil Circuit Failure
P1822	Transfer Case Clockwise Shift Relay Coil Short Circuit to Battery
P1824	4-Wheel Drive Clutch Relay Circuit Failure
P1828	Transfer Case Counter Clockwise Shift Relay Coil Circuit Failure
P1849	Transmission Transfer Case Contact Plate A Short Circuit to Ground
P1853	Transmission Transfer Case Contact Plate B Short Circuit to Ground
P1857	Transmission Transfer Case Contact Plate C Short Circuit to Ground
P1861	Transmission Transfer Case Contact Plate D Short Circuit to Ground
P1867	Transmission Transfer Case Contact Plate General Circuit Failure
P1891	Transmission Transfer Case Contact Plate Ground Return Open Circuit
U1900	CAN Communication BUS Fault—Received Error
U2051	One or More Calibration Files Missing/Corrupt

FIGURE 44–44 4WD DTC Chart.

the system has a separate self-diagnostic routine for the 4WD system, run that and then retrieve and record all DTCs. Always follow the procedures outlined by the manufacturer when connecting a scan tool to the system. Also always use the manufacturer's information when interpreting data.

Component Testing Individual inputs should be tested according to the procedures recommended by the manufacturer. The speed sensors are typically Hall-effect or magnetic pulse units. These are best checked with a scan tool or lab scope. Often, the manufacturer will recommend testing the sensors with a voltmeter or ohmmeter. Normally, these tests involve taking readings across a multiple-pin connector and at specific terminals.

The selector switch can be checked by connecting an ohmmeter across the terminals of the switch. As the switch is moved to various positions, the circuit through the switch should be either open or closed depending on the position. By referring to the wiring diagram, you can easily identify what should happen in the different switch positions. If the switch does not function as it should, it must be replaced.

When the transfer case shift motor is suspected as being faulty, begin diagnosis with a careful inspection. Then follow the manufacturer's procedures for testing it. Often, testing involves checking the motor for opens, shorts, and high resistance. If the motor is found to be defective, it must be replaced. Where placing the motor, make sure it is mounted correctly and its retaining bolts are tightened to specifications.

If the system uses a magnetic clutch, it can be checked with an ohmmeter. Noise from the clutch can be caused by a faulty clutch or a clutch that needs adjustment.

Shift-on-the-Fly Systems Shift-on-the-fly systems switch between 2WD and AWD electrically by a switch on the instrument panel. Many of these systems use electrically controlled vacuum motors to connect and disconnect the wheels from the axle or an electrical motor or electromagnetic clutch at the transfer case to transfer power to the additional axle. The 4WD indicator light will illuminate when 4WD is engaged. If there is a problem with the system or if 4WD cannot be engaged, the indicator lamp will blink to notify the driver of a problem. Diagnosis begins with watching the frequency of the blinking lamp. Check the service information for an interpretation of the blinking lamp.

If the vehicle will not engage in 4WD, there may be a faulty transfer case actuator motor or faulty vacuum solenoid assembly. If the motor in the transfer case is a possible cause, remove it and check its operation **(Figure 44–46)**. Check the transfer case and repair or replace any faulty components if the motor is not the cause of the problem. If no problem is found in the transfer case, it is likely that the electronic control unit is faulty.

Check for engine vacuum at the actuator and/or solenoid before checking anything else if the vacuum actuator is suspect. If no vacuum is present when the engine is running, check the transfer position switch. A voltage signal should be sent to the

Condition	Possible Cause
No communication with the control module (PCM)	Scan tool Data link connector (DLC) Control module (PCM) Circuitry
The 4WD indicators do not operate correctly or do not operate	Indicator lamp Circuitry Control module (PCM) Ignition switch
The vehicle does not shift between modes correctly	Mode select switch Transfer case Transfer case clutch Control module (PCM) Circuitry Locking hubs Ignition switch Transfer case shift lever Mode indication switch Ignition switch
4WD does not engage correctly at speed	Transfer case clutch coil Control module (PCM) Locking hubs Ignition switch
The front axle does not engage or disengage correctly or makes noise in 2WD under heavy throttle	Mode select switch Locking hubs Vacuum leaks Control module (PCM) Front half shaft Ignition switch
The transfer case jumps out of gear	Transfer case Vacuum solenoid vent Mode select switch Transfer case Shift lever
Driveline wind-up while moving straight	Tire inflation pressure Tire and wheel size Tire wear Axle ratio
Grinding noise during 4WD engagement, especially at high speeds	The front half shafts are not turning at the same speed
Flashing 4WD indicators	Loss of CAN communication between 4WD control module and instrument cluster Loss of high-speed (HS-CAN) communication between 4WD control module and PCM Ignition switch
The transfer case makes noise	Tire inflation pressure Unmatched tire and wheel size Tire tread wear Internal components Fluid level
The vehicle binds in turns, resists turning, or pulsates or shudders while moving straight	Unmatched tire sizes Unequal amounts of tire wear Unequal tire inflation pressures Unmatched front and rear axle ratios

FIGURE 44–45 A typical symptom chart.

FIGURE 44–46 A front differential locking motor.

vacuum solenoid when 4WD is selected. If no signal is being sent, then the switch or switch circuit is faulty. However, if the solenoid is receiving a voltage signal, suspect a faulty solenoid assembly.

Check the vacuum circuit for leaks if there are no electrical problems. Vacuum solenoids can be checked by connecting jumper leads from the battery to the terminals of the solenoid. Remove the vacuum solenoids and connect the battery to the terminals of each solenoid. Connect a hand-held vacuum pump to the inlet port of the solenoid and a vacuum gauge to the port for axle engagement. With the battery connected to the solenoid, there should be vacuum at the outlet port to the axle. Move the vacuum gauge to the other outlet port. Vacuum should not be present there. Now disconnect the battery from the solenoid. Recheck the vacuum at the outlet ports. A good solenoid will have vacuum only at the disengagement port when vacuum is applied and the solenoid is not connected to the battery.

On-Demand Systems On-demand systems operate at the discretion of the PCM or override controls selected by the driver. The division of power between the front and rear axles is controlled by the output clutch at the transfer case. The activity of the clutch is controlled by regulating its duty cycle. During normal operation, the duty cycle is low. This allows for a slight speed difference between the front and rear drive shafts, which normally occurs when the vehicle is moving through a curve. When slip is detected at the rear wheels, the duty cycle to the clutch is increased until the difference between the front and rear drive axles is reduced.

To vary the torque split, a computer monitors many things, especially the rotational speeds of the front and rear drive axles. Some systems rely on wheel-speed sensors for this, whereas others have additional speed sensors on the front and rear output shafts from the transfer case. Many of the inputs to the electronic module for 4WD are shared and work with other systems, and they are available on CAN **(Figure 44–47)**. The best place to start when diagnosing these systems is the service information. Go to the section on the system and identify the components involved in the various modes of operation.

AWD Systems Most AWD systems have a viscous coupling. A viscous coupling can be checked with a torque bias test. This check measures the torque required to rotate one front wheel when it is raised off the ground while the others are on the ground. The transfer case should be in 4WD and the transmission in neutral; compare the measured torque to specifications. A worn coupling is indicated by low readings.

Problems with AWD systems normally occur with the controls that provide for braking efficiency and AWD in reverse gear. Some systems use a vacuum solenoid setup to provide AWD in reverse. The

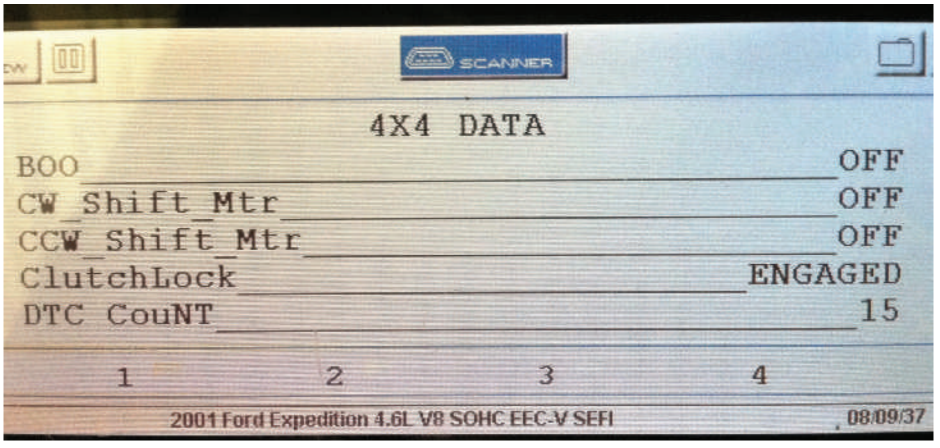


FIGURE 44–47 Scan data for a 4WD system.

solenoids are used to bypass the overrunning clutch. If AWD is not available in reverse gear, suspect the vacuum solenoids, their controls, or the dog-clutch assembly.

An overrunning clutch is used to prevent any feedback of front-wheel braking torque to the rear wheels. This allows the brake system to control braking as if it were a 2WD vehicle. The controls for this feature vary with the manufacturer, and you should always follow the troubleshooting charts provided by the manufacturer.

Axle Hub Diagnosis

Front hubs may make a ratcheting sound when water or dirt has entered the hub and contaminated the lubricant. This prevents free movement of the components in the hub. A ratcheting sound from an automatic locking hub may indicate that the hub on the opposite side of the axle is not disengaging.

Locking hubs can be quickly checked by rotating the brake drum or rotor slightly and turning the hub selector into the lock position. A click should be heard when the hub engages the axle, and the axle should now turn with the hub. Next, with the hub still turning, turn the selector to the free position. The axle should now be free of the hub. If both of these events do not happen, the hub assembly needs to be repaired or replaced.

Hubs can also be checked by raising the front wheels and spinning the front tires. Next, engage 4WD and spin the tire. If the hub is locked, both the tire and the axle will spin. Release 4WD and spin the tire again to make sure the hub releases. If the hub does not lock or stays locked, the hub needs to be serviced or replaced.

Wheel Bearings

To check the adjustment of the wheel bearings, raise the front of the vehicle. Grasp each front tire at the front and rear and push the wheel inward and outward. If any free play is noticed between the hub, rotor, and front spindle, adjust the wheel bearings.

Older vehicles with serviceable wheel bearings should be disassembled and serviced as part of normal maintenance **(Figure 44–48)** or any time the hubs have been submerged in water. During normal operation the bearings get warm and when they are quickly cooled off by the splash of water, their lubricant breaks down and the bearings can be destroyed. Always replace the bearings if they are worn or damaged.

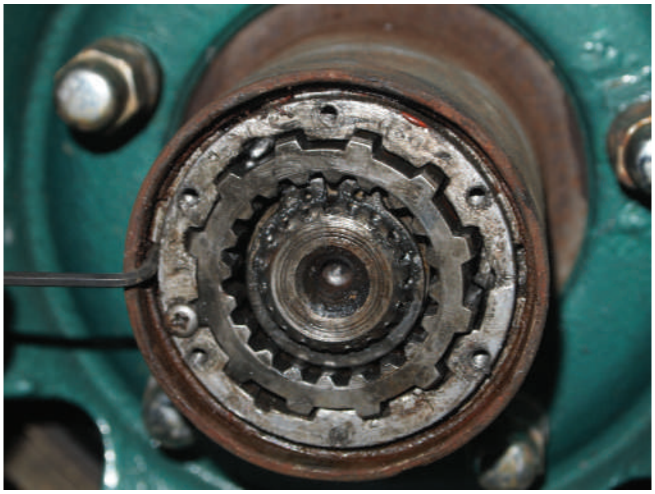


FIGURE 44–48 A manual locking hub wheel bearing retainer.

Another frequent cause of wheel bearing failure is the use of oversized tires mounted on wheels with substantial offset. These switch the load from the large inner bearing to the small outer wheel bearing, which was never intended to do much more than stabilize the wheel.

Servicing 4WD Vehicles

The components of 4WD vehicles are serviced in basically the same way as the same parts of a 2WD vehicle. Also it is important that the U-joints, slip joints, or CV joints in the drivetrain be lubed on a regular basis. To service the drive shafts and U-joints on a 4WD vehicle, use the general instructions given for a cross U-joint. A four-wheel-drive simply uses two drive shafts instead of one.

Maintenance

It is also important to make sure the transfer case and differentials have the correct fluid and are filled to the correct level. To check the differential fluid, locate the plug. Most manufacturers require the use of either a $^3/_8$ inch drive ratchet or a wrench to remove the plug **(Figure 44–49)**. Be careful not to damage it or its threads. The fluid level should be up to the bottom of the fill plug hole. If fluid is needed, refer to the owner's manual or service information for the correct lubricant.

Some AWD vehicles, like the Pilot and CR-V from Honda, require special lubricants for the viscous clutches and require the fluid to be replaced per the maintenance schedule. Failure to maintain the fluid can result in noise and damage to the clutch. Make

FIGURE 44-49 The fluid plugs on a transfer case.

sure your customers who own these types of vehicles are familiar with the special maintenance needs so services can be performed before a problem arises.

Most transfer cases and PTUs have a plug in the side of the case for checking the oil level. The oil should be at the bottom of this opening. Some transfer cases use ATF and others use gear oil; always use the recommended oil.

4WD and AWD Tires

Because 4WD and AWD vehicles can direct torque to the front and rear and side-to-side tires, maintaining proper rolling circumference of the tires is critical. Most manufacturers recommend tire circumference be maintained within ¼ to ½ inch of each other. If the difference in tire circumference is excessive, the speed differences may result in the 4WD or AWD system attempting to manage torque and traction all the time. This could result in rapid wear and damage to viscous clutches and other components.

In the event the owner of a 4WD or AWD vehicle has a tire blow out, replacing all four tires may be the only way to maintain the correct tire circumferences. Replacing one tire while leaving the remaining three worn may cause enough of variation in rotational speeds to affect the 4WD or AWD system. And, depending on the system, even replacing both tires on one axle while leaving the other two old tires installed on the other axle may cause problems.

GO TO Chapter 40 for a detailed look at servicing joints and drive shafts.

Servicing the Transfer Case

Be sure to check the manufacturer's service information for specific transfer case repair and overhaul procedures. It gives details for the particular make and model of transfer case to be worked on.

To remove the transfer case, raise and support the vehicle. Remove any skid plates and brace rods that block access to the transfer case or that are attached to it. Disconnect and remove all drive shaft assemblies. Be sure to mark the parts and their relative positions on their yokes so that the proper driveline balance can be maintained when reassembled. Disconnect the linkage to the transfer case shift lever. Also, disconnect all wires connected to the transfer case. Support the transfer case using a transmission jack and remove the fasteners that secure it to the transmission. Slide the transfer case off the rear of the transmission and remove it from the vehicle.

Once the transfer case has been removed from the vehicle and safely supported, inspect it for signs of oil leaks. Remove the case cover and then carefully loosen and drive out the pins that hold the shift forks in place. Remove the front output shafts and chain drive or gearsets from the case. Keep in mind that some cases use chain drives, whereas others use spur or helical cut gearsets to transfer torque from the transaxle or transmission to the output shafts. Planetary gearsets provide the necessary gear reductions in some transfer cases. Photo Sequence 39 shows the procedure for disassembling a Warner 13-56 transfer case, which is a commonly used unit.

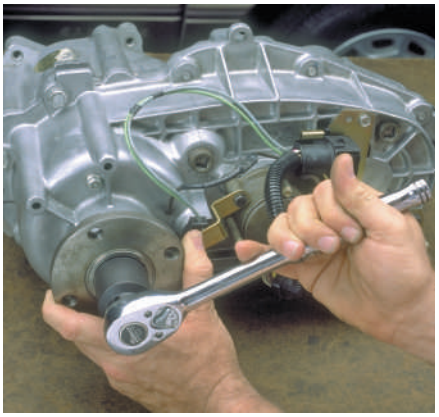
Clean and carefully inspect all parts for damage and wear. Check the slack in the chain drive according to the procedure given in the service manual. Replace any defective parts. It may be necessary to measure the shaft assembly end play. If excessive, new snaprings and shims may be used to correct the situation.

When reassembling the transfer case, the procedure is essentially the reverse of the removal. Be sure to use new gaskets between the covers when reassembling the unit. Photo Sequence 40 shows the procedure for reassembling a Warner 13-56 transfer case.

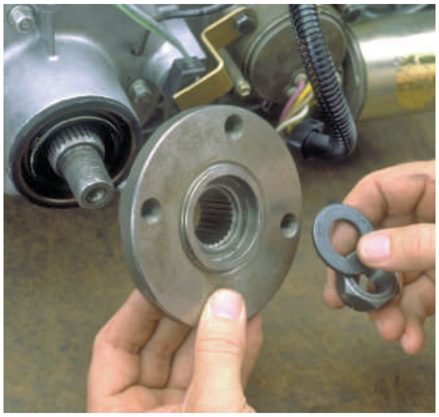
Caution! When removing and working on a transfer case, be sure to support it on a transmission jack or safety stands. The unit is heavy and, if dropped, could cause part damage and personal injury.

PHOTO SEQUENCE 39

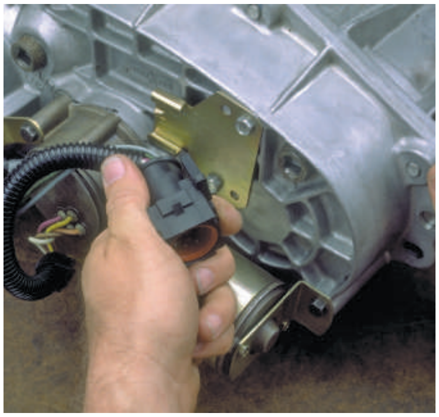
Typical Procedure for Disassembling a Warner 13-56 Transfer Case



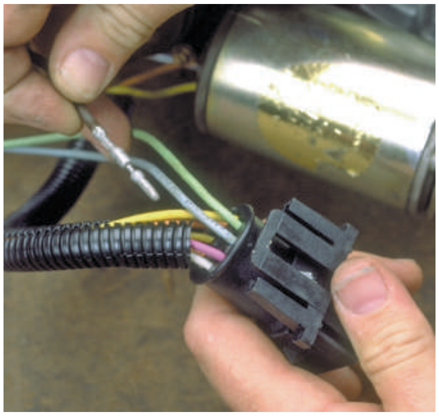
P39-1 If not previously drained, remove the drain plug and allow the oil to drain, then reinstall the plug. Loosen the flange nuts.



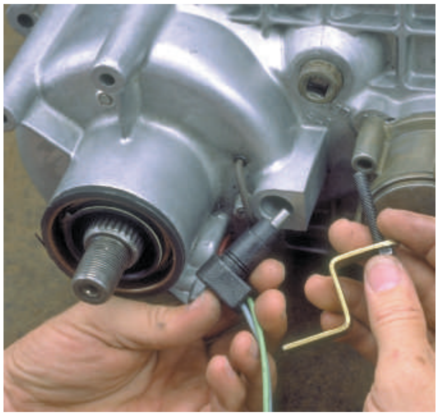
P39-2 Remove two output shaft yoke nuts, washers, rubber seals, and output yokes from the case.



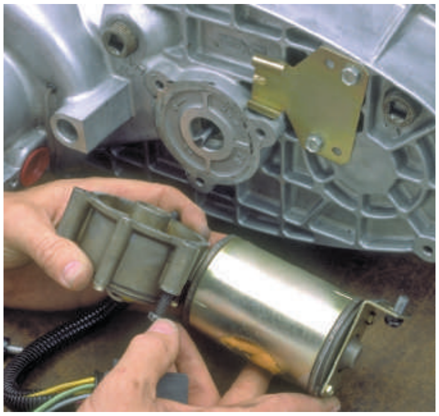
P39-3 Remove the four-wheel-drive indicator switch from the cover.



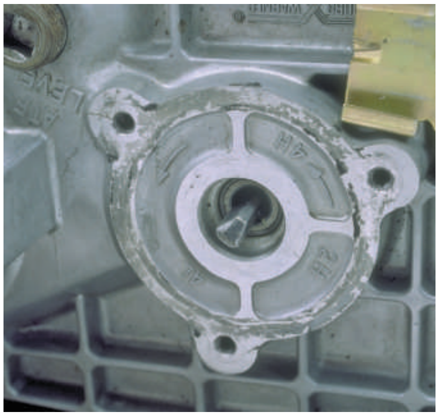
P39-4 Remove the wires from the electronic shift harness connector. Record the exact location of each disconnected wire.



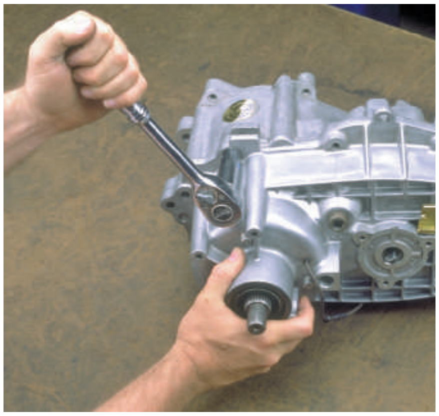
P39-5 Remove the speed sensor retaining bracket screw, bracket, and sensor.



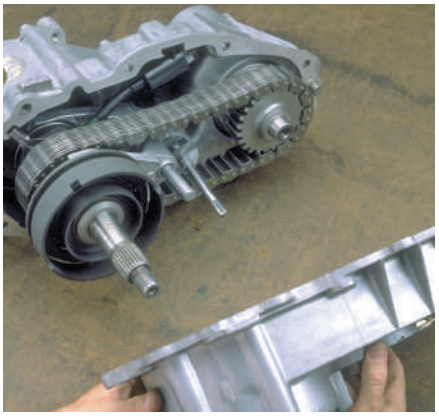
P39-6 Remove the bolts securing the electric shift motor and remove the motor.



P39-7 Note the location of the triangular shaft in the case and the triangular slot in the electric motor.

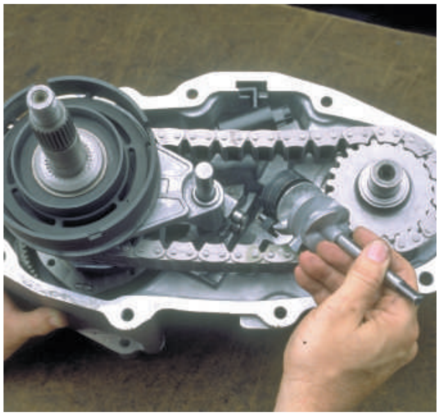


P39-8 Loosen and remove the front case to rear case retaining bolts.

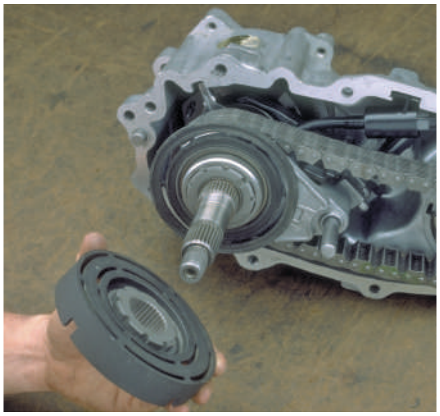


P39-9 Separate the two halves by prying between the pry bosses on the case.

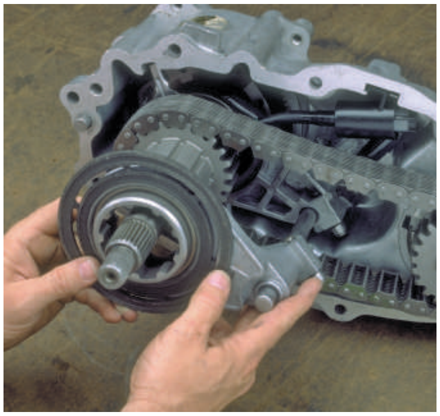
Typical Procedure for Disassembling a Warner 13-56 Transfer Case *(continued)*



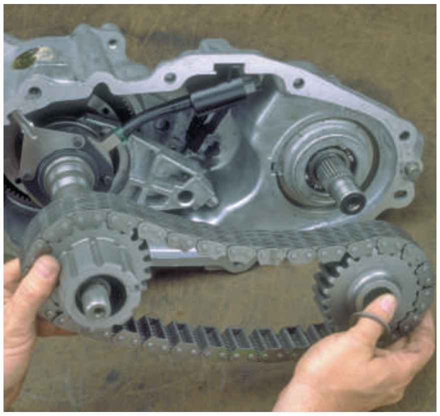
P39-10 Remove the shift rail for the electric motor.



P39-11 Pull the clutch coil off the mainshaft.

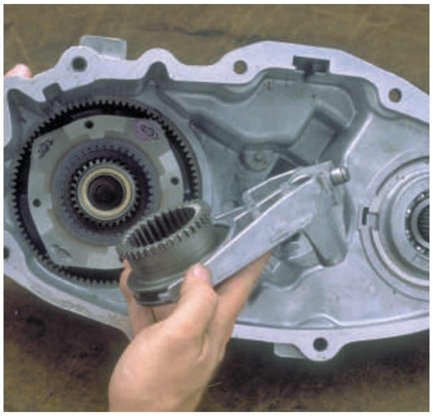


P39-12 Pull the 2WD/4WD shift fork and lockup assembly off the mainshaft.

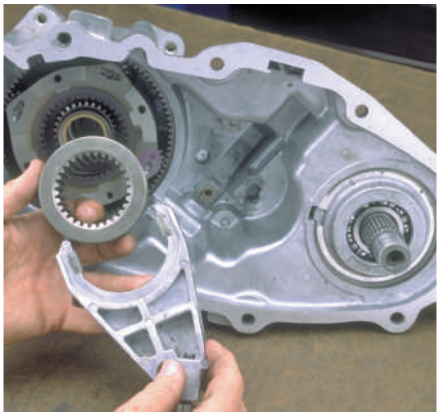


P39-13 Remove the chain, driven sprocket, and drive sprocket as a unit.

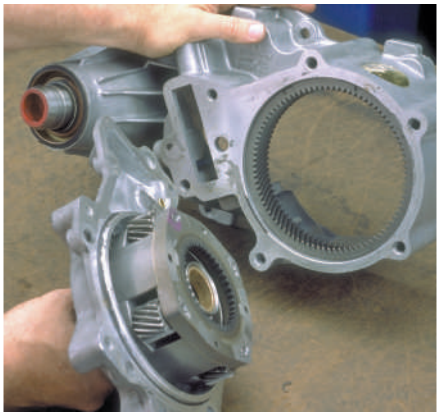
P39-14 Remove the mainshaft with the oil pump assembly.



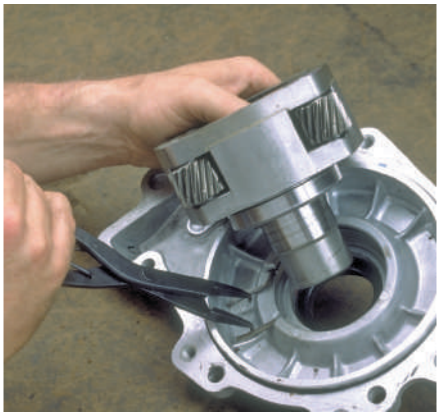
P39-15 Slip the high-low range shift fork out of the inside track of the shift cam.



P39-16 Remove the high-low shift collar from the shift fork.



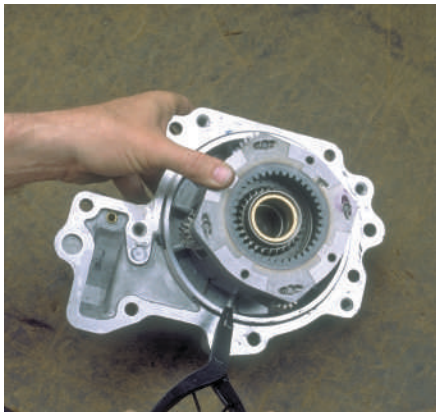
P39-17 Unbolt and remove the planetary gear mounting plate from the case.



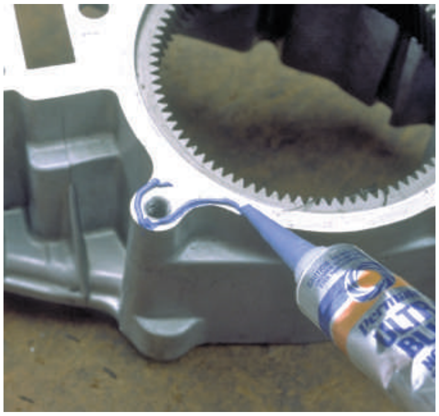
P39-18 Pull the planetary gear-set out of the mounting plate.

PHOTO SEQUENCE 40

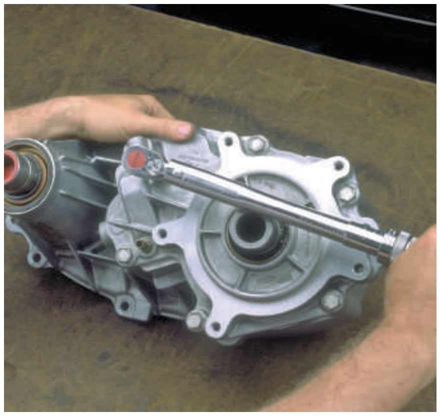
Typical Procedure for Reassembling a Warner 13-56 Transfer Case



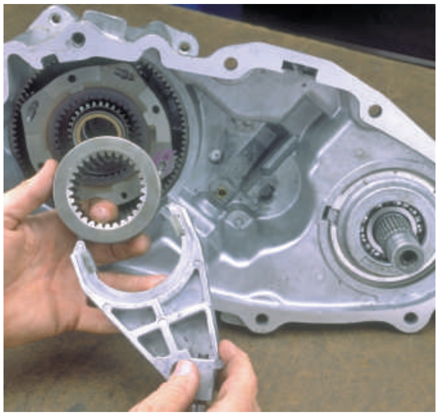
P40-1 Install the input shaft and front output shaft bearings into the case.



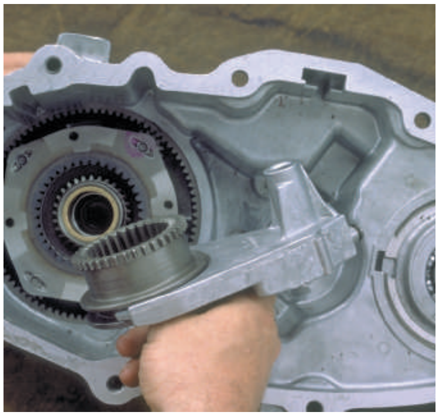
P40-2 Apply a thin bead of sealer around the ring gear housing.



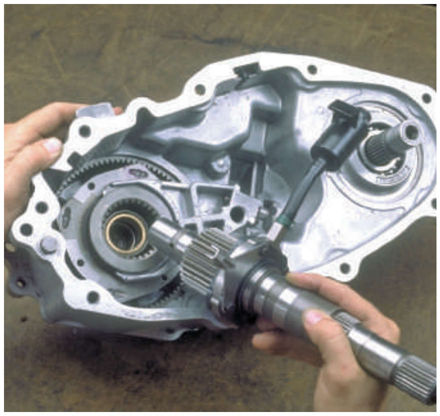
P40-3 Install the input shaft with planetary gearset and tighten the retaining bolts to specifications.



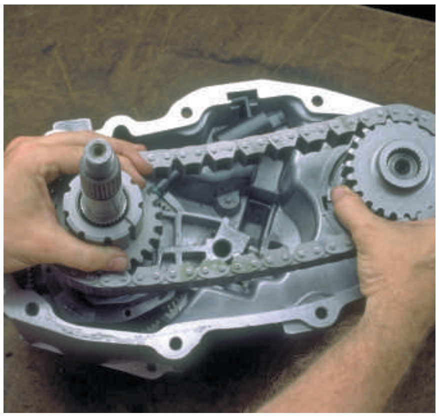
P40-4 Install the high-low shift collar into the shift fork.



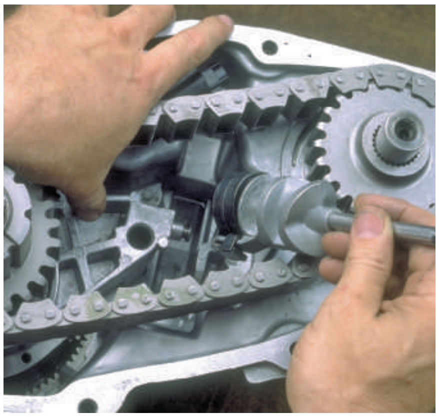
P40-5 Install the high-low shift assembly into the case.



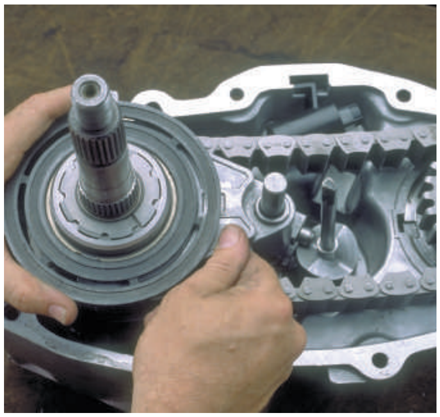
P40-6 Install the mainshaft with oil pump assembly into the case.



P40-7 Install the drive and driven sprockets and chain into position in the case.



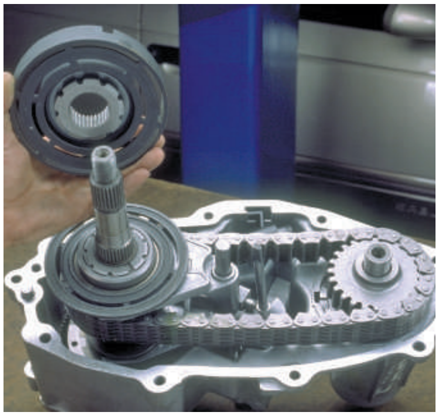
P40-8 Install the shift rails.



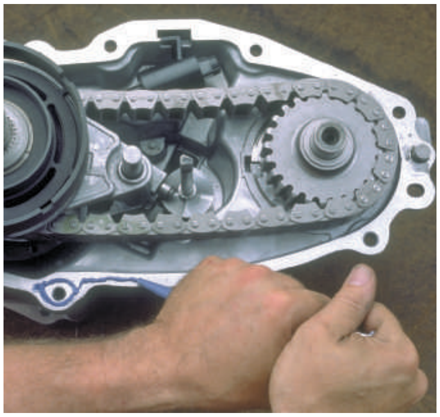
P40-9 Install the 2WD/4WD shift fork and lockup assembly onto the main-shaft.

PHOTO SEQUENCE 40

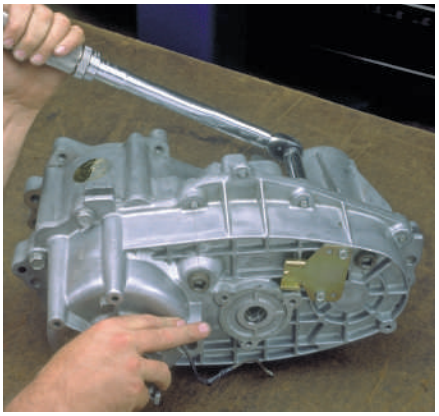
Typical Procedure for Reassembling a Warner 13-56 Transfer Case *(continued)*



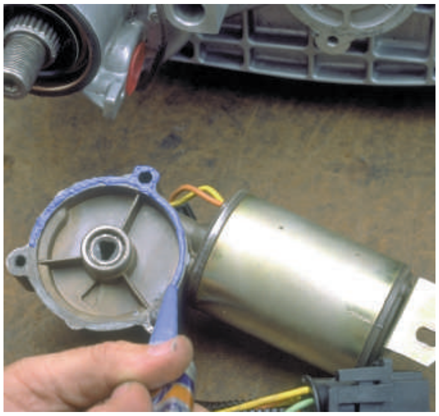
P40-10 Install the clutch coil onto the mainshaft.



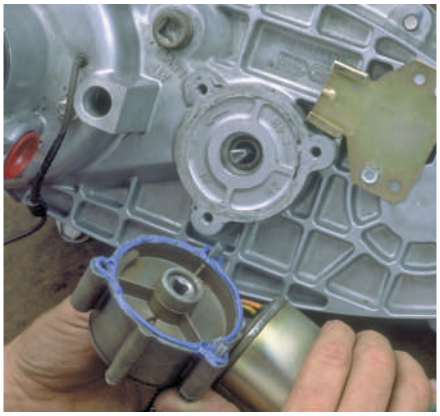
P40-11 Clean the mating surface of the case. Apply the recommended sealant on the areas where the case halves join.



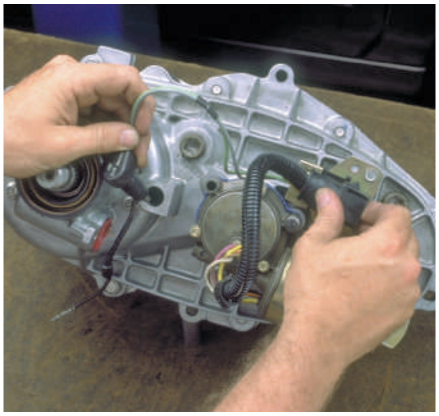
P40-12 Position the shafts and tighten the case halves together. Tighten attaching bolts to specifications.



P40-13 Apply a thin bead of sealer to the mating surface of the electric shift motor.

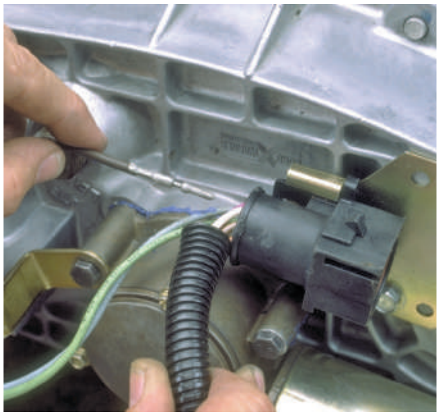


P40-14 Align the triangular shaft with the motor's triangular slot.

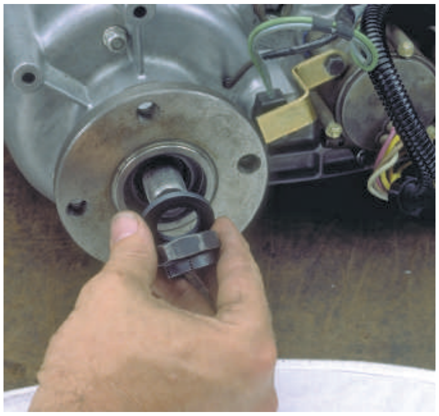


P40-15 Install the motor over the shaft, and wiggle the motor to make sure it is fully seated on the shaft.

P40-16 Tighten the motor's retaining bolts to specifications.



P40-17 Reinstall the wires into the connector and connect all electric sensors.



P40-18 Install the companion flanges' seal, washer, and nut. Then tighten the nut to specifications.

Front Axles and Hubs

The axles and locking hubs must be removed before the front differential and final drive assembly can be removed from the axle housing. Removing these components requires special procedures, and each type of 4WD system requires its own specific procedure.

GO TO Chapter 40 for details on serving a final drive unit in a transaxle.

Removal of the axle shafts begins with the removal of the hubs. Normally, the procedures for replacing manual hubs are somewhat different from those for replacing automatic hubs. Locking hubs are not serviceable; therefore, service of the hubs consists of merely replacing them. Also, the procedure for the replacement of the hubs varies with the type of hub and the manufacturer. The following are general procedures for the removal and installation of both manual and automatic locking hubs. Always follow the specific procedures for the type of hub you are servicing.

Manual Locking Hub To remove a manual hub, set the hub's control knob to the "Free" or unlocked position. Then remove the cover bolts and the outer snapring. If hubs are equipped with shims, remove them as well. Then remove the drive flange or gear from the axle. Now remove the bolts that attach the hub body to the hub. The hub assembly can now be pulled from the axle shaft. After the hub assembly has been removed, inspect the splines of the axle shaft for nicks and burrs.

To install a manual hub, separate the base and handle units of the hub lock assembly. Apply a light coat of grease to the axle shaft splines and the hub lock base. Also apply a light coating of lubricant to the O-ring. Make sure the gasket surface is smooth and clean, then place a new hub gasket onto the hub. Set the control handle to the unlocked position and install the hub assembly and the snapring onto the axle shaft. Tighten the attaching bolts to the specified torque. Install the hub cover with a new gasket onto the hub and tighten the remaining attaching bolts to specifications. Check the control handle for ease of operation.

Automatic Locking Hub There are basically two designs of automatic locking hubs: internally and externally retained. The procedure for servicing automatic hubs depends on how they are retained. Remove the bolts from the outer cap assembly and pull the cap off the body of the hub. Then remove the axle shaft bolt, lock washer, and axle shaft stop. In the wheel hub there is a groove that retains a lock ring; remove it and slide the hub assembly off the wheel's hub. Then loosen the set screws in the spindle locknut until their heads are flush with the face of the locknut. Remove the spindle locknut.

To install an automatic hub, adjust the wheel bearings and install the spindle locknut and tighten it to specifications. Firmly tighten the locking set screws. Apply multipurpose grease to the inner splines of the hub; do not pack the hub with grease. Slide the assembly into the wheel hub. Push firmly on the body until it seats in the hub. Then install the lock ring in the groove of the wheel hub. Place the lock washer and axle shaft stop onto the axle bolt. Install the bolt and tighten it to specifications. Apply a small amount of lube to the seal on the cap assembly. Do not grease the cap assembly. Install the cap assembly over the body assembly and into the wheel hub. Install the attaching bolts and tighten them to specifications. Firmly turn the control from stop to stop to check the assembly. Then set both hub controls in the same position: "auto" or "lock."

Wheel Bearings

The front-wheel bearings on a 4WD vehicle should be disassembled, cleaned, inspected, and lubricated on a regular basis. Upon reassembly, it is very important that the bearings be properly adjusted. The procedure for doing this is similar to other wheel bearings. However, because of the load on the bearings, the adjustment is more critical.

To adjust the wheel bearings, begin by removing the snapring at the end of the spindle, the axle shaft spacer, needle thrust washer, bearing spacer, outer wheel bearing locknut, and bearing washer. Then loosen the inner bearing locknut and tighten it fully to seat the bearings. The wheel bearing locknuts on most 4WD vehicles require the use of a four- or six-pronged spanner wrench. Spin the brake rotor on the spindle, then loosen the inner bearing locknut approximately ¼ turn. Install the outer bearing locknut and tighten it to the specified amount, usually 70 to 90 ft.-lb (95 to 122 Nm). Assemble the remaining parts of the hub assembly, making sure that the snapring is fully seated in its groove on the axle.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2014	**Make:** Honda	**Model:** Pilot	**Mileage:** 47,077	**RO:** 17141
Concern:	Customer states that there's noise coming from the rear of the vehicle while driving.			
The technician confirms the noise during a short test drive and notices that the maintenance indicator on the dash is on. Checking the service information, she finds Honda 4WD vehicles require periodic rear differential fluid service.				
Cause:	Noise coming from rear axle due to worn out differential lubricant.			
Correction:	Replaced rear differential lubricant with Honda VTM fluid. Noise no longer present.			

KEY TERMS

All-wheel drive (AWD)
Driveline windup
Four-wheel drive (4WD)
Haldex clutch
Interaxle (center) differential
Locking hubs
Transfer case
Viscous clutch

SUMMARY

- The importance of excellent traction and the benefits of four-wheel and all-wheel drive systems become readily apparent in snow or heavy rain.
- The heart of most conventional 4WD systems is the transfer case.
- The interaxle is placed in the transfer case to operate in the same fashion as the differentials at the axles. The only difference is that the transfer differential controls the speed of the drivelines instead of the axles.
- Many vehicles require that the front hubs be in a locked condition to operate as 4WD vehicles. This lockup may be made either manually or automatically.
- On 4WD vehicles with on-the-fly shifting, it is not necessary to come to a complete stop when changing operational modes.
- Components of 4WD vehicles can be serviced in basically the same manner as the identical components on a 2WD vehicle.
- All-wheel drive vehicles may use a viscous clutch, rather than a transfer case, to drive the axle with low tractive effort.
- Many AWD vehicles have a third differential, called an interaxle (center) differential, instead of a transfer case.

REVIEW QUESTIONS

Short Answer

1. Name the three main driveline components that are added to a RWD vehicle to make it a 4WD vehicle.
2. Describe the purpose of a viscous clutch.
3. What is the purpose of the interaxle differential?
4. Briefly explain how a Haldex clutch works.
5. What is the primary purpose of a transfer case?
6. What are the primary differences between a full-time and a part-time 4WD system?
7. When the plates of a viscous coupling (clutch) rotate at different speeds, the plates ___ the fluid.
8. How does a viscous clutch assembly work? Why is it used in AWD systems?

Multiple Choice

1. What results from having different axle ratios on the front and rear of a 4WD vehicle when it is operating in 4WD?
   a. Poor handling on dry surfaces
   b. Driveline windup
   c. Mechanical damage to the driveline
   d. All of the above
2. The transfer clutch in the all-wheel drive automatic transaxle takes the place of the ___.
   a. transmission
   b. reduction gears
   c. torque converter
   d. interaxle differential

3. In a viscous clutch, when the silicone fluid is heated, it ___.
   a. becomes a very thin fluid
   b. boils to a vapor
   c. thickens to a solid mass
   d. stiffens
4. When servicing transfer cases, all of the following are correct, *except* ___.
   a. it must be supported on a transmission jack or safety stands
   b. the chain drive and a planetary gearset must be adjusted to specifications
   c. visual inspections for leaks and damage are necessary
   d. follow the manufacturer's recommendations for lubricants
5. Which of the following is *least* likely to cause binding when turning on the front of a 4WD vehicle?
   a. Unmatched tire sizes
   b. Unequal tire wear
   c. Low differential fluid level
   d. Unequal tire pressures
6. Which of the following would *not* cause noise while driving in 2WD under a heavy throttle?
   a. Faulty ignition switch
   b. Worn transfer case clutch
   c. Inoperative locking hubs
   d. Bad front half shaft
7. Which of the following could cause the 4WD indicators not to operate correctly?
   a. A faulty control module (PCM)
   b. Inoperative locking hubs
   c. Worn transfer case clutch
   d. Damaged transfer case shift lever

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that viscous couplings are electronically controlled. Technician B says that Haldex clutches are electronically controlled. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Technician A says that some AWD systems have a center differential. Technician B says that some AWD vehicles have a viscous clutch. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. While discussing AWD systems: Technician A says that some systems are electronically controlled and use an electromagnetic clutch to engage and disengage the drive axles. Technician B says that some cars do not use a transfer case, but they are equipped with a third differential unit. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. Technician A says that the 4WD mode of part-time 4WD systems is designed to be used only when driving off the road or on slippery surfaces. Technician B says that AWD systems are intended for off-the-road use only. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. While diagnosing the cause of noise from a transfer case: Technician A says that a probable cause is incorrect tire size. Technician B says that the most probable cause is a faulty bearing or gear. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. Technician A says that a seized shift linkage may cause the transfer case to operate only in 4WD. Technician B says that a worn and loose linkage may cause a transfer case to operate only in 2WD. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. While diagnosing the cause of the transfer case jumping out of gear: Technician A says that the most probable cause is worn or broken synchronizers. Technician B says that a possible cause is an improperly adjusted shift linkage. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. While servicing an AWD vehicle: Technician A checks the service information to identify the correct lubricant for the center differential. Technician B says that the same lubricant is used for the viscous coupling, transfer case, and differentials on most vehicles. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. While discussing the various speed gear positions of a transfer case: Technician A says that when the transfer case is in low, the overall gear ratio is numerically increased. Technician B says that when the transfer case is in the high position, the vehicle operates in an overdrive mode due to the decrease in torque multiplication. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. While discussing automatic AWD systems: Technician A says that the systems operate in 2WD nearly all of the time. Technician B says that on many systems, when the PCM receives inputs from the CAN bus, it indicates that wheel slippage power is sent to the other drive axle. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

SUSPENSION AND STEERING SYSTEMS

SECTION 7

CHAPTER 45

TIRES AND WHEELS

OBJECTIVES

- Describe basic wheel and hub design.
- Explain the tire ratings and designations in use today.
- Describe why certain factors affect tire performance, including inflation pressure, tire rotation, and tread wear.
- Describe the operation, diagnosis, and service for a tire pressure monitor.
- Remove and install a wheel and tire assembly.
- Repair a damaged tire.
- Describe the differences between static balance and dynamic balance.

Tire and wheel assemblies provide the only connection between the road and the vehicle. Tire design has improved dramatically during the past few years. Modern tires require increased attention to achieve their full potential of extended service and correct ride control. Tire wear that is uneven or premature is usually a good indicator of steering and suspension system problems. Tires, therefore, become not only a good diagnostic aid to a technician, but can also be clear evidence to the customer that there is need for service.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2010	**Make:** Chevy	**Model:** Equinox	**Mileage:** 87,047	**RO:** 17726
Concern:	Customer states tire warning light and message stays on all the time. She checked tire pressure and all were OK.			
History:	Tires and TPM sensors were replaced 2 weeks ago at 86,585 miles.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

Wheels

Wheels are made of either stamped or pressed steel discs riveted or welded together. They are also available in the form of aluminum or magnesium rims that are die-cast or forged **(Figure 45–1)**. Magnesium wheels are commonly referred to as mag wheels, although they are usually made of an aluminum alloy. Aluminum wheels are lighter in weight when compared with the stamped steel type. This weight savings is important because the wheels and tires on a vehicle are unsprung weight. A few vehicles offer carbon fiber wheels as options to further help save weight. Though expensive, carbon fiber wheels can save several pounds per wheel.

FIGURE 45-1 An alloy wheel on a late-model car.

SHOP TALK

Sprung weight represents the weight of the vehicle that is supported by the suspension. The suspension and wheels are unsprung weight. Lower amounts of unsprung weight make the vehicle handle better, primarily on irregular surfaces. It also gives a better ride. This is because when a tire hits a bump, the shock is moved through the tire and wheel to the suspension. The shock that is not absorbed by the suspension then moves to the rest of the vehicle. When the unsprung weight is high, that weight and the shock from the road must be absorbed by the suspension. This means more shock will be passed to the rest of the vehicle.

Near the center of the wheel are mounting holes that are tapered to fit tapered mounting nuts (lug nuts) that center the wheel over the hub. The rim has a hole for the tire's valve stem and a drop center area designed to allow for easy tire removal and installation. Wheel offset is the vertical distance between the centerline of the rim and the mounting face of the wheel. The offset is considered positive if the centerline of the rim is inboard of the mounting face and negative if outboard of the mounting face. The amount and type of offset is critical because changing the wheel offset changes the front suspension loading as well as the scrub radius.

GO TO Chapter 49 for details on scrub radius and wheel alignment.

The wheel is bolted to a **hub**, either by lug bolts that pass through the wheel and thread into the hub, or by studs that protrude from the hub. In the case of studs, special lug nuts are required. A few vehicles have left-hand threads (which turn counterclockwise to tighten) on the driver's side and right-hand threads (which turn clockwise to tighten) on the passenger's side. All other vehicles use right-hand threads on both sides. Aftermarket wheels may have additional lug holes so that the wheels can fit a variety of stud patterns. Installing aftermarket wheels may require the use of a centerbore spacer in the wheel. The spacer is used to match the centerbore of the wheel to fit the hub of the vehicle.

Wheel size is designated by rim width and rim diameter **(Figure 45–2A)**. Rim width is determined by measuring across the rim between the flanges. Rim diameter is measured across the bead seating areas from the top to the bottom of the wheel. Wheel bolt pattern is determined by the distance between the studs **(Figure 45–2B)**. Rims have safety ridges near their lips. In the event of a tire blowout, these ridges tend to keep the tire from moving into the dropped center and from coming off the wheel.

Replacement wheels must be equal to the original equipment wheels in load capacity, diameter, width, offset, and mounting configuration. An incorrect wheel can affect wheel and bearing life, ground and tire clearance, or speedometer and odometer calibrations. A wrong size wheel can also affect the antilock brake system. Using the wrong size tire or wheel or improperly inflated tires will affect the rotational speed of the tire, and the ABS will be unable to operate correctly. Aftermarket replacement wheels

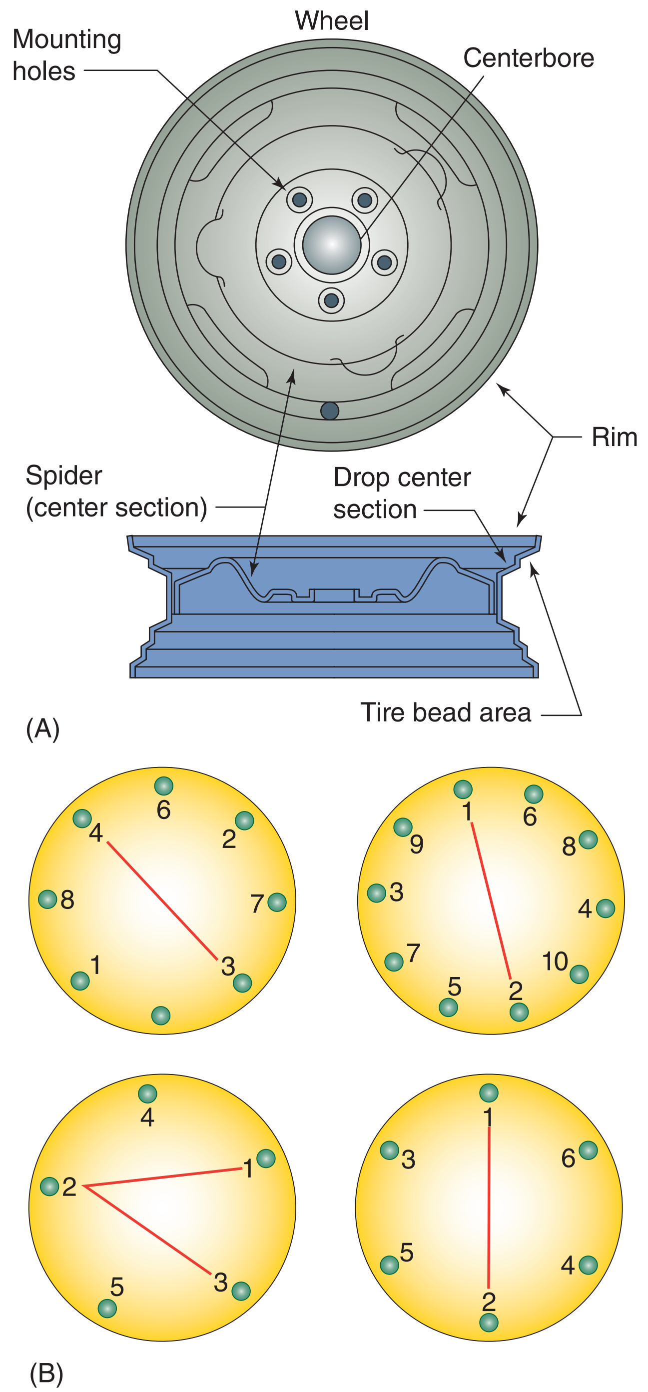


FIGURE 45-2 (A) Wheel dimensions are important when replacing tires. (B) Wheel bolt pattern is determined by the distance between the studs.

may not accommodate the factory tire pressure monitoring sensors as well. Due to the legal aspects regarding TPMS, make sure any replacement wheels are able to be fitted with pressure sensors if the vehicle is equipped with TPMS.

Some performance-oriented cars are equipped with different-sized wheels at the front and rear. It is important that the specific size wheel be at the specific axle. The wider or larger wheels are designed to use different-sized tires. For example, a Porsche 911 has 8.5 × 19 front wheels that are fitted with 235/40 ZR 19 tires. The rear is equipped with 11.5 × 19 wheels that carry 295/35 ZR 19 tires.

Tires

The primary purpose of tires is to provide traction. Tires also help the suspension absorb road shocks, but this is a side benefit. They must perform under a variety of conditions. The road might be wet or dry or paved with asphalt, concrete, or gravel, or there might be no road at all. The car might be traveling slowly on a straight road, or moving quickly through curves or over hills. All of these conditions call for special requirements that must be present, at least to some degree, in all tires.

In addition to providing good traction, tires are also designed to carry the weight of the vehicle, to withstand side thrust over varying speeds and conditions, and to transfer braking and driving torque to the road. All of this has to occur on a contact patch that may be as small as 35 square inches (226 square cm) per tire. As a tire rolls on the road, friction is created between the tire and the road. This friction gives the tire its traction. Although good traction is desirable, it must be limited. Too much traction means there is much friction. Too much friction means there is a lot of rolling resistance. Rolling resistance wastes engine power and fuel; therefore, it must be kept to a minimal level. This dilemma is a major concern in the design of today's tires.

Tire Construction

Early vehicle tires were solid rubber. These were replaced with pneumatic tires, which are filled with air. Tires with tubes, similar to bicycle tires, were used for many years but were replaced by tubeless designs in the 1950s.

A tubeless tire has a soft inner lining that keeps air from leaking between the tire and rim. On some tires, this inner lining can form a seal around a nail or other object that punctures the tread. A self-sealing tire holds in air even after the object is removed. The key to this sealing is a lining of sticky rubber compound on the inside of the tread area that will seal a hole up to 3⁄16 inch (4.76 mm).

A tire air valve has a central core that is spring-loaded to allow air to pass inward only, unless the pin is depressed. If the core becomes defective, it can be unscrewed and replaced. The airtight cap on

the end of the valve provides extra protection against valve leakage. A tubeless tire is mounted on a special rim that retains air between the rim and the tire casing when the tire is inflated.

Figure 45–3 shows a cutaway view of a typical tire. The cord body or casing consists of layers of rubber-impregnated cords, called **plies**, that are bonded into a solid unit. Typically, passenger car and light truck tires are made of 4 plies. Bias tires were actually constructed of many plies, up to 10 or 12 layers to increase tire strength. Modern tires do not require the many layers to increase the tire's load carrying capacity. The **bead** is the portion of the tire that helps keep it in contact with the rim of the wheel. It also provides the air seal on tubeless tires. The bead is constructed of a heavy band of steel wire wrapped into the inner circumference of the tire's ply structure. The **tread**, or crown, is the portion of the tire that comes in contact with the road surface. It is a pattern of grooves and ribs that provides traction. The grooves are designed to drain off water, while the ribs grip the road surface. Tread thickness varies with tire quality. On some tires, small cuts, called sipes, are molded into the ribs of the tread. These sipes open as the tire flexes on the road, offering additional gripping action, especially on wet road surfaces. The sidewalls are the sides of the tire's body. They are constructed of thinner material than the tread to offer greater flexibility.

1. Tread
2. Tread base
3. Two-ply nylon wound breaker
4. Two steel-cord plies
5. Two rayon-carcass plies
6. Double nylon bead reinforcement
7. Bead filler
8. Bead core

Courtesy of Pirelli Tire of North America, LLC.

FIGURE 45–3 A typical tubeless tire.

The tire body and belt material can be made of rayon, nylon, polyester, fiberglass, steel, amarid, or kevlar. Each has its advantages and disadvantages. For instance, rayon and cord tires are low in cost and give a good ride, but do not have the inherent strength needed to cope with long high-speed runs or extended periods of abusive use on rough roads. Nylon-cord tires generally give a slightly harder ride than rayon—especially for the first few miles after the car has been parked—but offer greater toughness and resistance to road damage. Polyester and fiberglass tires offer many of the best qualities of rayon and nylon, but without the disadvantages. They run as smoothly as rayon tires but are much tougher. They are almost as tough as nylon, but give a much smoother ride. Steel is tougher than fiberglass or polyester, but it gives a slightly rougher ride because the steel cord does not give under impact, as do fabric plies. Amarid and kevlar cords are lighter than steel cords and, pound for pound, stronger than steel.

There are three basic types of tire construction: bias ply, belted bias, and radial ply **(Figure 45–4)**. Bias ply

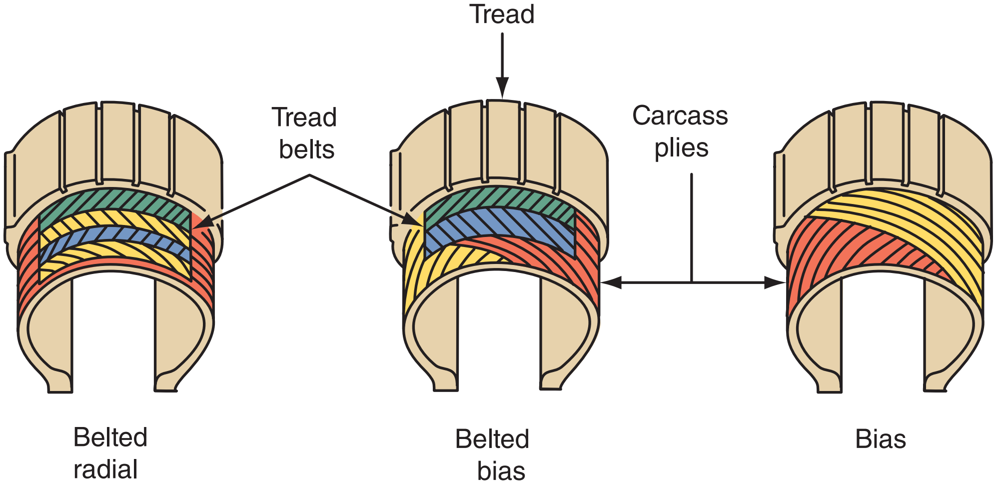


FIGURE 45–4 The construction of the three basic types of tires.

and belted bias tires are only used on off-road heavy equipment, some trailers, and older cars. Today, nearly all road-going vehicles are fitted with radial tires.

Bias ply tires have fabric plies that run alternatively and form a crisscross design. The angle varies from 30 to 38 degrees with the centerline of the tire. Belted bias ply tires are similar to bias ply tires, except that two or more belts run the circumference of the tire under the tread. This construction gives strength to the sidewall and greater stability to the tread.

Radial ply tires have body cords that extend from bead to bead at an angle of about 90 degrees or "radial" to the circumferential centerline of the tire—plus two or more layers of relatively inflexible belts under the tread. The construction of various combinations of rayon, nylon, fiberglass, and steel gives greater strength to the tread area and flexibility to the sidewall. The belts restrict tread motion during contact with the road, thus improving tread life and traction. Radial ply tires also offer greater fuel economy, increased skid resistance, and more positive braking.

Specialty Tires

Specialty tires reflect the advances made in tire development. These tires are designed for specific road conditions or applications. All-season tires are designed to perform well on all types of road conditions, but they are not excellent performers on all road surfaces. To provide traction in the snow and mud, at least 25 percent of the tread area is void **(Figure 45–5)**. This leaves open areas for the snow or mud to move into as the tire rotates. The open spaces also give the tires some bite as they move. The remaining tread area is designed to provide good traction on normal surfaces.

FIGURE 45–5 A directional all-season radial tire.

> **SHOP TALK**
>
> **Snow tires are designed to increase traction in the snow. They should be installed on all wheels and replaced with normal tires once the season changes.**

Tires can also be designed for heavy snow. These are commonly called "snow tires." The tread area is much more aggressive, with larger voids than all-season tires. Because of the decreased contact with the road, these tires do not provide good traction during normal conditions.

Studded tires provide superior traction on ice but are slowly disappearing from the tire market because their performance on dry surfaces is poor. In addition, many states have outlawed their use because they damage the road and can be a safety hazard on dry surfaces. Because the studs have more contact on the road than the tire's rubber, it is easy for the tire to slide on the road during cornering and stopping. The studs offer much less friction than the rubber tire tread.

Tires can be designed to be great on dry surfaces or wet surfaces. These are often called "All-Season" tires and offer fair traction on snow and ice. However, it is nearly impossible to have a tire that performs extremely well on all surfaces. Tires designed for dry and smooth roads do not need a tread pattern. They can be "slicks." The smooth surface gives the tires maximum grip on a smooth, dry surface. However, when a slick hits a wet spot, there is no traction. The tire simply slides on the water.

Tires designed for wet surfaces have tread designs that move the road's water behind and to the side of the tire. Moving the water is the only way a tire can grip the road. When too much water separates the tire from the road, hydroplaning takes place. This causes the tire to lift off the road and rotate on a layer of water. Traction is reduced and this can create an unsafe condition. Needless to say, when a tire has many directed and open channels for water in its tread, less rubber meets the road.

Some cars are equipped with summer performance tires. This type of tire maximizes handling and road holding but only in warm weather. In most cases, these tires should not be used in snow or when temperatures are 40 °F (4.4 °C) or below. Use of the tires below the recommended temperatures

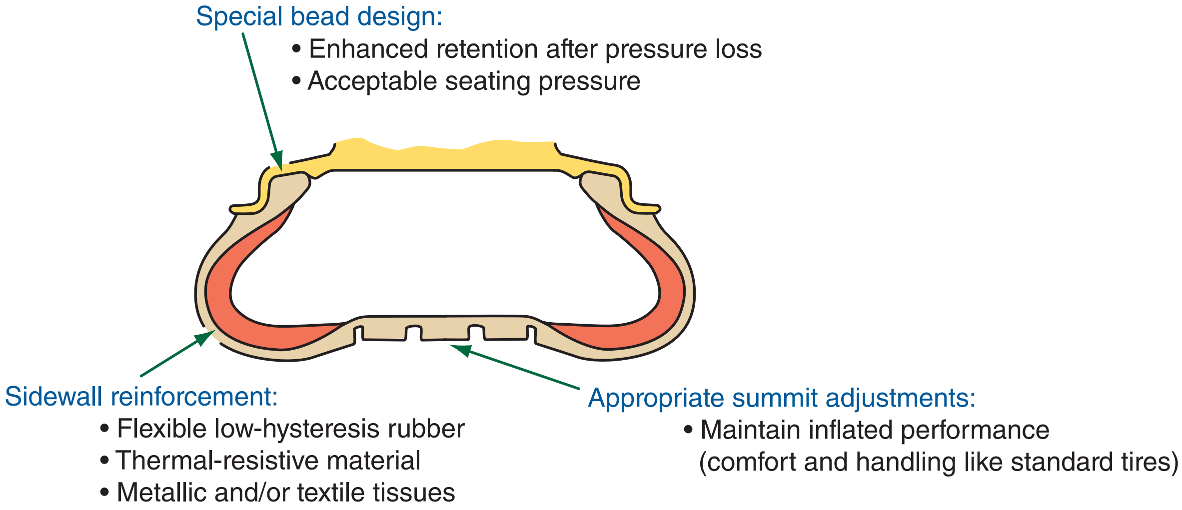


FIGURE 45-6 Features of a run-flat tire.

can cause reduced traction as the tires may not develop enough heat to become "sticky."

Run-Flat and Self-Sealing Tires

There are several types of run-flat tires available. Vehicles equipped with these have no spare tire or jack in the luggage compartment. Run-flats can be divided into two categories: self-supporting and auxiliary supported systems. Each of these uses different ways to allow a vehicle to be driven after a tire is punctured.

Self-Supporting When a self-supporting tire loses all of its air pressure, it is able to temporarily carry the weight of the vehicle and allow the vehicle to be driven. This is a result of the tire's construction. These tires have reinforced sidewalls and special beads **(Figure 45–6)**. The first "run-flat" tire available on a regular production vehicle was a self-supporting tire that was offered as an option on the 1994 Chevrolet Corvette. Today, many tire manufacturers offer self-supporting tires and self-supporting tires are standard equipment on most BMW models. Typically, a self-supporting tire can be driven for 50 miles (80 km) at speeds up to 55 mph (89 km/h) after it has lost air pressure.

Auxiliary Supported Run-Flat Systems Auxiliary supported systems are much different from other run-flat tires. They are systems that have special tires and wheels. The basis of these systems is a solid supporting ring that allows a flat tire's tread to rest on a support ring attached to the wheel when the tire loses pressure **(Figure 45–7)**. This support ring allows the tire to behave as it would when it was inflated. The wheel and tire are designed to prevent the tire from coming loose from the wheel when air pressure is lost. The most common system is Michelin's PAX system, which was introduced in 1996. This system allows the driver to drive the vehicle up to 125 miles (201 km) at 55 mph (89 km/h) before it needs service. This type of tire requires a special wheel and neither the wheel nor tire are interchangeable with standard wheels and tires.

Courtesy of The Goodyear Tire & Rubber Company.

FIGURE 45-7 A cutaway of a run-flat tire with an insert for support in case the tire goes very flat.

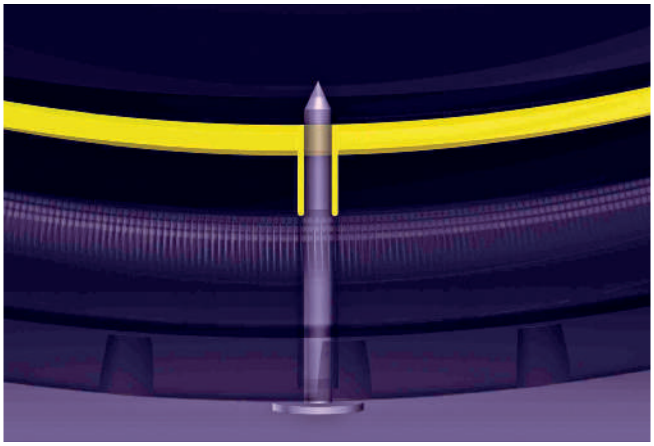
Self-Sealing Self-sealing tires are designed to quickly and permanently seal most tread-area punctures. The tires are constructed like other tires, but there is an additional lining inside the tire under the tread area. The lining is coated with a sealant that can permanently seal most punctures up to $^3/_{16}$ inch (4.76 mm) in diameter. The lining seals the area around the puncture and can fill in the hole once the object is removed from the tire **(Figure 45–8)**. There is no provision for reinflating the tire, so the tire will need to be inflated after the repair.

Tread Designs

The real purpose of a tire is to get a grip on the road. The ideal tire is one that wears little, holds the road well to provide sure handling and braking, and provides a cushion from road shock. The ideal tire should also provide maximum grip on dry roads, wet roads, and snow and ice, and operate quietly at any speed. This is a tall order, so tire manufacturers compromise on one or two of these qualities for the sake of excelling at another. A tire's tread design dictates what the tire will excel at.

There are basically four categories of tread patterns: directional, nondirectional, symmetric, and asymmetric.

A directional tire is mounted so that it revolves in a particular direction. These tires have an arrow on the sidewalls that show the designed direction of travel. A directional tire offers good performance only when it is rotating in the direction in which it was designed to rotate **(Figure 45–9A)**. Directional tread patterns are used with all-season tires to more effectively channel water from under the tire and improve wet traction. Many sports car tires also use a directional tread design. A nondirectional tire has the same handling qualities in either direction of rotation.



Courtesy of The Goodyear Tire & Rubber Company.

FIGURE 45-8 The action of a self-sealing tire.

The most common and basic tread designs are nondirectional. A symmetric tire has the same tread pattern on both sides of the tire. An asymmetrical tire has a tread design that is different from one side to the other **(Figure 45–9B)**. Asymmetrical tires are typically designed to provide good grip when traveling straight (the inside half) and good grip in turns (the outside half of the tread). Some asymmetric tires are also directional tires.

The number and size of the blocks, sipes, and grooves on a tire's tread not only determine how much rubber contacts the road and how much water can be displaced, they also determine how quiet the tire will be during travel. The more aggressive the tread, the more noise it will make. This statement is especially true if the tire's tread is made

(A)

(B)

FIGURE 45-9 There are many different tread designs available for today's vehicles. (A) This is a directional tread design. (B) This is an asymmetrical tread design.

SHOP TALK

Whenever a customer wants a better handling tire, make sure that he or she knows that a better gripping tire may make more noise and not wear as long as other tires. Knowing what design of tire will meet a customer's needs is a science. Always consult with a tire specialist before recommending one tire or another.

of a hard compound. Softer tires typically make less noise but wear more quickly. Soft tires also adhere to the road better.

Channels are cut into a tire's tread to allow water to move away from the tire's direction of travel. The deeper the channel, the more water the tire can move. The disadvantage of these channels is decreased road contact.

LRR Tires Some late-model vehicles are equipped with low rolling resistance (LRR) tires. These are designed to increase fuel economy and are found on some hybrid and electric vehicles. Rolling resistance is basically the power consumed by the tire's contact with the road and the flexing of its sidewalls. It is estimated that 5 to 15 percent of a vehicle's fuel consumption is used to overcome a tire's rolling resistance. Therefore, reduce the rolling resistance and use less fuel. The use of LRRs comes with a cost; they typically have less surface contact on the road and are not the best handling tires.

Spare Tires

Nearly all vehicles are equipped with a spare tire to be used in case one of the vehicle's tires loses air and goes flat. A spare tire can be a tire that matches the tires on the vehicle, usually called a full-size spare, or can be a compact spare. Compact spares are designed to reduce weight and storage space but still provide the driver with a tire in the case of an emergency. Compact tires are typically one of three types: high-pressure mini spare, space-saver spare, and lightweight skin spare.

A high-pressure mini-spare tire is a temporary tire **(Figure 45–10)**. It should not be used for extended mileage or for speeds above 50 mph (80 km/h). These tires typically require an inflation pressure of 60 psi (415 kPa). A space-saver spare must be blown up with a compressor that operates from the cigarette

CUSTOMER CARE

Make sure you warn your customer that a mini, space-saver, or similar type compact spare should be used only as a temporary tire. It should never be used as a regular tire. Any continuous use of a temporary spare will result in tire failure, which can cause loss of control and injury to the vehicle's occupants. It can also cause differential gear wear and will affect ABS and traction control operation.

FIGURE 45–10 Notice the warnings affixed to this temporary spare tire.

lighter or a built-in air compressor. A skin spare is a normal bias ply type tire with a reduced tread depth.

Some cars do not have spare tires, even if they are not fitted with run-flat tires. Instead, these cars have a high-pressure air pump and a can of tire sealant in the trunk. Normally the sealant will allow the car to be driven until the tire can be properly repaired.

Tire Ratings and Designations

The construction of a tire depends on its application. Needless to say, there are many different tires. These differences are based on not only size, but their construction to meet intended driving conditions. There are also standards that tire manufacturers must meet to ensure that the tire will be safe, not wear too rapidly, and offer good road isolation for the passengers

in the vehicle. The uniqueness of each tire is represented by information given on the sidewall of every tire produced. In fact, everything you need to know about a tire is imprinted on the tire **(Figure 45–11)**.

Tire Size

The best way to describe and explain the information given on the sidewall of a tire is to look at an example. Look at the tire size designation of P215/65 R15 89H and see what it tells.

On a **P**215/65 R15 89H tire, the *P* represents the application of the tire; in this case P = passenger car. If the tire had an "LT" designation, the tire would be for a light truck.

The *215* in P**215**/65 R15 89H represents the width of the tire measured in millimeters from sidewall to sidewall. This tire width is 215 millimeters. This is also called section width, and it varies with the wheel (rim) on which the tire is mounted. A wide rim increases the section width, whereas a narrow one decreases it. The measurement given on the tire was taken with the tire on a specific rim.

The *65* in P215/**65** R15 89H indicates the **aspect ratio** or profile (series) of the tire **(Figure 45–12)**. A tire's aspect ratio is the relationship of its cross-sectional

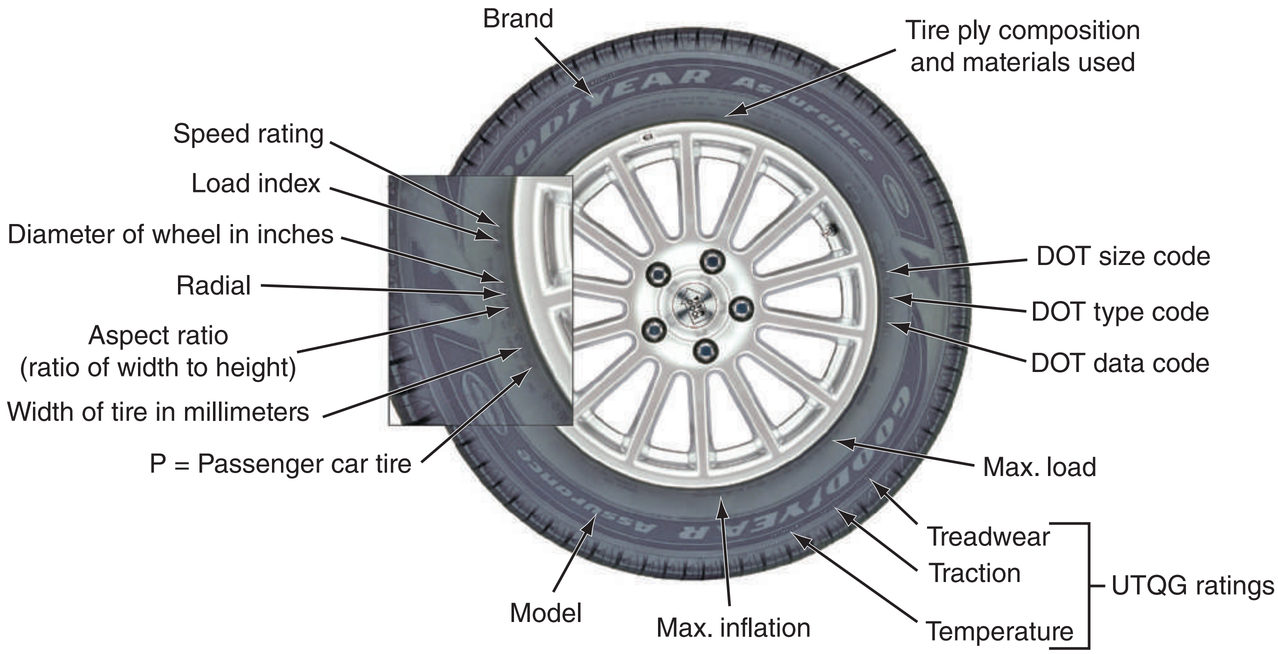


FIGURE 45–11 There is a lot of information about a tire on its sidewall.

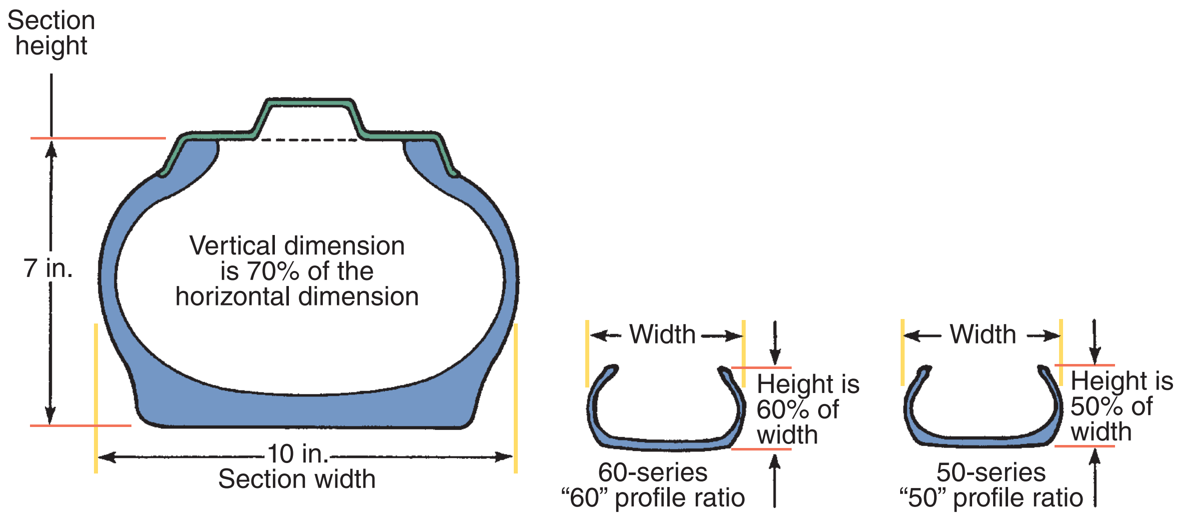


FIGURE 45–12 The aspect ratio (profile) of a tire is its cross-sectional height compared to its cross-sectional width expressed in a percentage.

height (from tread to bead) to its cross-sectional width (from sidewall to sidewall). In our example, the tire's height is equal to 65 percent of its width (the width equals 215 mm × 65 percent or 140 mm). The aspect ratio determines a tire's performance characteristics. Higher aspect ratios provide a softer ride because they will deflect more over irregular surfaces and under heavy loads. Shorter sidewall heights demand stiffer sidewalls. Therefore, tires with a low aspect ratio have a harsher ride. However, they provide a larger contact area with the road and therefore better traction.

For a tire rated as P215/65 **R**15 89H the *R* represents the basic ply construction of the tire. This letter can be an "R" for radial construction, a "B" for belted-bias construction, or a "D" for bias ply ("bias" means the plies are set diagonally or at a slant).

The diameter of the wheel is indicated by the *15* after the R. The diameter of the wheel for this tire is 15 inches. Wheel diameter is the height of the wheel from one end to the other.

Following the size notation is the load and speed ratings. These are expressed by a number and a letter; in this case the ratings are given as 89H. The *89* is the load index and the *H* is the speed rating.

The maximum load rating lists the maximum amount of weight the tire can carry at the recommended tire pressure. For bias tires, the load rating and the number of tread and sidewall plies are proportional. In most cases, the more plies a tire has, the more weight it can support. For modern radial tires, the higher the tire's load index number, the greater its load carrying capacity. The load ratings for passenger car and light truck tires range from 70 to 110. Following are some examples of load ratings and the weight they represent:

71 = 761 lb (345 kg)
79 = 963 lb (437 kg)
89 = 1,279 lb (580 kg)
99 = 1,709 lb (775 kg)
109 = 2,271 lb (1,030 kg)

So in our example, the tire can carry 1,279 lb (580 kg).

The speed rating indicates the maximum speed at which the tire should be used. In this case, the *H* means the tire has been tested to be safe at speeds up to 130 mph (210 km/h). The speed rating of a tire is really nothing more than an expression of how well the tire will withstand the temperatures of high speed. This does not necessarily mean that a high-speed-rated tire will perform better at low speeds than a lower-rated tire. Speed ratings apply only to properly maintained, and not overloaded, damaged, or patched tires.

Table 45–1 lists the various letters used to designate the speed rating of a tire and the maximum speed at which the tire was designed to safely operate. Driving a vehicle at speeds greater than the speed rating of the tires is risky. The heat generated can cause the tire to come apart. If this happens at high speeds, it will be close to impossible for the driver to maintain control of the vehicle.

Other Information

The sidewall of a tire also has a DOT safety code, tire identification or serial number, UTQG ratings, and maximum inflation values. The DOT code indicates that the tire has met all of the applicable safety standards established by the U.S. Department of Transportation (DOT). Next to the DOT code is a tire identification or serial number. This is a combination of numbers and letters that identify the tire manufacturer, where it was made, the tire design and size, and the week and year the tire was manufactured.

UTQG stands for Uniform Tire Quality Grading, a rating system developed by the DOT. This rating is comprised of three factors: tread wear, traction, and temperature resistance. All tires, except snow tires, have these ratings.

Tread Wear The tread wear grade is a rating based on a tire's wear rate when tested under controlled conditions on a specified government test track. Tread wear is listed as a number: The higher the number, the longer the tread will last. A rating of 100 is considered normal, whereas ratings lower than 100 mean poor tread wear. Ratings above 100 mean the tire has better-than-normal tread wear. These

TABLE 45–1 SPEED RATINGS

Symbol	Max. Speed
Q	99 mph (160 km/h)
S	112 mph (180 km/h)
T	118 mph (190 km/h)
U	124 mph (200 km/h)
H	130 mph (210 km/h)
V	149 mph (240 km/h)
Z	Above 149 mph (240+ km/h)
W	168 mph (270 km/h)
Y	186 mph (300 km/h)
(Y)	186+ mph (300+ km/h)

ratings should be used to compare the anticipated wear of tires from the same manufacturer and not to compare wear between manufacturers.

Traction Tire traction ratings are based on a tire's ability to stop on wet concrete and asphalt. It is not an indication of how well a tire will handle. The traction rating is given as AA, A, B, or C. A tire rated as C will provide less traction than one rated with an A.

Temperature Resistance This rating is an indication of how well a tire will dissipate heat and how it works when it is heated. The temperature rating applies only to a properly inflated tire that is not overloaded. Heat builds up when a tire is underinflated or overloaded. Temperature also increases with excessive speeds. Temperature resistance rating is given as A, B, or C. A rating of C means the tire is acceptable. A tire with an A temperature rating will be able to withstand high temperatures better than one rated B or C.

Additional Ratings Some tires carry additional markings related to their intended service. An M&S or M+S designation means the tire has been rated by the manufacturer as suitable for mud and snow use. This is the designation for many all-season tires. Some tires may also have a mountain/snowflake symbol, which indicates that these tires are suitable for severe snow conditions; these are commonly called winter tires.

Maximum Cold Inflation and Load

The sidewalls of all passenger tires are marked to indicate the tires' maximum load capacity and maximum cold inflation pressure. It is important to remember that the maximum inflation number on a tire is its maximum inflation, not its recommended inflation. Tires should never be inflated beyond their maximum rating.

Tire Placard

The tire placard, or safety compliance certification label, is generally found on the driver's door jamb. This label may also be located in the glove box or on the fuel door. It includes recommended maximum vehicle load, tire size (including spare), and the *correct* cold tire inflation for each tire of the vehicle **(Figure 45–13)**. Never use this information for other cars.

As a general rule, tires should be replaced with tires of the same size and design specifications or an approved optional size as recommended by the auto or tire manufacturer. Also, always follow the manufacturer's recommendations for tire type, inflation pressures, and rotation patterns.

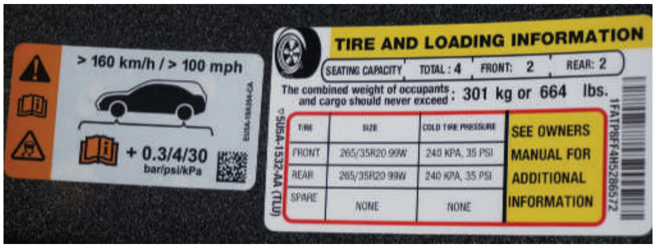


FIGURE 45–13 A tire placard on a door jamb.

SHOP TALK

Tires with a larger or smaller diameter than originally installed will affect the operation of the antilock brake system and the accuracy of the speedometer. It might be necessary to recalibrate the ABS and traction control computers and change the speedometer drive gears when tire size has been changed. Check the vehicle's service information for details.

Tire Care

To maximize tire performance, inspect for signs of improper inflation and uneven wear, which can indicate a need for balancing, rotation, or wheel alignment. Tires should also be checked frequently for cuts, stone bruises, abrasions, and blisters, and for objects that might have become imbedded in the tread. More frequent inspections are recommended when rapid or extreme temperature changes occur, or where road surfaces are rough or occasionally littered with debris.

To clean tires, use a mild soap and water solution only. Rinse thoroughly with clear water. Do not use any caustic solutions or abrasive materials. Never use steel wool or wire brushes. Avoid gasoline, paint thinner, and similar materials having a mineral oil base. These materials will cause premature drying of the tire's rubber. As the rubber dries, it gets harder and the tire will lose some of its performance characteristics.

GO TO Chapter 8 for more discussion on maintaining tires.

Inflation Pressure A properly inflated tire gives the best tire life, riding comfort, handling stability, and fuel economy. Keep in mind that it is the air pressure inside the tire that is actually supporting the weight of the vehicle. Too little air pressure can result in tire squeal, hard steering, excessive tire heat, abnormal tire wear, and increased fuel consumption by as much as 10 percent. An excessively low tire can cause severe and permanent damage to the sidewalls if driven on for even a short period of time. An underinflated tire shows maximum wear on the outside edges of the tread; there is little or no wear in the center **(Figure 45–14)**.

Conversely, an overinflated tire shows its wear in the center of the tread and little wear on the outside edges. Too much air can also cause a hard ride and tire bruising.

It is not unusual for a vehicle to specify different inflation pressure for the front and rear tires. Many inflation pressures listed for imported vehicles are given in kilopascals (kPa) rather than psi. **Table 45–2** converts kPa to psi.

SHOP TALK

The temperature of a tire affects its actual inflation. Pressure increases with an increase in temperature. The opposite is also true. Keep in mind that a 10 °F (5.5 °C) change in temperature will change the air pressure by 1 psi (6.9 kPa). Always adhere to the cold inflation pressures given on the tire placard.

SHOP TALK

Since 2010 in California, every vehicle under 10,000 pounds (4,536 km) GVW that enters a repair facility is to have the tire pressure checked and adjusted. In addition, the service must be documented and records kept for a minimum of three years.

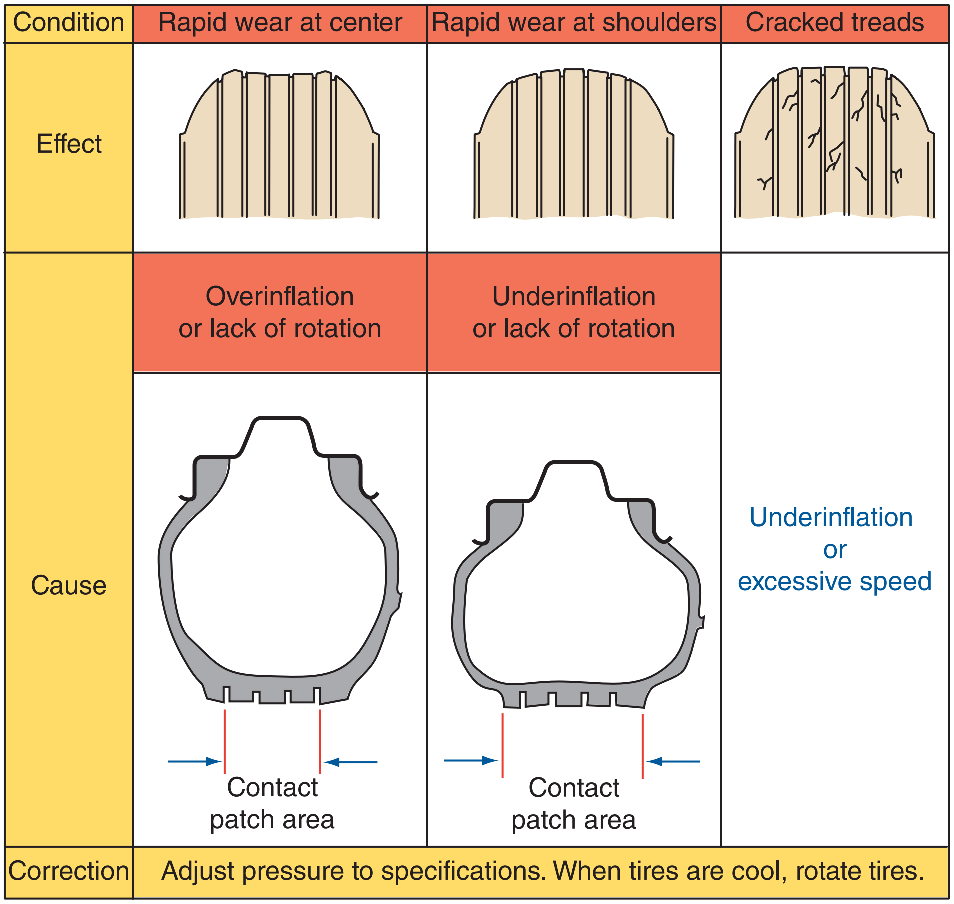


FIGURE 45–14 Effects of inflation on tread contact and wear.

TABLE 45–2 INFLATION PRESSURE CONVERSION (KILOPASCALS TO PSI)

kPa	psi	kPa	psi
140	20	215	31
145	21	220	32
155	22	230	33
160	23	235	34
165	24	240	35
170	25	250	36
180	26	275	40
185	27	310	45
190	28	345	50
200	29	380	55
205	30	415	60

Conversion: 6.9 kPa = 1 psi.

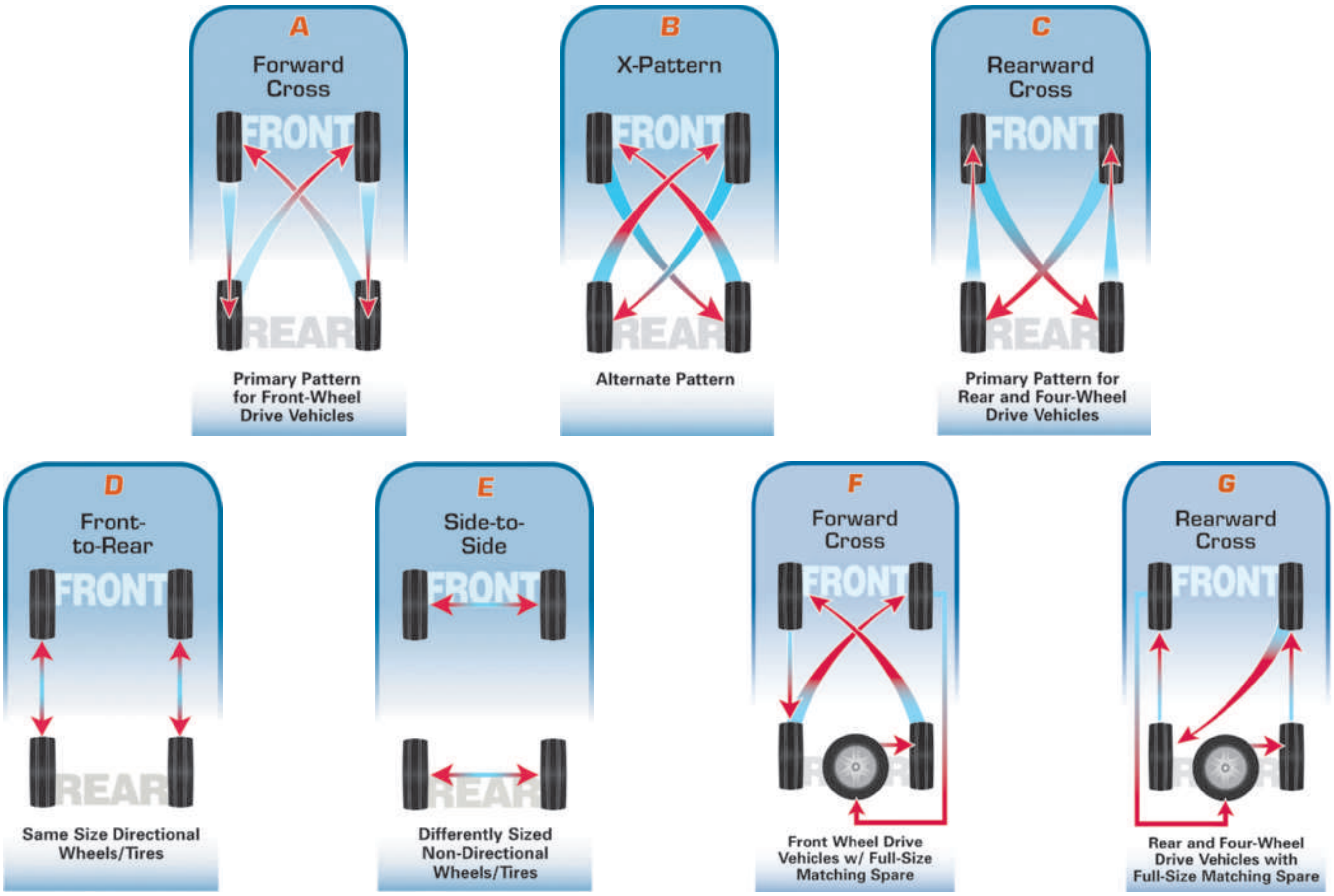
Tire Rotation

Part of a preventive maintenance program is the rotation of the tires. Doing this on a regular basis can preserve balanced handling and traction and even out tire wear. Most manufacturers recommend this be done at least every 6,000 miles (9650 km). It is important to remember that tire rotation will not correct wear problems due to misalignment, worn mechanical parts, or incorrect inflation pressures.

The industry has described seven rotation patterns that cover the procedure for most cars and light trucks **(Figure 45–15)**.

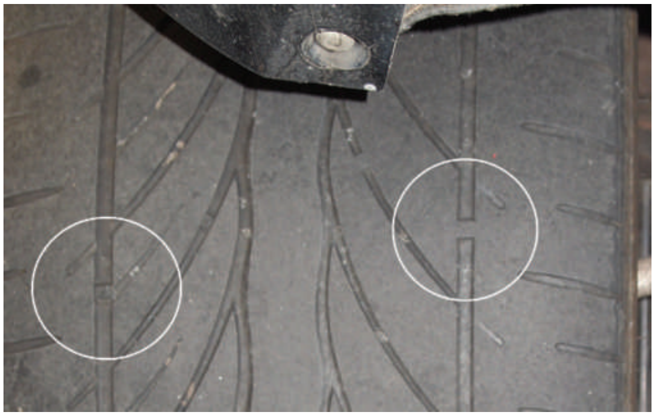
Tread Wear

Most tires used today have built-in tread wear indicators (wear bars) to show when they need replacement. These indicators appear as ½-inch wide bands when the tire tread depth wears to $\frac{1}{16}$ inch (1.6 mm) **(Figure 45–16A)**. When the indicators

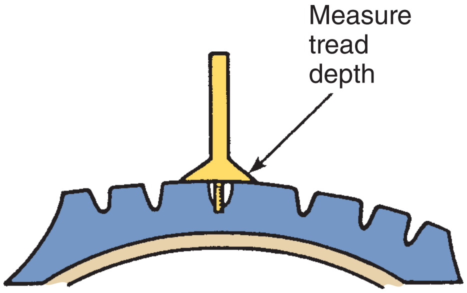


Courtesy of The Tire Rack.

FIGURE 45–15 On FWD cars, rotate the tires in a forward cross pattern (A) or the alternative pattern (B). On RWD or 4WD vehicles, rotate the tires in a rearward cross pattern (C) or the alternative pattern (B). The front-to-rear (D) pattern may be used for vehicles equipped with the same-size directional wheels and/or tires. The side-to-side (E) pattern may be used for vehicles equipped with different-sized nondirectional tires and wheels on the front axle compared to the rear axle. On FWD cars with a full-size matching spare, rotate the tires in a forward cross pattern (F). On RWD or 4WD vehicles with a full-size matching spare, rotate the tires in a rearward cross pattern (G).



(A)



(B)

FIGURE 45–16 (A) Tread depth wear bars. (B) Checking tread depth.

appear in two or more adjacent grooves at three locations around the tire or when cord or fabric is exposed, tire replacement is recommended.

If the tires do not have tread wear indicators, a tread depth indicator **(Figure 45–16B)** quickly shows in 32nds of an inch how much tire tread is left. When only $^{2}/_{32}$ inch is left, it is time to replace a tire.

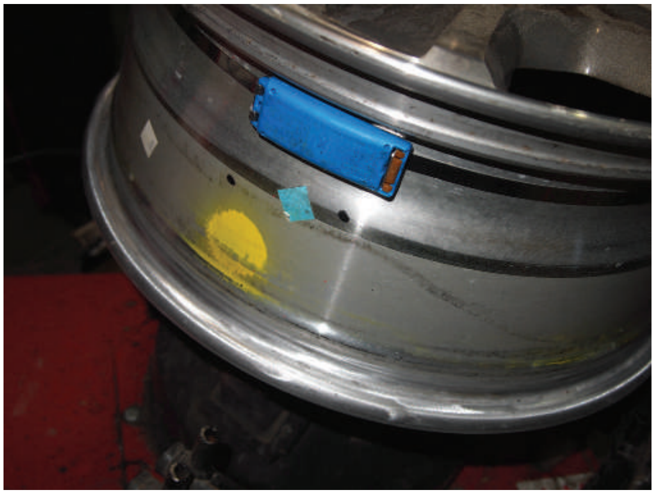
Proper wheel alignment allows the tires to roll straight without excessive tread wear. The wheels can go out of alignment from striking raised objects or potholes. Misalignment subjects the tires to uneven and/or irregular wear.

GO TO Go to Chapter 49 for more information about wheel alignment.

Tire Pressure Monitor (TPM) Systems

The U.S. DOT National Highway Traffic Safety Administration (NHTSA) has developed a federal motor vehicle safety standard that requires the installation of tire pressure monitoring (TPM) systems on all 2008 and newer passenger cars, trucks, multipurpose passenger vehicles, and buses with a gross vehicle weight rating of 10,000 pounds or less, except those vehicles with dual wheels on an axle. The monitoring systems must illuminate a warning light if one or more tires is at least 25 percent below the recommended cold-inflation pressure to warn the driver of an underinflated tire. As a result of this standard, two basic TPM designs are being used.

The most commonly used system is referred to as a direct system. In this system an air pressure sensor is strapped around the drop center of each wheel **(Figure 45–17A)**, or the sensor is attached to a special tire valve **(Figure 45–17B)**. The pressure sensor measures the tire's inflation pressure and relays this information to the vehicle via radio waves. These signals are picked up by a body-mounted antenna typically, the remote door lock receiver.



(A)

(B)

FIGURE 45–17 (A) A TPMS strapped to the inside of the wheel. (B) A tire pressure monitor and air valve assembly.

A central electronic control unit processes the signals from the four wheels and reports any variations to the system.

The tire pressure monitor (TPM) checks the inflation pressures in all four tires at frequent periodic intervals. The TPM sensors keep track of the tire pressures both when the vehicle is moving and when it is stationary. If the TPM detects enough change in any tire's inflation pressure, it responds by triggering a warning lamp on the instrument panel.

A typical **direct TPM** system has the following components:

- Tire pressure sensor and air valve. This may be a single unit, called a clamp-in sensor **(Figure 45–18A)** or the stem may be separate and replaceable **(Figure 45–18B)**. These are called snap-in sensors. Either type may be able to adjust the angle of the stem to the sensor, allowing them to be used in different wheel applications. The sensor measures tire pressure and temperature and transmits a signal and unique ID number for that particular sensor. Both types of sensors have a built-in battery that is not replaceable.
- Tire pressure warning antenna and receiver **(Figure 45–19)**. This unit receives and transmits the signals from the transmitters to the tire pressure warning control unit. The TPM receiver is often built into the remote keyless entry (RKE) receiver located in the driver's door though some vehicles use a dedicated TPM receiver.
- Tire pressure warning control unit. This unit receives the signal from the receiver. If the measured air pressure is equal to or lower than a specified value, this unit transmits a signal, causing the air pressure warning light to illuminate.
- Tire pressure warning light. Located in the instrument cluster, this unit informs the driver of low tire pressure or a problem in the system.
- Tire pressure warning reset switch. This unit is used after setting the tire pressure, or after sensor, tire, or wheel replacement. It is used to allow the control unit to relearn the system.

In an attempt to meet the TPM standard without the cost of a direct system, some manufacturers use an indirect system. These systems do not use pressure sensors; rather they rely on the inputs from wheel-speed sensors. These signals have been used for ABS or other systems. With **indirect TPM**, the PCM is reprogrammed to use those signals to identify when a tire has lost air pressure. Indirect systems are also used on some older vehicles with run-flat tires. This was necessary because run-flat

(A)

(B)

FIGURE 45-18 (A) A clamp-in pressure sensor. (B) Snap-in pressure sensors with replaceable stems.

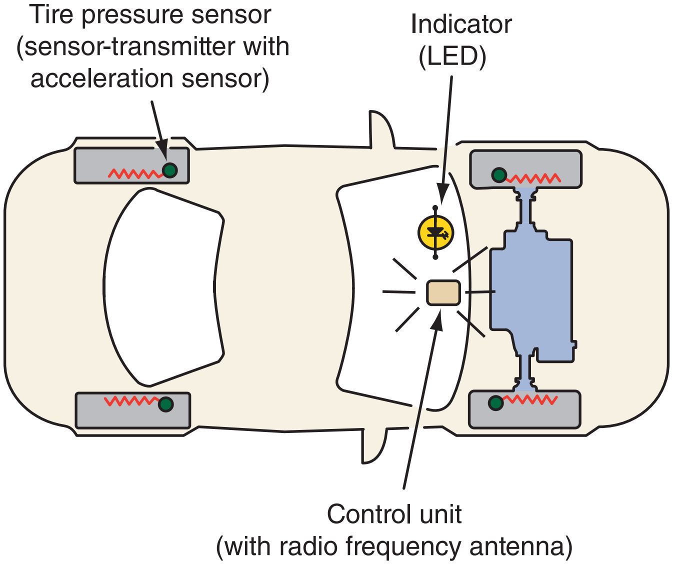


FIGURE 45-19 Basic components for a direct TPM system.

tires without air appear normal. The driver needs to be alerted to the loss of air.

The input signals from the wheel-speed sensors are used to compare the rotational speeds of the four tires. When a tire loses or gains air pressure, it will roll at a slightly different number of revolutions per mile than the other three tires. When the computer senses this difference, a warning lamp will light.

Indirect systems are not as effective as direct systems, however. These systems cannot tell the driver which tire has low pressure. They also are not capable of informing the driver when all four tires are losing air pressure. This commonly happens when the outside temperature drops.

Warning System The TPM warning system can vary from a warning lamp to a graphic display that shows which tire is low on pressure. Many systems allow the driver to monitor the current air pressure of each tire. If the PCM detects a problem with the TPM system, a warning lamp or message will appear in the instrument cluster. After tires have been rotated or replaced, the system may need to relearn tire position. During this time, a message or warning lamp may be illuminated. Once the relearning process is completed, the message will turn off.

If the system is working correctly, the TPM lamp and the low tire pressure lamp should illuminate for about 2 seconds when the ignition is turned on. If the lamps do not turn off, there is a problem in the system. Typically, low tire pressure keeps the warning lamp on after the vehicle is started. A problem with the system, such as failed sensor, will cause the light to flash. The system will typically set a DTC when there is a problem with the system or when it detects low pressure in any of the four tires.

Testing a TPM System

The TPM system in most vehicles is tied directly to the PCM; therefore, faults cause DTCs to set. TPM system data can often be monitored and DTCs retrieved with a scan tool **(Figure 45–20)**. Special tools are required to accurately test the problem sensor(s). A TPM sensor tool is a wireless tool that may be used with a scan tool for diagnosing sensors and allowing the system to relearn when a part has been replaced. Some TPM tools can plug into the DLC and perform a system relearn after tire service, eliminating the need for using a scan tool.

The TPM sensor tester is used to reset the system, which may be needed after tires are rotated, tires or wheels are replaced, repairs are made to the system, and when the vehicle's battery is low or replaced. The tester activates the sensors and the transmitted data from them can be observed. Most systems require placing the tool near the sensor and then activating the sensor via the tool **(Figure 45–21)**. The sensor then broadcasts information such as the sensor ID,

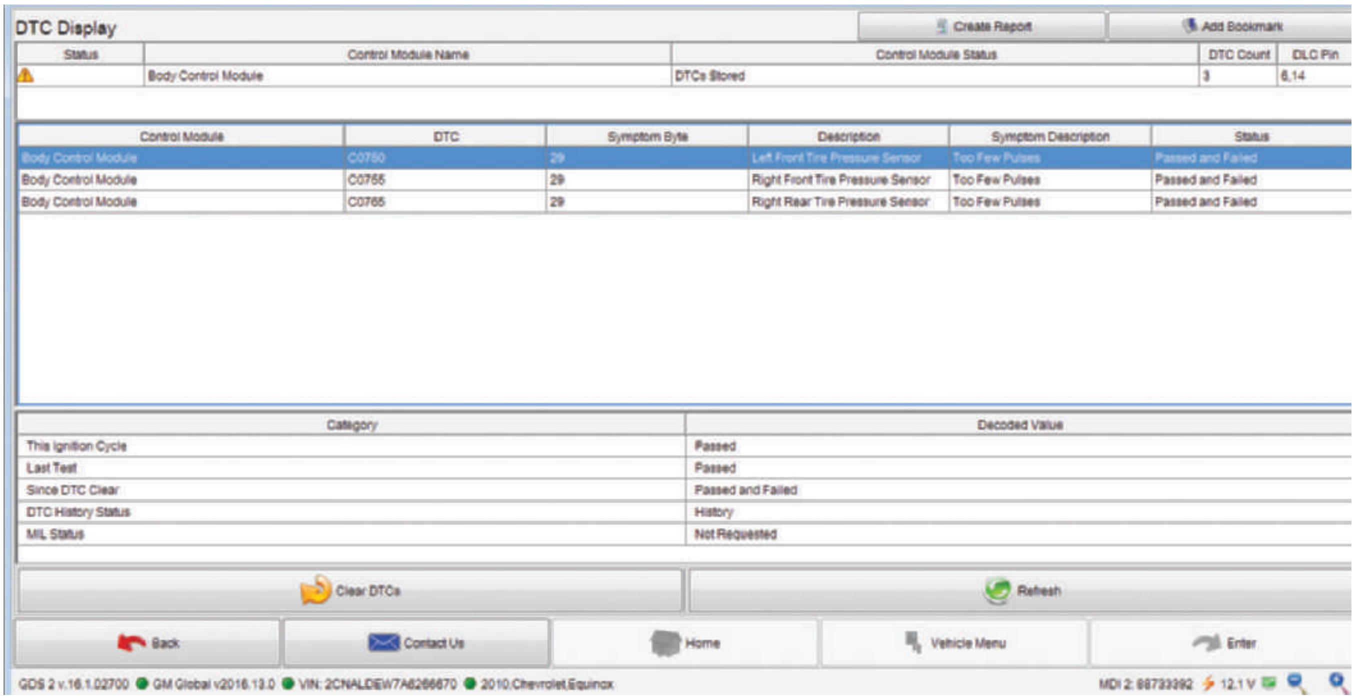


FIGURE 45–20 TPM data displayed on a scan tool.

FIGURE 45–21 A TPM tester.

tire pressure and temperature, and battery information. If a sensor fails to communicate, the internal battery may be dead or the sensor is faulty. Any problem with the sensor requires sensor replacement.

TPMS Service

TPMS service can range from simply checking and setting tire pressure to replacing sensors and correcting faults with the receiver, wiring, or network. Before working on the tires or TPM system, verify system operation by observing the TPM warning light on the dash. Make sure the light comes on during the key-on bulb check and goes out once the engine starts. If the TPM light remains on or flashes, test the sensors and system to determine the fault before continuing. This approach is called “test before you touch” and has been adopted by the auto repair industry as a way to check TPM system condition before doing any tire service, even adjusting air pressure. Any problems with the TPM need to be documented on the repair order and addressed with the customer.

CUSTOMER CARE

A customer may ask about not replacing TPM sensors that have stopped working or removing them when installing new tires. Because the TPM system is a mandated safety system installed from the factory, it is not up to the shop or the technician to decide whether or not the sensors should be installed. Removing or bypassing any type of safety system on a vehicle is unwise and can have legal consequences.

Because the TPM systems are mandated safety equipment, it is illegal for technicians and shops to disable or tamper with its operation. If the TPM system is inoperative when the vehicle comes into the shop, such as from dead sensor batteries, the customer can refuse to replace the faulty sensors. The RO should thoroughly document the condition, and you should have the customer sign off that the system in inoperative.

If a vehicle is in for service, such as tire replacement, and a sensor becomes damaged, it will need to be replaced to keep the system operational. Disabling the TPMS and putting the vehicle back out on the road could have serious legal consequences if an accident were to occur due to an inflation issue.

The TPM system usually requires a relearn after work is performed, including setting tire pressure, rotating the tires, and replacing a sensor. Before performing a tire rotation on a vehicle with a direct TPM system, check the service information for any special procedures that need to be followed to perform the relearn. On many indirect systems, pressing the TPM Learn button places the vehicle into learn mode. After driving for several minutes, the system learns tire rotation speeds and infers each tire’s pressure. Activating learn mode on direct systems vary on the year, make, and model of vehicle. **Table 45–3** shows common TPM relearn procedures.

A fault in the TPM system will set DTCs in the computer system and cause the TPMS warning light to flash and/or stay on as well. Nonfunctioning pressure sensors are the most common reason for failures. These sensors cannot be serviced and must be replaced when faulty or when the battery is too weak to broadcast the signal. Most manufacturers recommend replacing the sensors when the tires are replaced or every five to seven years.

Replacing a TPM Sensor

Once you have confirmed a sensor needs replacement, dismount the tire from the wheel. Some vehicles use a band clamp sensor. To replace this type,

TABLE 45-3

GM and some Asian Vehicles - Scan tool reset	Ignition ON Install scan tool and initiate TP sensor learn mode. Horn will sound twice and LF turn signal light will turn on. Start at LF sensor and activate with TPM tool and wait for horn to sound. Once horn sounds, continue and repeat for RF, RR, and LR wheels.
Some GM - Driver Information Center reset	Ignition ON Activate TPM relearn mode in DIC. Horn will sound twice and LF turn signal light will turn on. Start at LF sensor and activate with TPM tool and wait for horn to sound. Once horn sounds, continue and repeat for RF, RR, and LR wheels.
Some Ford	Ignition OFF Press and release brake pedal Turn ignition OFF to RUN three times Press and release brake pedal Turn ignition OFF Turn ignition OFF to RUN three times, horn should sound once. Activate LF tire with TPM tool, horn will sound when sensor is learned. Activate RF, RR, LR sensors.
Various	Press and hold the TPM reset button on the dash. The TPM light will blink. Once the vehicle is driven approximately 20 minutes, the TPM system will calibrate.
Various	Press Brake and release Cycle ignition on/off, on/off, on Press Brake and release Cycle ignition off/on, off/on, off/on Horn honks indicating now in learn mode and dash will indicate which wheel to start with (normally front left, then clockwise around the car) Use TPM tool to trigger each sensor Car horn will sound as each tire's sensor is learned and honk twice when completed successfully
Some GM Vehicles	Cycle ignition ON (on not start) Press "lock/unlock" on key fob at the same time or use DIC menu Vehicle horn sounds twice indicating now in learn mode. Turns on lights in order of relearn (normally front left, then clockwise) Use TPM tool to trigger each sensor Car horn will sound as each tire's TPMS is relearned A double horn honk when completed.
Various Indirect Systems	Set pressure to specifications. Press and hold down button "RESET" button. Press and hold down TPM SET button until warning light flashes three times. Drive vehicle (speed and times vary by make, model, year).

remove the clip holding the sensor to the band and rotate the sensor from the clamp. For clamp-in sensors, remove the outer cap and pull the sensor out from the valve stem hole in the rim. Snap-in sensors require removing the screw holding the stem to the sensor. Apply tire lubricant if indicated by the sensor manufacturer and install the new sensor on the wheel. With both types of stem sensors, it is important that they are properly installed and torqued. Clamp-in sensors require a seal between the stem and the wheel and that the cap be torqued, typically to around 30 to 80 in.-lbs. Snap-in stems are torqued using a special torque wrench screwdriver for TPM sensors. Valve cores are also torqued with a special tool. With both sensor types, do not guess when tightening, check the

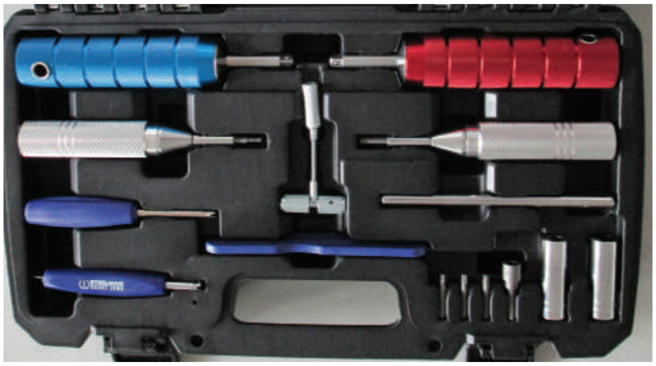


FIGURE 45–22 A TPM sensor took kit.

torque specifications and use the proper tools **(Figure 45–22)** or you can damage the sensors.

Replacement sensors can be either OE or aftermarket types, which determines how the new sensor is programed to the vehicle. For some systems or sensors, you need to locate and record the old sensor ID number and use it for the new sensor. This is called sensor cloning. Other systems allow the new sensor ID numbers to register into the system. Refer to the service information for which type of sensor is used and how new sensors are programed.

New sensors are shipped turned off or in a shipping mode. To program the new sensor to the vehicle, activate the TPM learn mode. This may be done through the driver information center **(Figure 45–23)**,

FIGURE 45–23 Performing a TPM relearn through the driver information center.

the key fob, TPM tool, or scan tool. Activate each sensor per the manufacturer's procedures and verify proper system operation once complete.

Tire/Wheel Runout

A tire that is off center or egg shaped is said to run out. This is known as **radial runout** or eccentricity. One that wobbles side-to-side is said to have **lateral runout**. If a tire with some built-in runout is mismatched with a wheel's runout, the resulting total runout can exceed the ability of the balance weights to correct the problem. For this reason, part of a tire/wheel inspection should be for excessive runout. Sometimes tires or wheels can be remounted to lessen or correct runout problems.

To avoid false readings caused by temporary flat spots in the tires, check runout only after the vehicle has been driven. Visually inspect the tire for abnormal bulges or distortions. The extent of runout should be measured with a dial indicator. All measurements should be made on the vehicle with the tires inflated to recommended load inflation pressures and with the wheel bearing adjusted to specification.

Measure tire radial runout at the center and outside ribs of the tread face. Measure tire lateral runout just above the buffing rib on the sidewall **(Figure 45–24)**. Mark the high points of lateral and radial runout for future references. On radial ply tires, radial runout must not exceed 0.081 inch (2.06 mm) and lateral runout must not exceed 0.099 inch (2.51 mm).

If the total radial or lateral runout of the tire exceeds the specified limits, it is necessary to check wheel runout to determine whether the wheel or tire is at fault. Wheel radial runout is measured at the wheel rim just inside the wheel cover retaining nibs. Wheel lateral runout is measured at the wheel rim bead flange just inside the curved lip of the flange. Wheel radial runout should not exceed 0.035 inch (0.89 mm) and wheel lateral runout should not exceed 0.040 inch (1.02 mm). Mark the high points of radial and lateral runout for future reference.

If the total tire runout, either lateral or radial, exceeds the specified limit but wheel runout is within the specified limit, it might be possible to reduce runout to an acceptable level. This is done by changing the position of the tire on the wheel so that the previously marked high points are 180 degrees apart. Many computer wheel balancing machines can detect wheel and tire runout and determine the best way to remount the tire on the wheel to reduce total runout.

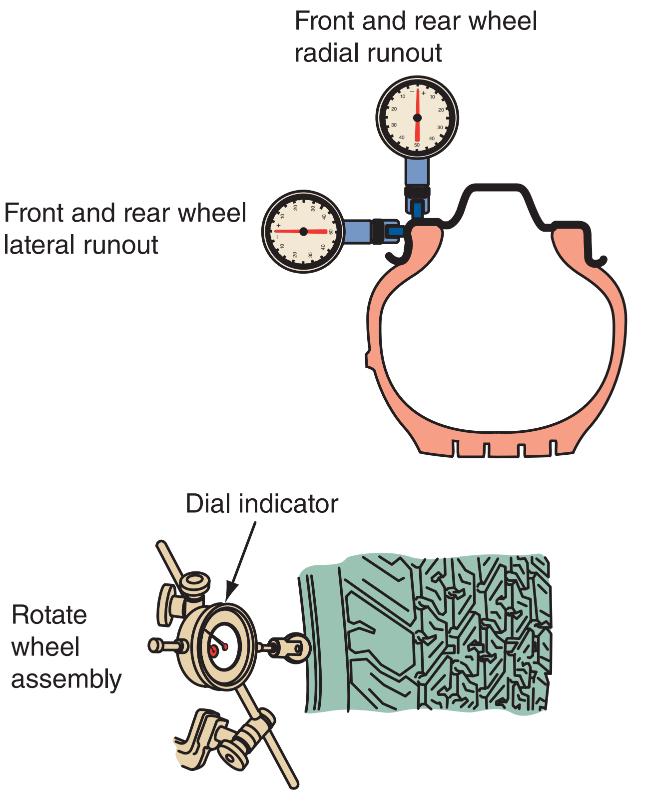


FIGURE 45–24 Checking wheel runout.

Axle flange runout can cause vibration concerns similar to those caused by wheel and tire runout. The axle flange can be damaged or bent by impacts with curbs and cause the wheel to wobble when driving. Use a dial indicator to measure runout at the flange **(Figure 45–25)** and compare to specifications.

Tire Pull

It is not uncommon for a tire to cause a pull to one side when driving. This is caused by conicity, meaning the tire has a cone shape. As the tire rotates, it tries to go in the direction of the narrow end of the cone shape, pulling the vehicle either left or right. Unfortunately, this problem occurs during tire construction and cannot be fixed. Depending on the severity of the conicity problem, the tire, if installed on the rear of the vehicle, may not cause a pull until it is moved to the front of the vehicle during a tire rotation. If this occurs, the customer may return to the shop complaining the car pulls to one side since the tires were rotated. To check if conicity is the cause, switch the front tires from side-to-side and test drive the vehicle. If the pull goes away or pulls in the other direction, conicity is the problem.

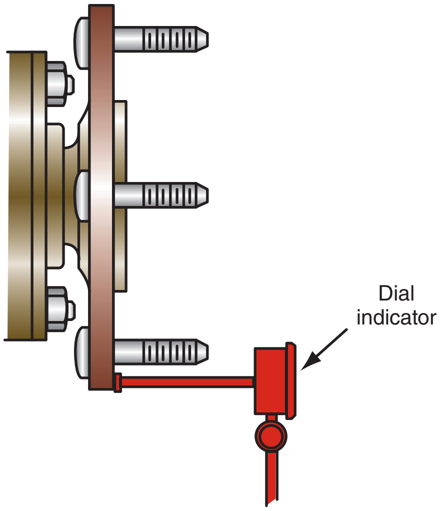


FIGURE 45–25 Measuring axle flange runout.

Tire Replacement

Tires should be replaced when they are worn or heavily damaged. In addition, because modern tires last much longer than those even 20 years ago, tire age needs to be considered. Tires, especially those that remain outside all year, are subject to dry rot and cracking. Over time this weakens the tire and can lead to tire failure. Although there is not a current replacement age requirement in the United States, many tire and rubber manufacturers recommend tire replacement based on age alone at 6 to 10 years. Tires that reach 6 years of service should be very carefully inspected for wear, damage, and rot. Once a tire reaches 10 years, it should be replaced.

Replacement tires should match the tires that were on the vehicle originally. This is the preferred choice unless a change in appearance or handling is desired. Vehicle manufacturers know how important the right tire is. They spend a great deal of time developing a suspension system that works in the way they believe it should. Part of that development is tire design. However, the tire choice by manufacturers is a compromise—a compromise between characteristics. Manufacturers choose the characteristics they believe owners of that model vehicle want. If the owner is happy with the vehicle, recommend that the replacement tires match the ones the vehicle was originally sold with. When replacing tires, installing tires that do not meet the requirements of the OE tires could place you in legal trouble. If a tire does not meet the OE specifications for the vehicle, such as for load capacity or speed rating, and the

replacement tire fails, you could face legal consequences for installing a sub-standard tire.

Replacing One Tire

In some cases, only one tire needs to be replaced. The usual causes of this are that the tire was damaged due to an accident, a road hazard, or vandalism. Replacing one tire is recommended only if the other tires have a satisfactory amount of tread left. Make sure the replacement tire is the same brand, type, size, and speed rating as the other tires. If the replacement tire is different from the rest, the vehicle can exhibit unsafe handling problems. Also, the replacement tire should have a similar tread design as the remaining tires. This helps reduce noise and other issues that can be caused by dissimilar tread designs. The replacement tire should be mounted on the rear axle and the tire (of the remaining three) with the most tread depth should be mounted on the opposite side of the axle.

Replacing Two Tires

If there is a need to replace two tires and the other two have good treads, the replacement pair should be mounted on the rear axle. The replacement tires should match the remaining pair of tires as closely as possible.

Four-Wheel and All-Wheel Drive Vehicles

Because of the increased popularity of small SUVs and other vehicles using all-wheel drive, replacing tires as a set of four is now recommended. These all-wheel drive systems use a center differential or viscous clutch to apply power to a set of wheels when there is a speed difference between the front and rear wheels. If only a pair of tires is replaced, this leaves a set of worn tires on one axle. The worn tires will have a slightly smaller diameter than the new tires are on the other axle. Even this small amount of size difference can cause a speed difference between the front and rear tires. The difference in size creates a difference in wheel rotation speeds, which can damage the differential or viscous clutch over prolonged use.

Changing Tire and/or Wheel Size

An owner may want more emphasis on handling or fuel economy and may desire a different type of tire and/or wheel. There are several other factors that may dictate a change in tire size, and the customer may come to you for advice. Perhaps one of the most important considerations is that the tire must be able to carry the weight of the vehicle. The load-carrying capacity of a tire must be the same as or higher than the OEM tire. Changing tires from one aspect ratio to another also changes the sectional width, which relates to the load-carrying capacity of the tire.

Most tire width changes affect the overall diameter of the tire. A change in the tire's outside diameter will cause a change in the overall gear ratio and will affect the accuracy of the speedometer and odometer. A change in tire diameter or aspect ratio may also affect overall driveability. This is due to false readings from the vehicle or wheel-speed sensors. On passenger cars and mini-vans, a 3 percent or less change in tire diameter is acceptable. Most SUVs and pickups can handle a change as much as 15 percent. The overall diameter of a tire can be calculated.

A vehicle may have the ability to change the tire size that is programmed into the on-board computer system. Typically the options to change the tire size is one of the sizes offered as an option from the vehicle manufacturer **(Figure 45–26)**.

Plus Sizing A way to change the contact area of a tire without seriously affecting its overall diameter is using the plus sizing system. This system is based on the overall diameters of a combination of different-sized tires and wheels. The system requires much research but it is the best way to achieve the

FIGURE 45-26 Changing wheel and tire size with a scan tool.

desired results. For example, the customer wants to have a wider tread area **(Figure 45–27)**. The OEM tire was a 195/75-14 tire mounted on a 14 × 6 inch wheel. The overall diameter of this assembly is 25.5 inches (647.7 mm). There are three available wheel/tire combinations that closely match that diameter. If a 205/65-15 tire is mounted on a 15 × 7 inch wheel, the width increases by 0.39 inches (10 mm), whereas the diameter stays the same. If a 16 × 7.5 inch wheel is used along with a 225/55-16 tire, the width increases by 1.18 inches (30 mm) and the overall diameter increases by only 0.2 inch (5.1 mm). Going even wider, if a 235/45-17 tire is mounted on a 17 × 8 inch wheel, the tire's width increases by 1.57 inches (40 mm) and the overall diameter decreases by 0.2 inch (5.1 mm). Although the latter two changes do not match the OEM diameter, they are certainly within the 3 percent rule.

Additional Points Here are some additional important points to consider:

- Handling improvement typically comes from more tire contact on the road, and fuel economy increases with less.
- Increasing tread width and tire contact can affect steering effort as more tire is in contact with the road surface.
- Tires of different sizes, constructions, and wear may affect handling, stability, and fuel economy.
- Too wide of a tire may rub against the body or suspension.
- Radial tires should never be mixed with another type of tire on the same vehicle.
- All tires on the vehicle should be the same size, construction, tread design, and speed rating unless the vehicle was otherwise equipped by the OEM.
- Tires should be replaced with ones of the same or higher speed rating. Speed ratings should not be downgrades from original equipment ratings.
- A hard tread will provide long wear and low rolling resistance but will also have poorer traction.
- An aggressive tread pattern may provide resistance to hydroplaning or better traction in the snow, but they are noisier on dry surfaces.
- A tire with stiff sidewalls will increase high-speed stability and improved handling, but it will make the overall ride rougher.
- A replacement rim should provide the same overall tire diameter as the original.
- A narrower rim pulls the beads of the tire closer together, causing the sidewalls to curve. This allows the sidewalls to flex more, which results in a softer ride but reduces tire life.
- A wide rim increases the distance between the beads, which stiffens the sidewalls and provides a harsher ride and shorter tire life. However, it will improve the handling of the vehicle.
- A replacement tire should have, at minimum, the qualities of the tires installed when the vehicle was new. Replacing tires with ones with a reduced load capacity, traction, or temperature rating is not recommended.

Calculating Tire Dimensions When replacing tires with other than the original tire size, you may need to calculate the dimensions of a desired replacement tire. Like everything else, there are formulas to make these calculations.

To determine the section height of a tire, multiply its aspect ratio by the sectional width.

$$\text{Width} \times \text{Aspect Ratio} = \text{Section Height}$$

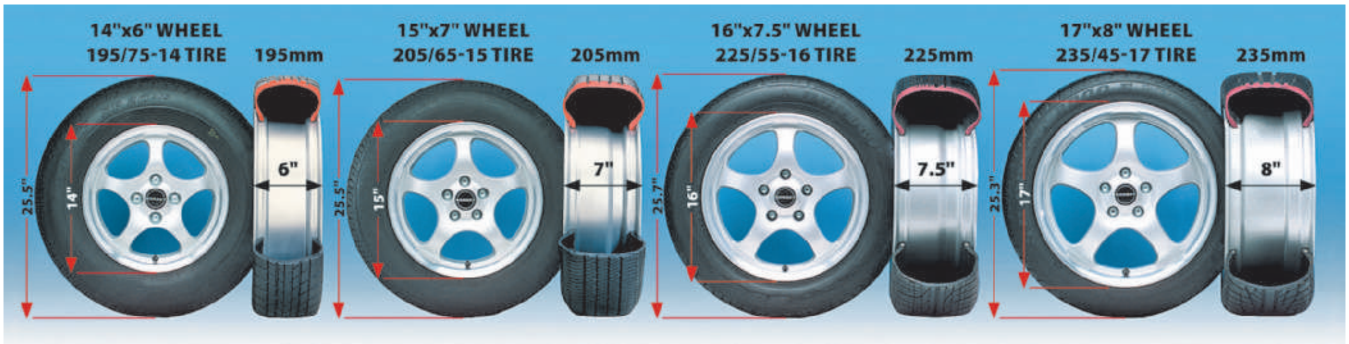


FIGURE 45–27 The effects of plus sizing.

To determine the overall diameter of a tire, multiply the sectional height by 2 (this is called the combined sectional height because there are two), then add the diameter of the wheel.

Combined Section Height (Sectional Height × 2) + Wheel Diameter = Tire Diameter

Tire/Wheel Assembly Service

For most tire/wheel service, the assembly must first be removed from the vehicle. The wheel and the tire must be separated whenever tires are replaced or repaired. The wheel and tire mount on the hub flange, which may be on the end of an axle or part of a brake rotor or drum. The wheel is held against the hub and drum or rotor by the wheel nuts or bolts. Most cars and trucks use lug nuts that thread onto studs. However, many European cars use wheel bolts that thread into holes in the hub flange to secure the wheels in place.

Tire Repair

The most common tire problem besides wear is a puncture. When properly repaired, the tire can be put back in service without the fear of an air leak recurring. Punctures in the tread area are the only ones that should be repaired or even attempted to be repaired. Never attempt to service punctures in the tire's shoulders or sidewalls. In addition, do not service any tire that has sustained the following damage:

- Bulges or blisters
- Ply separation
- Broken or cracked beads
- Fabric cracks or cuts
- Wear to the fabric or visible wear indicators
- Punctures larger than ¼-inch (6 mm) diameter

Some car owners attempt to seal punctures with tire sealants. These sealants are injected into the tire through the valve stem. Sometimes the chemicals in the sealant do a great job sealing the hole, other times they fail. The sealants should never be used for and will not work on sidewall punctures. Some of the sealants are very flammable and carry a warning that the tire should be marked so that the next technician knows the sealant has been used.

Sealants may interfere with the operation of TPM sensors. If tire sealant has been used, the customer should be notified that damage to the sensor may occur and it may need to be replaced.

Warning! Tire sealants injected through the valve stem can produce wheel rust and tire imbalance.

To locate a puncture in a tire, inflate it to the maximum inflation pressure indicated on its sidewall. Then submerge the tire/wheel assembly in a tank of water or spray it with a soapy water solution. Bubbles will identify the location of any air leakage.

Mark the location of the leak with a tire crayon so it can be easily found once the tire is removed from the wheel. Also use the crayon to mark the location of the valve stem so that original tire and wheel balance can be maintained after the tire is put back on the wheel.

The proper procedure for dismounting and remounting a tire is illustrated in Photo Sequence 41. Do not use hand tools or tire irons alone to change a tire because they might damage the beads or wheel rim. When mounting or dismounting tires on vehicles using aluminum or wire spoke wheels, it is recommended that the tire changer manufacturer be contacted about the accessories that are required to protect the wheel's finish.

Warning! Once a tire puncture has been repaired, many tire manufacturers state that the tire no longer retains its speed rating. This is because the puncture compromises the tire and could ultimately fail under the stress of high-speed driving. Because of this, the work order must be noted and the customer be informed that the speed rating is no longer applicable to the repaired tire.

TPM Sensors

If the wheel/tire assembly has a direct TPM system, the sensor can be removed after the air pressure has been released from the tire. This should be done before the tire is removed from the rim. Unbolt the air valve assembly and allow it to drop into the tire. Before servicing the tire or wheel, remove the

SHOP TALK

Some air valves for TPM systems are made of brass and have an aluminum valve stem. Over time, the valves will experience galvanic corrosion and will seize within the brass valve core. If the tire you are working on shows these problems, replace this unit with a nickel-plated valve core.

sensor. After tire and/or wheel repairs have been made, install the sensor with a new rubber O-ring or seal and aluminum retaining nut. The retaining nut must be torqued to specifications.

Repair Methods

Once the tire is off the wheel and the cause of the puncture is removed and the location marked, the tire can be repaired from the inside using a service plug and a vulcanized patch. Although the repair kit's instructions should always be followed, there are some general guidelines that help make a good, permanent patch of the puncture. The following methods are the most common methods used to repair a tire.

Plug Repair The head-type plug is commonly used. A plug that is slightly larger than the size of the puncture is inserted into the hole from the inside of the tire with an insertion tool. Before doing this, insert the plug into the eye of the tool and coat the hole, plug, and tool with vulcanizing fluid. Sealing the puncture with a plug from the outside of the tire is not a proper repair.

CUSTOMER CARE

The repair of a Michelin PAX system requires special equipment, replacement parts, and specialized training. If you attempt to repair one of these systems without the necessary equipments, parts, and training, the tire warranty will become void. Make sure your customer understands this. Also, the use of plugs and/or sealants to repair the tire will void the warranty.

While holding and stretching the long end of the plug, insert it into the hole. The plug must extend above both the tread and inner liner surface. If the plug pops through, throw it away and insert a new plug. Once the plug is in place, remove the tool and trim off the plug $\frac{1}{32}$ inch (0.7 mm) above the inner surface. Be careful not to pull on the plug while cutting it.

Cold Patch-Plug Repair To properly repair a puncture, a one piece patch-plug or stem patch is used. This type of repair requires removing the tire from the wheel to inspect for internal damage. A tire that has been driven on flat will show obvious damage once removed **(Figure 45–28)**. This tire needs to be replaced and is dangerous if put back on the road due to the damage to the sidewalls. Removing the tire is the only way to check for this type of damage.

Remove the item that punctured the tire and ream the hole with a carbide cutting tool and drill. Once the tire is dismounted, buff the liner to prepare the surface. Clean and apply rubber cement and let it dry. Next, carefully remove the backing from the patch. Center the patch base over the punctured area and pull the plug through the puncture and seat the patch. Run a stitching tool over the patch to help bind it to the tire.

Warning! When repairing radial tires, use only a patch specially approved for that application. Some radial patches have arrows that must be lined up parallel to the radial plies.

Hot Patch Repair A hot tire patch application is similar to a cold patch. The difference is that the hot

FIGURE 45-28 Dismounting to repair from the inside reveals this tire is destroyed.

PHOTO SEQUENCE 41

Dismounting and Mounting a Tire on a Wheel Assembly

P41-1 Dismounting the tire from the wheel begins with releasing the air, removing the valve stem core, and unseating the tire from its rim. The machine does the unseating. The technician merely guides the operating lever.

P41-2 Once both sides of the tire are unseated, place the tire and wheel onto the machine. Then depress the pedal that clamps the wheel to the tire machine.

P41-3 Lower the machine's arm into position on the tire and wheel assembly.

P41-4 Insert the tire iron between the upper bead of the tire and the wheel. Depress the pedal that causes the wheel to rotate. Do the same with the lower bead.

P41-5 After the tire is totally free from the rim, remove the tire.

P41-6 Prepare the wheel for the mounting of the tire by using a wire brush to remove all dirt and rust from the sealing surface. Apply rubber compound to the bead area of the tire.

P41-7 Place the tire onto the wheel and lower the arm into place. As the machine rotates the wheel, the arm will force the tire over the rim. After the tire is completely over the rim, install the air ring over the tire. Activate it to seat the tire against the wheel.

P41-8 Reinstall the valve stem core and inflate the tire to the recommended inflation.

patch is clamped over the puncture and heat is applied to the patch to make it adhere.

Mounting Run-Flat Tires

Mounting and dismounting a run-flat tire requires patience and skill. Most shops have rim-clamp tire changers. Some of these use rollers to loosen the beads, whereas others have side-shovel bead looseners. As the tire revolves on the changer, the rollers automatically loosen the beads. When using side-shovel bead looseners, the tire must be manually placed into position, rotated on the changer, and flipped. Roller bead looseners are preferred for run-flat tires.

The bead looseners must be positioned on the sidewall near the bead. If the loosener is placed too far away from the bead, it may damage the sidewall inserts in the tire. The rotation of the bead loosener should begin with the bead on the back of the tire and only be inserted enough to free the bead from the wheel. Tire lubricant should be applied to the tire and wheel as the bead moves away from the rim. The process is then repeated on the front side of the tire until the outside bead is loose. Care should be taken not to damage the TPMS sensor or the inner wheel ring (if so equipped). The tire should then be removed from the wheel, following the instructions of the tire changer.

Tire Recycling

When a tire is damaged or badly worn, it should be replaced and the old tires be disposed of properly. Used tires should never be just thrown away. Due to their construction, they present many environmental hazards if not disposed of properly. In fact it is against the law to add them to the trash and send them to a landfill. Old, used tires can trap methane gas. The gas can then leak through landfill liners and pollute the soil and ground water associated with the landfill. Tires can also serve as a breeding ground for disease-carrying organisms, particularly mosquitoes. Tires disposed of improperly also present a fire risk. Tire fires burn very hot and are extremely difficult to extinguish. Also, in the extreme heat of the fire, the tires can melt into an oily substance. This oily substance can run off and contaminate the ground and nearby surface water.

Proper disposal of tires includes sending them to a recycling plant. The tires' rubber is used to produce asphalt, shoes, playground cover, floor mats, and many other rubber products. Old tires can also be used to make a tire-derived fuel, or TDF, which produces a higher amount of energy than either oil or coal. The non-rubber portions of a tire are also recycled. For example, the steel beads are processed and used by steel mills to produce new steel.

Wheel Inspection

The wheels should be carefully inspected each time a tire is to be mounted on it. The major causes of wheel failure are improper maintenance, overloading, age, and accidents, including pothole damage. The use of low-profile tires often increases the risk of wheel damage as the short sidewalls absorb less of the road shock. Wheels must be replaced when they are bent, dented, or heavily rusted; have leaks, cracks or elongated bolt holes; and have excessive lateral or radial runout. Wheels with a lateral or radial runout greater than specifications can cause high-speed vibrations. Wobble or shimmy caused by a damaged wheel eventually damages the wheel bearings. Stones wedged between the wheel and disc brake rotor or drum can unbalance the wheel.

Inflation

After the tire is mounted to the wheel, inflate the tires to the recommended pressure. Also check to see if any air is leaking from the beads or the point of repair.

Nitrogen Tire Inflation Many tire experts recommend that tires be filled with nitrogen rather than compressed air. Other experts say there is no need

SHOP TALK

When installing new tires, always install new air valve stems. The life of tire rubber is close to the life of the valve stem rubber. Most stems are the snap-in type. These are installed from inside the wheel with a pulling tool. Make sure that the stem is properly seated. Another style of stem has a retaining nut that must be removed when pulling off the old stem. Be sure to completely tighten the new nut. Vehicles equipped with TPM sensors should also have the sensors replaced when new tires are installed.

to do this if owners watch the air pressure in their vehicle's tires. The idea behind using nitrogen is simple: Nitrogen molecules are larger than air molecules. Therefore, it is less likely to leak out of a tire. Those in favor of using nitrogen claim that nitrogen-filled tires stay inflated about three times longer than air-filled tires. Nitrogen also helps keep tires cooler while traveling on the highway. This means the air pressure stays more constant and is less likely to leak out. The supposed result of these advantages is safer and longer lasting tires. The idea of using nitrogen in tires is not new. Race cars, commercial airliners, and trucks have used nitrogen-filled tires for many years.

Nitrogen inflation requires a nitrogen filling station **(Figure 45–29)**. Typically, a fill/purge cycle fills the tire, purges the air and refills the tire with nitrogen until the desired amount of nitrogen is reached. Once a tire is filled with nitrogen, a green valve stem cap is installed to alert others to refill the tire with nitrogen only. However, an owner may refill a tire with compressed air if the tire is severely deflated, but that tire should be refilled with nitrogen shortly afterward.

FIGURE 45-29 A nitrogen filling unit.

Installation of Tire/Wheel Assembly on the Vehicle

Before reinstalling a tire/wheel assembly on a vehicle, inspect the wheel bearings as described later in this chapter. Sometimes a wheel rusts or corrodes to the hub flange. If necessary, clean the axle/rotor flange and wheel center bore with a wire brush or steel wool. Then coat the axle pilot flange with disc brake caliper slide grease or an equivalent.

Place the wheel on the hub. Make sure the wheel is seated on the hub. A common mounting problem is caused by improperly positioning the wheel on the wheel hub or by improperly tightening the lug nuts. If the wheel uses a hub flange adaptor, make sure it is installed so the wheel properly centers on the flange **(Figure 45–30)**.

Install the locking wheel cover pedestal (if used) and lug nuts, and tighten them alternately to draw the wheel evenly against the hub. They should be tightened to a specified torque and sequence **(Figure 45–31)** to avoid distortion. The best way to do this is to snug up the lug nuts, then use a torque wrench for the final tightening. Loose lug nuts can cause shimmy and vibration and can also distort the stud holes in the wheels. The worst case is when the wheel comes off while the vehicle is being driven. Go over each lug twice with the torque wrench to be sure each is torqued to specification. Once torqued, check and adjust the air pressure in all tires.

FIGURE 45-30 An aftermarket wheel with a hub adaptor ring.

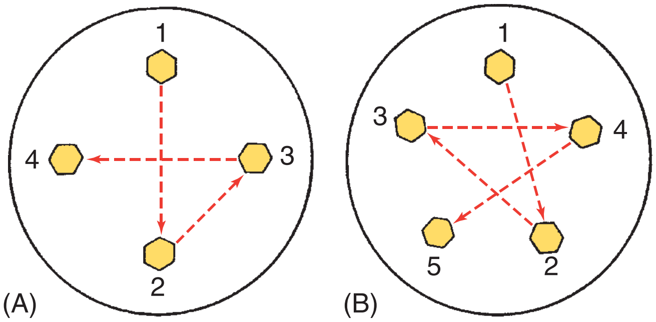


FIGURE 45-31 The lug nut tightening sequence for (A) a four-lug wheel and (B) a five-lug wheel.

Warning! Overtorqueing and uneven tightening of the lug nuts are a common cause of disc brake rotor distortion. Also, an overtorqued lug distorts the threads of the lug and could lead to premature failure. Undertorqueing the lug nuts could cause the wheel and tire to come off as the vehicle is being driven.

Tire/Wheel Balance

An out-of-balance condition can cause steering wheel shimmy and vibrations that can be felt throughout the vehicle. These vibrations are typically felt between 50 and 70 mph (81–113 km/h). Out-of-balance problems can also cause increased wear on the ball joints, as well as deterioration of shock absorbers and other suspension components.

Should an inspection show uneven or irregular tire wear, wheel alignment and balance service is a must. Wheel balancing distributes weights along the wheel rim, which counteract heavy spots in the wheels and tires and allow them to roll smoothly without vibration. The wheel weights are adhered to the wheel or are clipped over the edge of the wheel's rim. There are two types of wheel imbalance: static and dynamic.

Static Balance **Static balance** is the equal distribution of weight around the wheel. Wheels that are statically unbalanced cause a bouncing action called **wheel tramp**. This condition eventually causes uneven tire wear. As the name implies, static balance means balancing a wheel at rest. This is done by adding a compensating weight. A statically unbalanced wheel tends to rotate by itself until the heavy portion is down. A bubble balancer can be used to

FIGURE 45-32 A typical wheel weight attached to a wheel.

statically balance a tire and wheel. When it is placed on the balancer, any imbalance moves the bubble off center.

Many equipment manufacturers recommend static balancing a wheel at equal distances from the center of the light area. Balance weights are normally hammered on with their holding tabs between the tire bead and rim **(Figure 45–32)**. Wheel weights are not normally hammered onto alloy or mag wheels; rather, special tape weights are adhered to the wheels to balance them.

Dynamic Balance **Dynamic balance** is the equal distribution of weight on each side of the centerline. When the balanced tire spins, there is no tendency for the assembly to move from side-to-side. Wheels that are dynamically unbalanced can cause **wheel shimmy** and a wear pattern **(Figure 45–33)**. Dynamic balance, simply stated, means balancing a wheel in motion. Once a wheel starts to rotate and is in motion, the static weights try to reach the true plane of rotation of the wheel because of the action of centrifugal force. In an attempt to reach the true plane of rotation when there is an imbalance, the static weights force the spindle to one side.

At 180 degrees of wheel rotation, static weights kick the spindle in the opposite direction. The resultant side thrusts cause the wheel assembly to wobble or wiggle. When the imbalance is severe enough, as already mentioned, it causes vibration and front-wheel shimmy.

To correct dynamic unbalance, equal weights are placed 180 degrees opposite each other, one on the

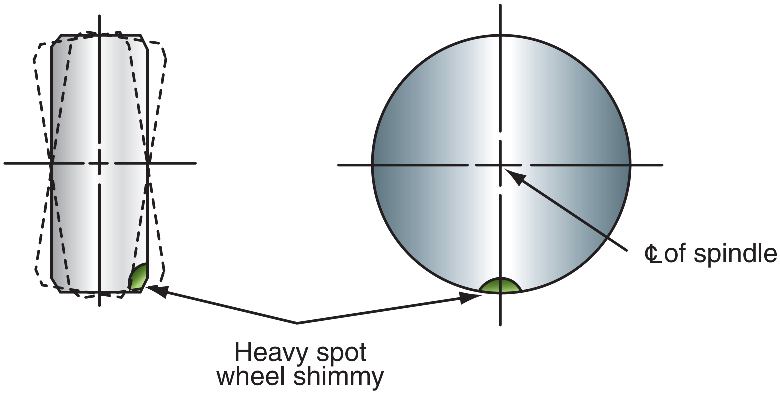


FIGURE 45-33 Dynamic wheel balancing calls for a weight to be attached to the wheel to compensate for a heavy spot on the wheel.

inside of the wheel and one on the outside, at the point of unbalance. This corrects the couple action or wiggle of the wheel assembly. Also, note that dynamic balance is obtained, while static balance remains unaffected.

Wheel Balancing

The most commonly used dynamic wheel balancer requires that the tire/wheel assembly be taken off and mounted on the balancer's spindle. The machine spins the entire assembly and determines the correct placement of weights to correct any static or dynamic imbalance. The results are shown in the balancer's display, which indicates where and how much weight to apply to the wheel. Newer balancers can help hide adhesive weights behind wheel spokes to give the wheel a cleaner appearance. There are several electronic dynamic/static balancer units available that will permit balancing while the wheel and tire are on the car. A switch on the console sets the machine for either static or dynamic balancing or both. When the wheel balancing assembly is mounted for static balancing, it rotates until the heavy spot falls to the bottom. Weights are added to balance the assembly.

In the dynamic balance mode, the wheel assembly is rotated at high speed. Observing the balance scale, the operator reads out the amount of weight that has to be added and the location where the weights should be placed.

Many newer wheel balance machines also check for wheel and tire runout. These machines may use cameras or lasers to monitor wheel and tire movement while spinning the tire and checking the balance.

Road Force Measurements The wheel balancer shown in **Figure 45–34** is designed to also eliminate all causes of vibration due to the wheel and tire assembly. Like many other current wheel balancers, this unit can simulate a road test with a load roller. This roller applies a heavy force on the tire while it is rotating on the balancer. The roller also measures the deflection of the tire as it rolls under pressure. The machine then makes recommendations for the service required to remove all runout and ensure vibration-free operation.

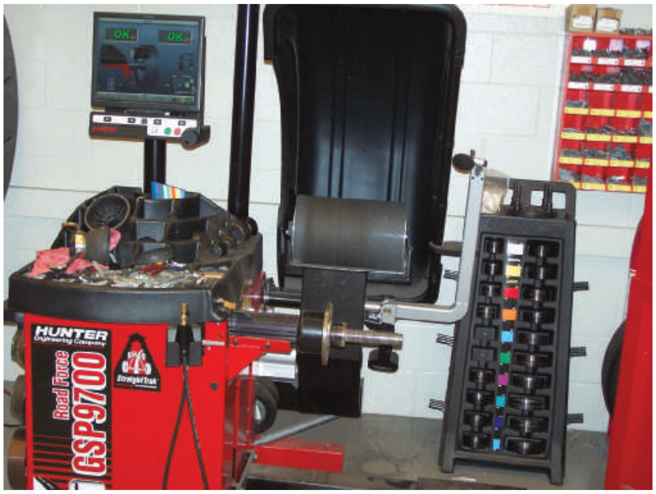


FIGURE 45-34 A computerized "road force" tire balancer.

Wheel Bearings

The purpose of all bearings is to allow a shaft to rotate smoothly in a housing or to allow the housing to rotate smoothly around a shaft. Wheel and axle bearings do this for a vehicle's wheels. Typically, on driving axles, the wheel is mounted to the hub of an axle shaft and the shaft rotates within a housing on an axle bearing. Wheel bearings are used on nondriving axles. The wheel's hub rotates on a shaft called the spindle. Axle bearings are typically serviced with the drive axle. Tapered roller wheel bearings, however, require periodic maintenance and are

often serviced with suspension and brake work. Although there is a distinction between axle and wheel bearings, the bearings for the front wheels on a FWD and 4WD vehicle are commonly called wheel bearings. Regardless of what they are called, bad bearings can cause noise, vibration, handling, and tire wear problems.

Tapered Roller Bearing Troubleshooting

Bearings rarely fail suddenly. Rather, they deteriorate slowly because of dirt, lack of lubrication, and improper adjustment. Bearing wear and failure are almost always accompanied by noise and/or vibration.

Normal bearing sounds should be uniform as the wheel spins on its spindle. An uneven rumble or a grinding sound indicates possible bearing problems. While rotating the wheel, try to move it in and out on the spindle and note the amount of movement. Worn or damaged bearings or bearings that need adjustment will have a noticeable amount of end play. Also grasp the top and bottom of the tire and try to wobble the wheel and tire back and forth. You should feel little or no wobble.

End play can be measured with a dial indicator placed against the wheel hub. Set the indicator to zero, move the wheel in and out on the spindle, and note the reading. Compare your readings to specifications.

Inspect the wheel and the brake drum or rotor for grease that may be leaking past a bad seal. Bearing grease can contaminate brake linings, and a leaking grease seal can let dirt into the bearing. A leaking seal must be replaced, but the bearings also must be cleaned, inspected, and repacked to be sure they have not been damaged. Whether you are installing a used bearing or installing a new one, always install a new grease seal and cotter pin.

Front Wheel Tapered Roller Bearing Service

Most front wheel bearings are sealed units and are lubricated for life. They should be replaced and serviced as an assembly. On older cars and trucks, the nondriven front or rear wheel hub bearing assembly has two tapered bearings **(Figure 45–35)** facing each other. Each of the bearings rides in its own race. These bearings are serviceable and require periodic lubrication and adjustment. Put on a pair of nitrile gloves before servicing the bearings. It will save you a lot of time cleaning yourself up if you do. The following are general procedures for servicing tapered roller bearings.

1. Using a special dust cap removal tool **(Figure 45–36)**, wiggle the cap out of its recess in the hub.
2. Now remove the cotter pin and locknut from the end of the spindle.
3. Loosen the spindle nut while supporting the brake assembly and hub. On many vehicles the

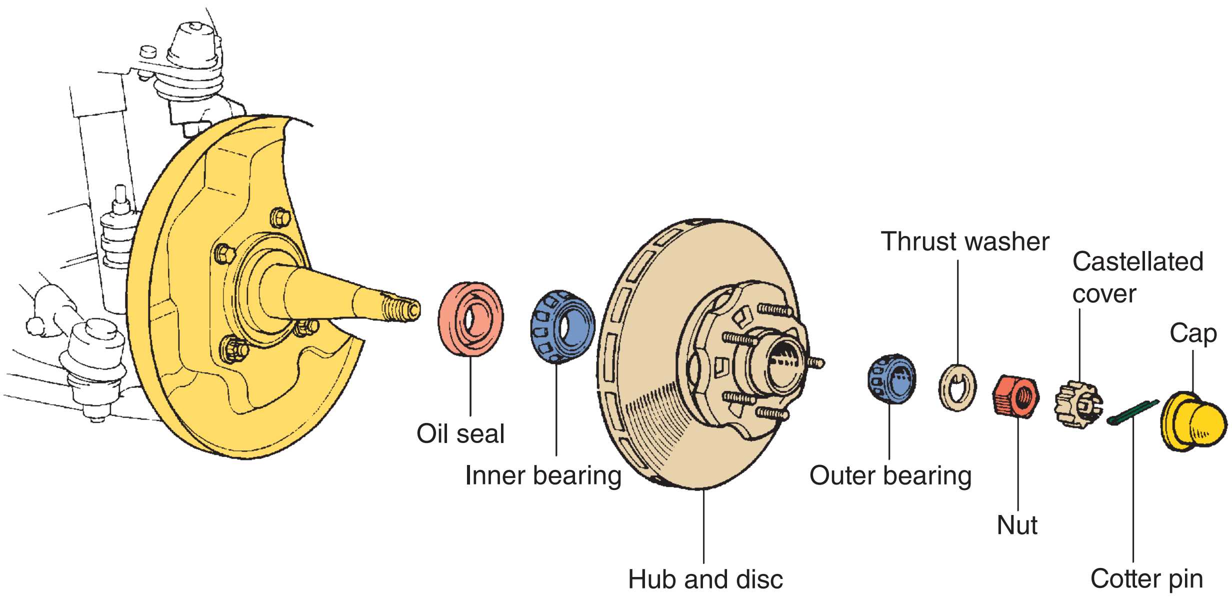


FIGURE 45–35 An exploded view of a typical front wheel bearing assembly for a RWD vehicle.

FIGURE 45-36 A special tool for removing a dust cap.

brake caliper must be removed to remove the brake disc and hub.

4. Once the hub is free from the spindle, remove the spindle nut and the washer behind the nut. Move the hub slightly forward, and then push it back. This should free the outer bearing so you can remove the hub assembly.

A grease seal located on the back of the hub normally keeps the inner bearing from falling out when the hub is removed. To remove the bearing assembly, the grease must be removed. In most cases, the seal can be pried out of the hub. The inner bearing should then fall out. Keep the outer bearing and inner bearing separated if you plan on reusing them.

5. Wipe the grease off the bearings and races and use a parts cleaner to clean them **(Figure 45–37)**. While doing this, pay close attention to the condition and movement of the bearings. The bearings need to rotate smoothly. Also visually inspect the bearings and races; any noticeable damage means they should be replaced. Also inspect the spindle. If it is damaged or excessively worn, the steering knuckle assembly should be replaced.

FIGURE 45-37 Thoroughly clean the bearings and races and then carefully inspect them before reusing them.

Whenever a bearing is replaced, its race must be replaced with it. Races are pressed in and out of the hub. Typically, the old race can be driven out with a large drift punch and a hammer. Once the race has been removed, wipe all grease from the inside of the hub. The new race should be installed with the proper soft-faced driver.

6. During assembly, the bearings and hub assembly must be thoroughly lubricated **(Figure 45–38)**. Care must be taken not to get grease on the brake disc or on any part that will directly contact the disc. Always use the recommended grease. The grease must be able to withstand much heat and friction. If the wrong grease is used, it may not offer the correct protection or it may liquefy from the heat and leak out of the seals.

7. The bearings must be packed with new grease. It is important that the grease be forced into and around all of the rollers in the bearing. Merely coating the outside of the bearing with grease will not do the job. A bearing packer does the best job at packing in the grease.
8. Install the greased inner bearing into the hub and install a new grease seal into the hub. To avoid damaging the seal, use the correct size driver to press the seal into the hub.
9. Lubricate the spindle, and then slip the hub over the spindle.
10. Install the outer bearing, washer, and locknut.

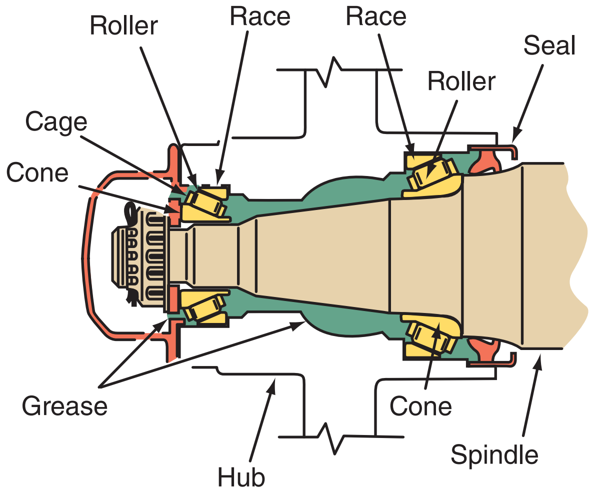


FIGURE 45-38 Wheel bearing lubrication.

Warning! Throughout this entire process, your hands will have grease on them. Be very careful not to touch the brake assembly with your greasy hands. Clean them before handling the brake parts or use a clean rag to hold the brake assembly.

Wheel Bearing Adjustment The locknut should be adjusted to the exact specifications given by the manufacturer. Often it is tightened and loosened before it is adjusted. The initial tightening seats the bearings into their races.

Hub and Bearing Assemblies

The front bearing arrangement used on most vehicles is often nonserviceable. To replace these bearings, either the hub unit is unbolted and removed or the bearing must be pressed in and out of the hub.

To replace a bolted-in hub, you have to remove the bolts securing the assembly to the steering knuckle **(Figure 45–39)**. To get access to these bolts, you may need to remove axle shaft or push it back out of the hub a bit to access the bolts. Depending on the vehicle, you may have to separate the knuckle from the lower ball joint or strut to get enough room to remove the hub retaining bolts. Remove the brake caliper, bracket and rotor and remove the hub assembly. The hubs can be difficult to remove if rusted or corroded in place. Once the bearing is out, clean the surface of the knuckle and the bore where the bearing attaches to ease installation. Install the new assembly and torque the bolts to specifications. When tightening the axle nut, do not use an impact to seat the nut. Hand tighten the nut and then torque to specifications. Overtightening the axle nut can damage the new bearing and lead to rapid wear and failure.

PROCEDURE

To properly adjust front tapered bearings, follow these steps:

STEP 1 Support the rotor or drum with one hand and install the outer bearing and thrust washer into the hub.

STEP 2 Finger tighten the bearing adjusting nut against the thrust washer.

STEP 3 Then adjust the bearings by one of the following methods:

a. Rotate the drum or rotor and snug up the adjusting nut with a wrench to seat the bearings. While continuing to rotate the drum or rotor, back off the nut ¼ to ½ turn or until it is barely loose. Then tighten the nut by hand to a snug fit.

b. Rotate the drum or rotor and tighten the adjusting nut with a torque wrench to the specified torque. Then back off the nut $^{1}/_{3}$ turn and retorque it to the specified value while continuing to rotate the drum or rotor. Final torque is usually in inch-pounds.

c. Rotate the drum or rotor and tighten the adjusting nut with a torque wrench to 12 to 25 foot-pounds. Then back off the nut ¼ to ½ turn or until it is just loose. Mount the base of a dial indicator as close as possible to the center of the hub. Locate the tip of the indicator's plunger on the tip of the spindle. Set the indicator to zero. Move the drum or rotor in and out and note the indicator reading. Turn the adjusting nut as necessary to obtain the specified end play, which is usually 0.001 to 0.005 inch (0.025 to 0.125 mm).

STEP 4 After adjustment, install the locknut over the top of the adjusting nut so the slots in the locknut align with the cotter pin hole in the spindle.

STEP 5 Install a new cotter pin through the spindle and locknut and bend its ends to secure it. Reinstall the dust cap in the hub.

STEP 6 If the axle has drum brakes that were backed off to allow removal of the drum, readjust the brakes.

STEP 7 If the axle has disc brakes, reinstall the caliper.

STEP 8 Reinstall the wheel and tire and lower the vehicle to the ground.

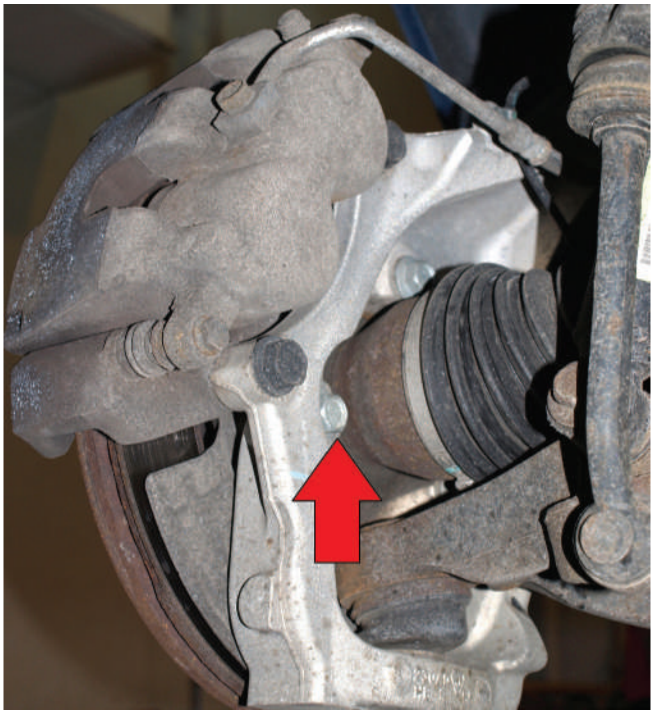


FIGURE 45-39 The bolts holding the wheel bearing to the knuckle.

To replace a pressed-in bearing, the axle or half shaft is removed, as is the steering knuckle and hub assembly. First, press the hub flange from the bearing. A hydraulic press or a bearing tool **(Figure 45–40)** is used to press both the hub flange and bearing from and back into the knuckle. When installing the new bearing, note the installation instructions as some bearings are directional or need to be installed one way so the ABS wheel speed sensor can function properly. This means the bearings is meant to rotate mainly in one direction or it may have two different sized inner races. The bearings may be sealed

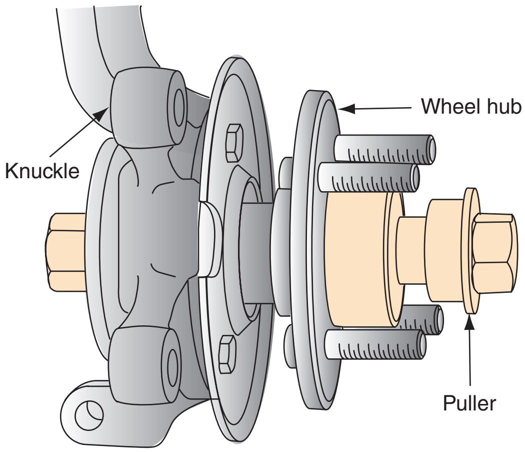


FIGURE 45-40 Pressing the hub flange back into the bearing.

SHOP TALK

Because an axle nut is heavily torqued, it is wise to loosen the nut before the vehicle is raised for service. The weight of the vehicle on the tires will stop the hub from rotating while the nut is being loosened. The same holds true for final torquing. Tighten the nut as tight as possible with the vehicle raised, then lower the vehicle and torque the nut to specifications.

and require no additional lubrication or they may need to be packed with grease when they are reassembled. In most cases, the bearings are not adjusted. A heavily torqued axle nut is used to hold the assembly in place on the axle. This nut is typically replaced after it has been removed and is staked in place after it is tightened.

Rear Hubs

The rear bearings on a FWD vehicle are serviced in the same way as the nondriving front wheel bearings. Most RWD axle bearings are of the straight roller bearing design, in which the drive axle tube serves as the bearing race. Some rear wheel axle bearings are of the ball or tapered roller bearing type.

Wheel Bearing Grease Specification

The grease for wheel bearings should be smooth textured, consist of soaps and oils, and be free of filler and abrasives. Recommended are lithium complex (or equivalent) soaps, or solvent-refined petroleum oils. Additives could be added to inhibit corrosion and oxidation. The grease should be noncorrosive to bearing materials with no chance of separating during storage or use.

Using the correct amount of lube is also essential. Failure to maintain proper lubrication might result in bearing damage, causing a wheel to lock. Greases are classified by the National Lubricating Grease Institute (NLGI) to indicate their application.

GO TO Chapter 8 for a detailed discussion and chart of NLGI lubricants.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2010	**Make:** Chevy	**Model:** Equinox	**Mileage:** 87,047	**RO:** 17726
Concern:	Customer states tire warning light and message stays on all the time. She checked tire pressure and all were OK.			
History:	Tires and TPM sensors were replaced 2 weeks ago at 86,585 miles.			
After confirming the TPM light is staying on, the technician attempts to get data from each sensor using a TPM tool; only one of the pressure sensors will respond. After checking the vehicle history, the technician learns that the TPM sensors were replaced with the tires.				
Cause:	Three inoperative TPM sensors.			
Correction:	Replaced all four TPM sensors with different brand sensor, rebalanced wheels and tires. All sensors operating and TPM light is off.			

KEY TERMS

Aspect ratio
Bead
Direct TPM
Dynamic balance
Hub
Indirect TPM
Lateral runout
Plies
Radial ply
Radial runout
Static balance
Tread
Wheel shimmy
Wheel tramp

SUMMARY

- Wheels are made of either stamped or pressed steel discs riveted or welded into a circular shape or are die-cast or forged aluminum or magnesium rims.
- The primary purpose of tires is to provide traction. They are also designed to carry the weight of the vehicle, to withstand side thrust over varying speeds and conditions, to transfer braking and driving torque to the road, and to absorb much of the rock shock from surface irregularities.
- Pneumatic tires are of two types: those that use inner tubes and those that do not. The latter are called tubeless tires and are the only type used on passenger cars today.
- There are three types of tire construction on the road today: bias ply, belted bias ply, and radial ply.
- Tires are rated by their profile, ratio, size, and load range.
- An ideal tire is one that wears little, holds the road well to provide sure handling and braking, and provides a cushion from road shock. It should also provide maximum grip on dry roads, wet roads, and snow and ice, and operate quietly at any speed.
- The number and size of the blocks, sipes, and grooves on a tire's tread determines how much rubber contacts the road, how much water can be displaced, and how quiet the tire will be during travel.
- To maximize tire performance, inspect for signs of improper inflation and uneven wear, which can indicate a need for balancing, rotation, or alignment. Tires should also be checked frequently for cuts, bruises, abrasions, and blisters, and for stones or other objects that might have become imbedded in the tread.
- A properly inflated tire gives the best tire life, riding comfort, handling stability, and even gas mileage during normal driving conditions.
- To equalize tire wear, most car and tire manufacturers recommend that the tires be rotated. It must be remembered that front and rear tires perform different jobs and can wear differently, depending on driving habits and the type of vehicle.
- Most tires used today have built-in tread wear indicators to show when tires need replacement.

- There are three popular methods of tire repair: head-type plug, cold patch repair, and hot patch repair.
- There are two types of wheel balancing: static balance and dynamic balance.
- The bearings on an axle that drives the wheels are called axle bearings. Wheel bearings are used on nondriving axles. Axle bearings are typically serviced with the drive axle. Wheel bearings require periodic maintenance and are often serviced with suspension and brake work.
- Bad axle and wheel bearings will cause handling and tire wear problems.
- The front wheel hubs on ball or tapered roller bearings are lubricated by wheel bearing grease.
- Rear wheels are bolted to integral or detachable hubs.

REVIEW QUESTIONS

Short Answer

1. List five things that could cause premature bearing failure.
2. Define lateral and radial runout.
3. Why is tire rotation recommended by most manufacturers?
4. Define dynamic and static wheel balance.
5. Describe the proper procedure to seal a puncture in a tire.
6. The rim offset is the vertical distance between the rim centerline and the ___ of the disc.
7. To calculate the tire aspect ratio, the tire section width is divided by the ___.
8. Explain why a TPMS relearn should be performed even after a basic tire service.

Multiple Choice

1. A tire that wobbles from side-to-side is said to have ___.
   a. radial runout
   b. lateral runout
   c. static imbalance
   d. none of the above
2. A front tire has excessive wear on both edges of the tire tread. The most likely cause of this problem is ___.
   a. overinflation
   b. underinflation
   c. improper static balance
   d. improper dynamic balance
3. All of the following statements are correct *except*?
   a. Belts are reinforcing materials that encircle the tire under the tread.
   b. The carcass of a tire is made up of plies, layers of cloth, and rubber.
   c. Most tread patterns are designed to work well on both wet and dry roads.
   d. The bead is the decorative pattern at the outer edge of the tread.
4. All of the following statements are correct *except*?
   a. Tire inflation pressure directly affects traction.
   b. The recommended tire pressure for front and rear tires may be different.
   c. The recommended tire pressures are often lower than maximum pressures.
   d. The recommended tire pressure is molded into the sidewall of the tire.
5. Which of the following statements about sidewall markings is correct?
   a. The load index is given as a letter.
   b. The traction and temperature ratings are based on the speed rating of the tire.
   c. The tire's recommended inflation pressure and load are indicated.
   d. The DOT code indicates when and where the tire was made.
6. All of these statements about improper wheel balance are true *except*?
   a. Dynamic imbalance may cause wheel shimmy.
   b. Dynamic imbalance may cause steering pull in either direction.
   c. Static imbalance causes wheel tramp.
   d. Static imbalance causes rapid wear on suspension components.

7. Recommended tire inflation pressure can be found on the ___.
   a. engine block
   b. tire placard
   c. VIN tag
   d. certification label

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that the front wheel bearings on a typical FWD car are pressed in and out of the steering knuckle assembly. Technician B says that the front wheel bearings on a typical FWD may be bolted into the steering knuckle. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Technician A says that dynamic wheel imbalance causes wheel tramp. Technician B says that static wheel imbalance causes wheel tramp. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. Technician A says that front bearing assembly locknuts for RWD vehicles are typically heavily torqued to maintain the bearing adjustment. Technician B says that the axle nuts for a FWD wheel bearing assembly is often staked in place to maintain its specified torque. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. Technician A says that replacement wheel rims should be the same as the original equipment wheels in load capacity, offset, width, diameter, and mounting configuration. Technician B says that if wheels are installed that have a different stock width or diameter, make sure to use a tire that has the same overall width as the original tires. Otherwise the vehicle's wheel-speed sensors, speedometer, antilock brake system, and many other systems will be affected. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. Technician A says that underinflation can increase the rolling resistance of a tire. Technician B says that underinflation can cause hard steering and a 10 percent decrease in fuel economy. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. While choosing the correct tire for a vehicle: Technician A says that replacing a tire with a temperature resistance rating of B with one rated with an A will increase tire life and improve ride quality. Technician B says that the traction rating indicates how well a tire will perform in the snow. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. Technician A says that on most vehicles, the wheel/tire assembly is considered sprung weight. Technician B says that low unsprung weight makes the vehicle handle better on irregular surfaces. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

8. While discussing run-flat tires: Technician A says that some are self-sealing tires and are designed to quickly and permanently seal side-wall area punctures. Technician B says that most of these tires have reinforced sidewalls that are able to support the vehicle at any speed without air in the tire. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. Technician A says that the aspect ratio of a tire represents the relationship between the tire's cross-sectional height to its cross-sectional width. Technician B says that low aspect ratios provide a softer ride because they will deflect more over irregular surfaces and under heavy loads. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. While discussing the effects of loose wheel bearings: Technician A says that vibration may occur while driving. Technician B says that the bearing may make noise. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER

46 SUSPENSION SYSTEMS

Like the other systems on cars and light trucks, the suspension system has become more advanced through the years. These advances have been made to provide better and safer handling and a better ride. Today, front and rear suspensions have many parts and can be quite complex.

As a vehicle moves, the suspension and tires must react to the current driving conditions. Specifically, the suspension system:

- Supports the weight of the vehicle
- Keeps the tires in contact with the road
- Controls the direction of the vehicle's travel
- Attempts to maintain the correct vehicle ride height
- Maintains proper wheel alignment
- Reduces the effect of shock forces as the vehicle travels on an irregular surface

OBJECTIVES

- Explain the important differences between sprung and unsprung weight with regard to suspension control devices.
- Identify the functions of shock absorbers and struts and describe their basic construction.
- Identify the components of a MacPherson strut system and describe their functions.
- Identify the functions of bushings and stabilizers.
- Perform a general front-suspension inspection.
- Identify the three basic types of rear suspensions and know their effects on traction and tire wear.
- Identify the various types of springs, their functions, and their locations in the rear-axle housing.
- Describe the advantages and operation of the three basic electronically controlled suspension systems: level control, adaptive, and active.
- Explain the function of electronic suspension components including air compressors, sensors, control modules, air shocks, electronic shock absorbers, and electronic struts.
- Explain the basic towing, lifting, jacking, and service precautions that must be followed when servicing air springs and other electronic suspension components.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2010	**Make:** GMC	**Model:** Acadia	**Mileage:** 140,951	**RO:** 19261
Concern:	Noise over bumps, ride is rougher, and the body seems to move around more.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

Frames

To provide a rigid structural foundation for the vehicle body and a solid anchorage for the suspension system, a frame of some type is essential. There are two basic frames in common use today.

Conventional Frame Construction

In the conventional body-over-frame construction, the frame is the vehicle's foundation. The body and all major parts of a vehicle are attached to the frame **(Figure 46–1)**. It must provide the support and strength needed by the assemblies and parts attached to it. In other words, the frame is an independent, separate component because it is not welded to any of the major units of the body shell.

Unibody Construction

Unibody construction has no separate frame. The body is constructed in such a manner that the body parts themselves supply the rigidity and strength required to maintain the structural integrity of the car **(Figure 46–2)**. The unibody design significantly lowers the base weight of the car, and that, in turn, increases gas mileage capabilities.

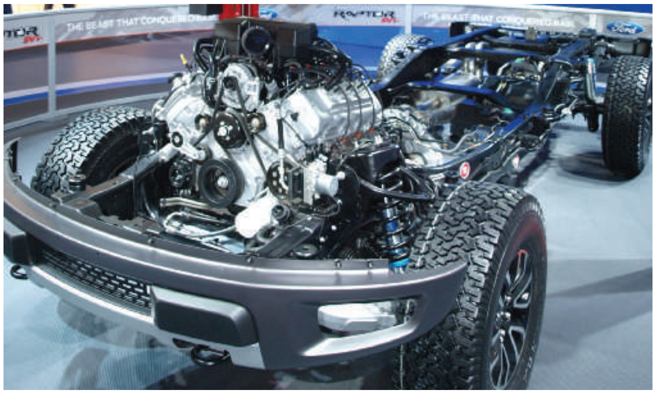


FIGURE 46–1 An example of body-over-frame construction.

FIGURE 46–2 Unibody construction is the most common frame design today.

Suspension System Components

Nearly all automotive suspensions have the same basic components and they operate similarly. The basic differences between the suspensions found on various vehicles are the construction and placement of the parts.

Springs

A spring is the core of all suspension systems. Springs carry the weight of the vehicle and absorb shock forces while maintaining correct riding height. They are compressible links between the vehicle's frame and body and the tires. Doing this, they dampen road shock and provide a comfortable ride. If a spring is worn or damaged, other suspension parts will shift out of their proper positions and will experience increased wear.

Various types of springs are used in suspension systems **(Figure 46–3)** —coil, torsion bar, leaf (both mono- and multileaf types), and air springs. Springs are mounted in rubber or nylon to reduce road shock and noise.

Automotive springs are generally classified by the amount they compress under a specific load. This is referred to as the spring rate. A force (weight) applied to a spring causes it to compress in direct proportion to the force applied. When that force is

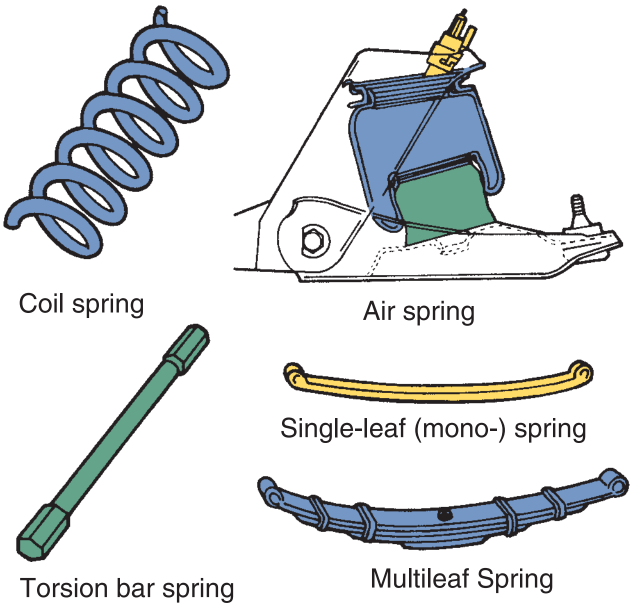


FIGURE 46–3 Various types of automotive springs.

removed, the spring returns to its original position if it is not overloaded. This is why a heavy vehicle needs stiffer springs than a lightweight car.

The springs take care of two fundamental vertical actions: jounce and rebound. **Jounce**, or compression, occurs when a wheel hits a bump and moves up **(Figure 46–4A)**. When this happens, the suspension system acts to pull in the top of the wheel, maintaining an equal distance between the two wheels and preventing a sideways scrubbing action as the wheel moves up and down. **Rebound**, or extension, occurs when the wheel hits a dip or hole and moves downward **(Figure 46–4B)**. In this case, the suspension system acts to move the wheel in at both the top and bottom equally, while maintaining an equal distance between the wheels.

When the spring experiences compression or extension, it stores energy. This energy forces the spring to return to its normal shape. The spring oscillates between jounce and rebound until all energy has moved from the spring. Each oscillation becomes smaller until it stops. A **shock absorber** is added to each suspension to dampen and stop the motion of the spring after jounce.

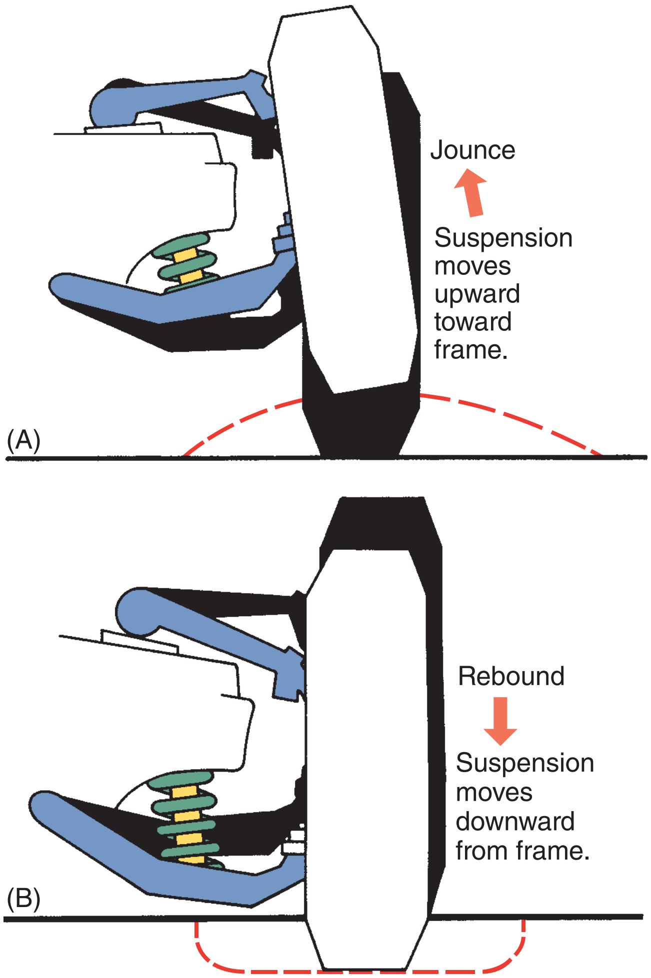


FIGURE 46–4 (A) Upward and (B) downward suspension movement.

FIGURE 46–5 The different designs of coil springs.

Coil Springs Two basic designs of coil springs are used: linear rate and variable rate **(Figure 46–5)**. **Linear rate** springs characteristically have one basic shape and a consistent wire diameter. All linear springs are wound from a steel rod into a cylindrical shape with even spacing between the coils. As the load is increased, the spring is compressed and the coils twist (deflect). As the load is removed, the coils flex (unwind) back to the normal position. The amount of load necessary to deflect the spring 1 inch (25.4 mm) is the spring rate. On linear rate springs this is a constant rate, no matter how much the spring is compressed. For example, 250 pounds (112 kg) compress the spring 1 inch (25.4 mm) and 750 pounds (340 kg) compress the spring 3 inches (76.2 mm). Spring rates for linear rate springs are normally calculated between 20 percent and 60 percent of the total spring deflection.

Variable rate spring designs are characterized by a combination of wire sizes and shapes. The most commonly used variable rate springs have a consistent wire diameter, are wound in a cylindrical shape, and have unequally spaced coils. This type of spring is called a progressive rate coil spring.

The design of the coil spacing gives the spring three functional ranges of coils: inactive, transitional, and active. Inactive coils are usually the end coils and introduce force into the spring. Transitional coils become inactive as they are compressed to their point of maximum load-bearing capacity. Active coils work throughout the entire range of spring loading. Theoretically in this type of design, at stationary loads the inactive coils are supporting all of the vehicle's weight. As the loads are increased, the transitional coils take over until they reach maximum capacity. Finally, the active coils carry the remaining

overload. This allows for automatic load adjustment while maintaining vehicle height.

Another common variable rate design uses tapered wire to achieve this same type of progressive rate action. In this design, the active coils have a large wire diameter and the inactive coils have a small wire diameter.

Later designs of variable rate springs deviate from the old cylindrical shape. These include the truncated cone, the double cone, and the barrel spring. The major advantage of these designs is the ability of the coils to nest, or bottom out, within each other without touching, which lessens the amount of space needed to store the springs in the vehicle.

Unlike a linear rate spring, a variable rate spring has no predictable standard spring rate. Instead, it has an average spring rate based on the load of a predetermined spring deflection. This makes it impossible to compare a linear rate spring to a variable rate spring. Variable rate springs, however, handle a load of up to 30 percent over standard rate springs in some applications.

Leaf Springs Although leaf springs were the first type of suspension spring used on automobiles, today they are generally found only on light-duty trucks, vans, and some passenger cars. There are three basic types of leaf springs: multiple leaf, monoleaf, and fiber composite.

Multiple-Leaf Springs. Multiple-leaf springs consist of a series of flat steel leaves that are bundled together and held with clips or by a bolt placed slightly ahead of the center of the bundle. One leaf, called the main leaf, runs the entire length of the spring. The next leaf is a little shorter and attaches to the main leaf. The next leaf is shorter yet and attaches to the second leaf, and so on. This system allows almost any number of leaves to be used to support the vehicle's weight **(Figure 46–6)**. It also

FIGURE 46–6 An example of stacked, multiple-leaf springs used on a light-duty pickup truck.

gives a progressively stiffer spring. The spring easily flexes over small distances for minor bumps. The farther the spring is deflected, the stiffer it gets. The more leaves and the thicker and shorter the leaves, the stronger the spring. It must be remembered that as the spring flexes, the ends of the leaves slide over one another. This sliding could be a source of noise and can also produce friction. These problems are reduced by interleaves of zinc and plastic placed between the spring's leaves. As the multiple leaves slide, friction produces a harsh ride as the spring flexes. This friction also dampens the spring motion.

Multiple-leaf springs have a curve in them. This curve, if doubled, forms an ellipse. Thus, leaf springs are sometimes called semielliptical or quarter-elliptical. The semi or quarter refers to how much of the ellipse the spring actually describes. The vast majority of leaf springs are semielliptical.

Leaf springs are typically mounted at right angles to the axle **(Figure 46–7)**. However, on late-model Toyota trucks, the leaf springs are angled outward toward the front, so the distance between the front ends of the two springs is greater than the distance

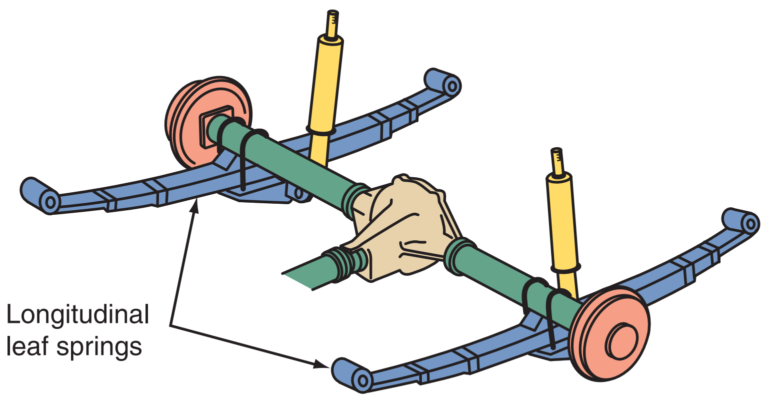


FIGURE 46–7 These leaf springs support and locate the drive axle.

between the rears of the springs. In addition to absorbing road shock, leaf springs also serve as a mount for the drive axle. A centering pin is often used to keep the axle properly located on the springs. If a spring is broken or not in its proper position, the drive axle may be sitting at an angle; this will cause handling problems.

Some vehicles have a transversely mounted leaf spring. The center of the spring is mounted to the vehicle's chassis and the outer ends are fastened to the ends of the axle housing or wheel spindles.

The front eye of the main leaf at either end of the axle is attached to a bracket on the frame of the vehicle with a bolt and bushing connection. The rear eye of the main leaf is secured to the frame with a shackle, which permits some fore and aft movement **(Figure 46–8)** in response to physical forces of acceleration, deceleration, and braking.

Monoleaf Springs. Monoleaf or single-leaf springs are usually the tapered plate type with a heavy or thick center section tapering off at both ends. This provides a variable spring rate for a smooth ride and good load-carrying ability. In addition, single-leaf springs do not have the noise and static friction characteristic of multiple-leaf springs.

Fiber Composite Springs. While most leaf springs are still made of steel, fiber composite types are increasing in popularity **(Figure 46–9)**. Some automotive people call them plastic springs in spite of the fact that the springs contain no plastic at all. They are made of fiberglass, laminated and bonded together by tough polyester resins. The long strands of fiberglass are saturated with resin and bundled together by wrapping (a process called filament winding) or squeezed together under pressure (compression molding).

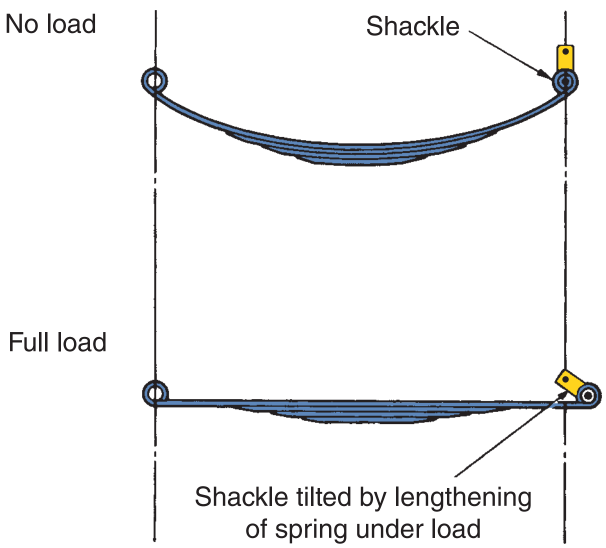


FIGURE 46–8 The action of a leaf spring as it compresses.

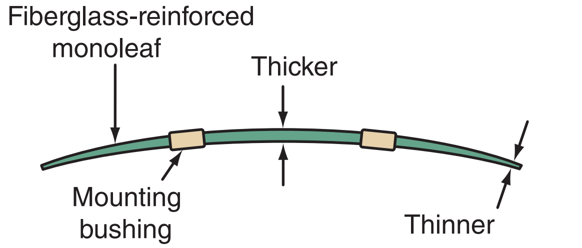


FIGURE 46–9 The construction of a fiberglass-reinforced monoleaf spring.

Fiber composite leaf springs are incredibly lightweight and possess some unique ride control characteristics. Conventional monoleaf steel springs are real heavyweights, tipping the scale at anywhere from 25 to 45 pounds (11 to 20 kg) apiece. Some multiple-leaf springs can weigh almost twice as much. A fiber composite leaf spring is a featherweight by comparison, weighing a mere 8 to 10 pounds (3.6 to 4.5 kg). As every performance enthusiast knows, springs are dead weight. Reducing the weight of the suspension not only reduces the overall weight of the vehicle, but also reduces the sprung mass of the suspension itself. This reduces the spring effort and amount of shock control that is required to keep the wheels in contact with the road. The result is a smoother riding, better handling, and faster responding suspension, which is exactly the sort of thing every performance enthusiast wants.

Air Springs Another type of spring, an air spring, is used in an air-operated microprocessor-controlled system that replaces the conventional coil springs with air springs to provide a comfortable ride and automatic front and rear load-leveling. This system, fully described later in this chapter, uses four air springs to carry the vehicle's weight. The air springs are located in the same positions where coil springs are usually found. Each spring consists of a reinforced rubber bag pressurized with air. The bottom of each air bag is attached to an inverted pistonlike mount that reduces the interior volume of the air bag during jounce **(Figure 46–10)**. This has the effect of increasing air pressure inside the spring as it is compressed, making it progressively stiffer. A vehicle equipped with an electronic air suspension system is able to provide a comfortable street ride, about a third softer than conventional coil springs. At the same time, its variable spring rate helps absorb bumps and protect against bottoming.

FIGURE 46-10 A rear-suspension setup with air springs.

Torsion Bar Suspension System

Torsion bars serve the same function as coil springs. In fact, they are often described as straightened-out coil springs. Instead of compressing like coil springs, a torsion bar twists and straightens out on the recoil. That is, as the bar twists, it resists up-and-down movement. One end of the bar—made of heat-treated alloy spring steel—is attached to the vehicle frame. The other end is attached to the lower control arm **(Figure 46–11)**. When the wheel moves up and down, the lower control arm is raised and lowered. This twists the torsion bar, which causes it to absorb

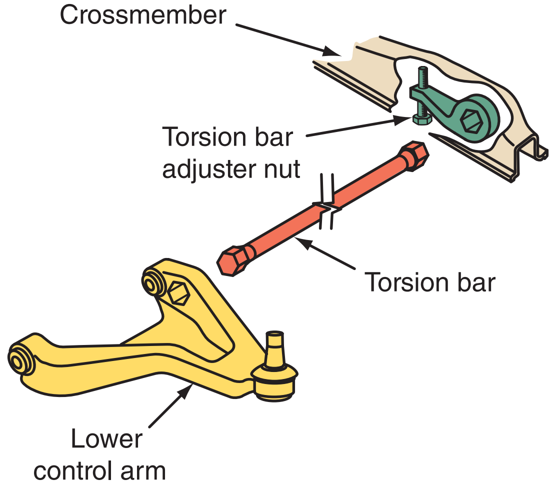


FIGURE 46-11 A torsion bar setup.

road shocks. The bar's natural resistance to twisting quickly restores it to its original position, returning the wheel to the road.

When torsion bars are manufactured, they are prestressed to give them fatigue strength. Because of directional prestressing, torsion bars are directional. The torsion bar is marked either right or left to identify on which side it is to be used.

Because the torsion bar is connected to the lower control arm, the lower ball joint is the load carrier. A shock absorber is connected between the lower control arm and the frame to damp the twisting motion of the torsion bar.

Many late-model pickups and SUVs use torsion bars in their front suspensions. They are primarily used in this type vehicle because they can be mounted low and out of the way of the driveline components.

Shock Absorbers

Shock absorbers damp or control motion in a vehicle. If unrestrained, springs continue expanding and contracting after a blow until all the energy is absorbed. Not only would this lead to a rough and unstable—perhaps uncontrollable—ride after consecutive shocks, it would also create a great deal of wear on the suspension and steering systems. Shock absorbers prevent this. Despite their name, they actually dampen spring movement instead of absorbing shock. As a matter of fact, in England and almost everywhere else but the United States, shock absorbers are referred to as **dampers**.

Today's conventional shock absorber is a velocity-sensitive hydraulic damping device. The faster it moves, the more resistance it has to the movement **(Figure 46–12)**. This allows it to automatically adjust to road conditions. A shock absorber works on the principle of fluid displacement on both its compression (jounce) and extension (rebound) cycles. A typical car shock has more resistance during its extension cycle than its compression cycle. The extension cycle controls motions of the vehicle body spring weight. The compression cycle controls the same motions of the unsprung weight. This motion energy is converted into heat energy and dissipated into the atmosphere.

Shock absorbers can be mounted either vertically or at an angle. Angle mounting of shock absorbers improves vehicle stability and dampens accelerating and braking torque.

Conventional hydraulic shocks are available in two styles: single-tube and double-tube. The vast majority of domestic shocks are double-tubed. While they are

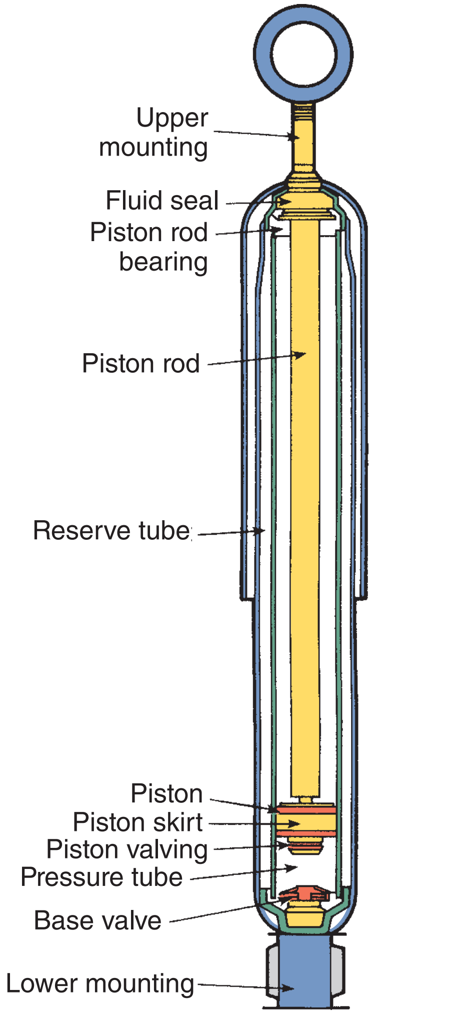


FIGURE 46–12 A cross section of a conventional shock absorber.

a little heavier and run hotter than the single-tubed type, they are easier to make. The double-tube shock has an outer tube that completely covers the inner tube. The area between the tubes is the oil reservoir. A compression valve at the bottom of the inner tube allows oil to flow between the two tubes. The piston moves up and down inside the inner tube.

In a single monoshock, there is a second floating piston near the bottom of the tube. When the fluid volume increases or decreases, the second piston moves up and down, compressing the reservoir. The fluid does not move back and forth between a reservoir and the main chamber. There are no other valves in a single-tube shock besides those in the main piston. The second piston prevents the oil from splashing around too much and getting air bubbles in it. Air in the shock oil is detrimental. Air, unlike oil, is compressible and slips past the piston easily. When this happens, the result is a shock that offers poor vehicle control on bumpy roads.

In addition to these conventional hydraulic shocks, there are a number of others the technician may encounter.

Gas-Charged Shock Absorbers On rough roads, the passage of fluid from chamber to chamber becomes so rapid that foaming can occur. Foaming is simply the mixing of the fluid with any available air. Since aeration can cause a skip in the shock's action, engineers have sought methods of eliminating it. One is the spiral groove reservoir, the shape of which breaks up bubbles. Another is a gas-filled cell or bag (usually nitrogen) that seals air out of the reservoir so the shock fluid can only contact the gas.

A gas-charged shock absorber **(Figure 46–13)** operates on the same hydraulic fluid principle as

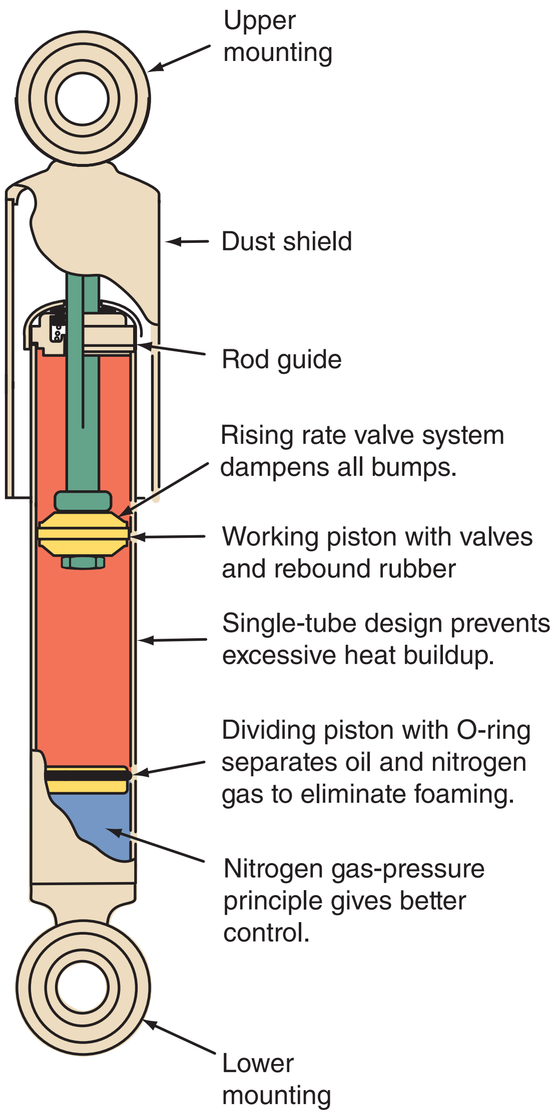


FIGURE 46–13 Gas-pressure damped shocks operate like conventional oil-filled shocks. Gas is used to keep oil pressurized, which reduces oil foaming and increases efficiency under seven conditions.

conventional shocks. It uses a piston and oil chamber similar to other shock absorbers. Instead of a double-tube with a reserve chamber, it has a dividing piston that separates the oil chamber from the gas chamber. The oil chamber contains a special hydraulic oil, and the gas chamber contains nitrogen gas under pressure equal to approximately 25 times atmospheric pressure.

As the piston rod moves downward in the shock absorber, oil is displaced, just as it is in a double-tube shock. This oil displacement causes the divided piston to press on the gas chamber. The gas is compressed and the chamber reduces in size. When the piston rod returns, the gas pressure returns the dividing piston to its starting piston. Whenever the static pressure of the oil column is held at approximately 100 to 360 psi (690 to 2.482 kPa) (depending on the design), the pressure decreases behind the piston and so cannot be high enough for the gas to escape from the oil column. As a result, a gas-filled shock absorber operates without aeration.

Air Shock Systems There are two basic adjustable air shock systems: manual fill and automatic load-leveling. The manual fill system can be installed on almost any vehicle manufactured without it.

There are several different types of manual fill air shock systems available. One common manual fill air shock system uses a high-speed, direct current (DC) motor to transfer a command signal that is manually selected from the driver's seat. In another manual air system, the units are inflated through air valves mounted at the rear of the vehicle. Air lines run between the shocks and the valve. A tire air pressure pump is used to fill the shocks to bring the rear of the vehicle to the desired height.

SHOP TALK

Some high-pressure gas-charged shocks are monotube shocks with fluid and gas in separate chambers. The gas is charged to 360 psi (2.482 kPa). Its basic design does not allow the valving range needed for a more responsive ride over a broad range of road conditions. The high-pressure gas charge can provide a harsh ride under normal driving conditions and is usually found on small trucks.

Dynamic Suspensions Spool Valve Dampers

A new type of shock that is being used in some high-performance applications is the spool valve damper. Instead of using traditional disc-type valves to control oil flow, DSSV dampers use two spool valves, one for compression and one for extension **(Figure 46–14)**. Precisely machined orifices in the spool valves regulate oil flow than conventional shock valves as the outer sliding sleeve moves past the spool valves.

Shock Absorber Ratio Most shock absorbers are valved to offer roughly equal resistance to suspension movement upward (jounce) and downward (rebound). The proportion of a shock absorber's ability to resist these movements is indicated by a numerical formula. The first number indicates jounce resistance. The second indicates rebound resistance. For example, passenger cars with normal suspension requirements use shock absorbers valued at 50/50 (50 percent jounce/50 percent rebound). Damping rates within the shock absorbers are controlled by the size of the piston, the size of the orifices, and the closing force of the valves.

It is important to keep in mind that the shock absorber ratio only describes what percentage of the shock absorber's total control is compression and what percentage is extension. Two shocks with the same ratio can differ greatly in their control capacity. This is one reason the technician must be sure correct replacement shocks are installed on the vehicle.

Stabilizer Bars

Nearly all suspension systems have a **sway bar**, which is also known as the **antisway bar** or stabilizer. This bar, like the shock absorbers, provides

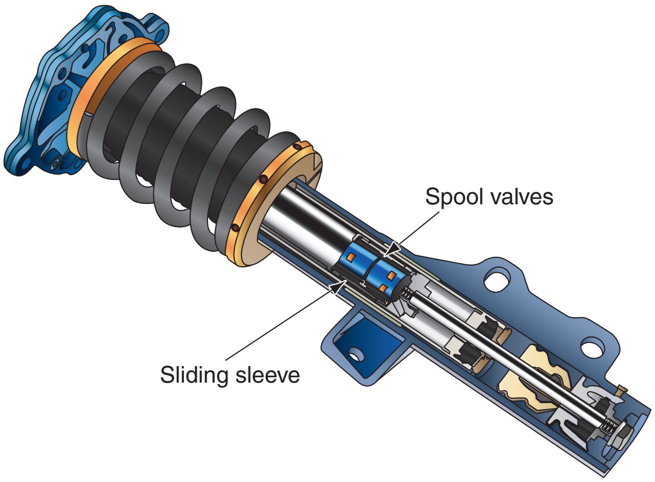


FIGURE 46–14 A spool valve damper.

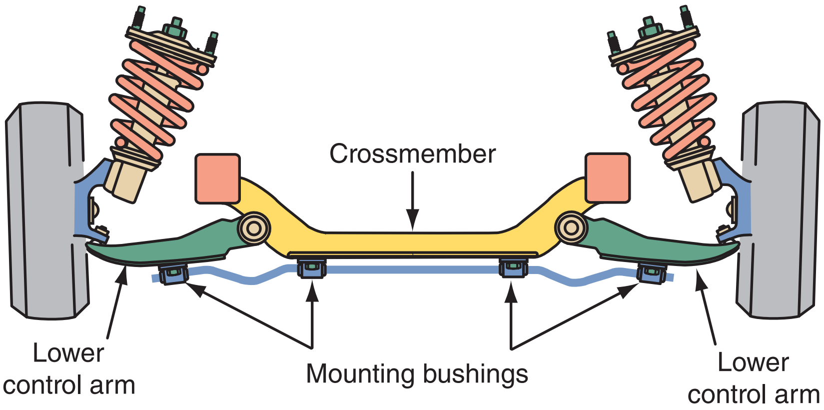


FIGURE 46–15 The typical location of a stabilizer bar.

directional stability by reducing body roll. It is a metal rod running between the opposite lower or upper control arms **(Figure 46–15)**. As the suspension at one wheel responds to the road surface, the sway bar transfers a similar movement to the suspension at the other wheel. For example, if the right wheel is drawn down by a dip in the road surface, the sway bar is drawn with it, creating a downward draw on the left wheel as well. In this way, a more level ride is produced. Sway or lean during cornering is also reduced. Depending on its thickness, the antisway bar can reduce vehicle roll or sway by up to 15 percent.

If both wheels go into a jounce, the sway bar simply rotates in its bushings. When only one wheel goes into jounce, the bar twists like a torsion bar to lift the frame and the opposite side of the suspension. This reduces body roll.

The sway bar is typically a one-piece, U-shaped rod connected to the control arms with rubber bushings, or it can be attached to each control arm by a separate sway bar link **(Figure 46–16)**. The sway bar link may be comprised of a bolt, nut, washers, and rubber bushings. Many modern sway bar links use a steel or plastic rod and ball-socket joints to connect the sway bar to the control arm or strut assembly. The sway bar is also mounted to the frame in the center with rubber bushings. If it is too large, the sway bar causes the vehicle to wander. If it is too small, it has little effect on stability.

Some newer cars and trucks have electronic stabilizer bars **(Figure 46–17)**. In car applications, the action of the stabilizer bar is controlled by a module as part of the stability control system. The amount of resistance provided by the bar can be changed based on driving conditions and the mode selected, such as comfort, sport, or sport +. The motor is used to create resistance to body roll by resisting the movements of the stabilizer bar segments. When driving straight down the road, the system can uncouple the stabilizer bar to allow for a smoother ride.

Strut Rods

Strut rods are used on models that do not use lower A-shaped control arms. In some suspensions, the strut rods also form the sway bar. Strut bars are attached to the lower control arm and frame with bushings, allowing the arm-limited forward and backward movement. Strut rods are directly affected by braking forces and road shocks, and their failure can quickly lead to failure of the entire suspension system.

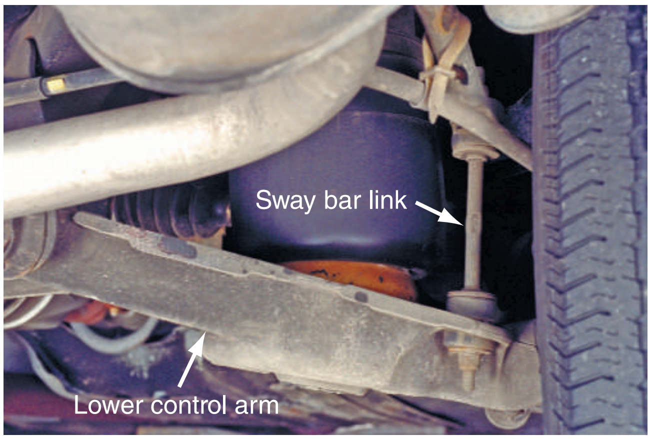


FIGURE 46–16 A sway bar link connects the sway bar to the lower control arm.

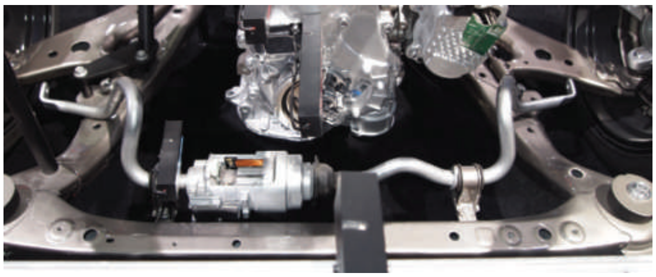


FIGURE 46–17 An electronically controlled or active stabilizer bar.

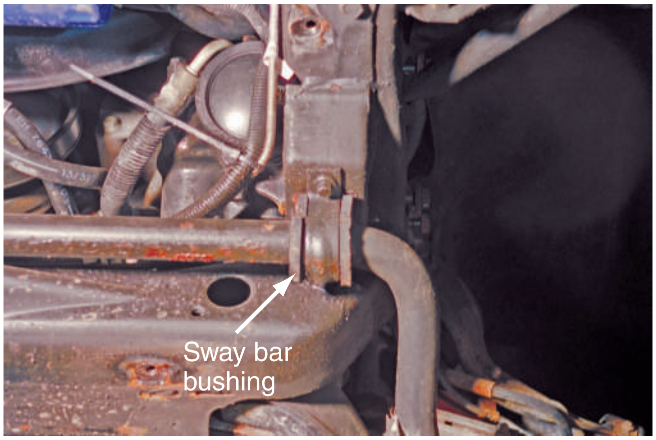


FIGURE 46–18 The center section of a sway bar rides in bushings.

Bushings

Bushings are used at the stabilizer bars **(Figure 46–18)**, control arms, radius arms, and strut rods. They make good suspension system pivots, minimize the number of lubrication points, and allow for slight assembly misalignments. Bushings are able to absorb some of the road shock before the force is transferred to the vehicle's frame, or body.

Suspension bushings are typically made of a rubber material, commonly an elastomer. Elastomers are capable of compressing in response to a force. When the force is removed, elastomers return to their original shape. They also allow movement or shifting of the parts they are between. The amount of movement depends on the design of the bushing. For example, control arms are attached to the frame of the vehicle with rubber elastomeric bushings. The bushings become the pivoting point for the control arms. During suspension travel, the bushings twist as the control arm moves. The bushings, acting like a spring, attempt to untwist and push the control arm back into its original position. This action provides some resistance to suspension movement while the bushings absorb some of the road shock.

This twisting and untwisting of the bushings generate heat. Rough road conditions and/or bad shock absorbers will cause the suspension to move more than normal. This causes more heat to buildup in the bushings, shortening their life. Excessive heat tends to harden the rubber and as the bushings become harder, they break, crack, or fall apart.

Worn suspension bushings may allow suspension parts to change positions **(Figure 46–19)**. This can lead to vibrations, wheel alignment problems, tire wear, and poor ride and handling. Often, a clunking noise when traveling on a rough surface will be an indication of a worn bushing. Worn or damaged bushings should be replaced.

(A)

(B)

FIGURE 46–19 (A) A failing control arm bushing. (B) A completely separated bushing.

Noise may also result from dry bushings and this may be corrected by lubricating them. Only rubber lubricant or a silicone-based lubricant should be used. Rubber bushings should not be lubricated with petroleum-based lubricants. These will cause the bushings to deteriorate.

Performance TIP

Many technicians replace stock rubber bushings with harder bushings made of high-grade polyurethane materials. These bushings do not have the give that rubber bushings do and tend to improve handling, steering response, and ride control. These bushings can also help to reduce torque steer on FWD vehicles.

Independent Front Suspension

Front-suspension systems are fairly complex. They have somewhat contradictory jobs. They must keep the wheels rigidly positioned and at the same time allow them to steer right and left. In addition, because of weight transfer during braking, the front-suspension system absorbs most of the braking torque. While accomplishing this, it must provide good ride and stability characteristics.

MacPherson Strut Suspensions

The **MacPherson strut** suspension is dramatically different in appearance from the traditional independent front suspension **(Figure 46–20)**, but similar components operate in the same way to meet suspension demands. Because of its compact design and being suited to work with FWD configurations, the MacPherson strut is one the most common types of front suspension system being used.

The MacPherson strut suspension's most distinctive feature is the combination of the main elements into a single assembly. It typically includes the spring, upper suspension locator, and shock absorber. It is mounted vertically between the top arm of the steering knuckle and the inner fender panel.

Struts have taken two forms: a concentric coil spring around the strut itself **(Figure 46–21)** and a spring located between the lower control arm and the frame **(Figure 46–22)**. The location of the spring on the lower control arm, not on the strut as in a conventional MacPherson strut system, allows

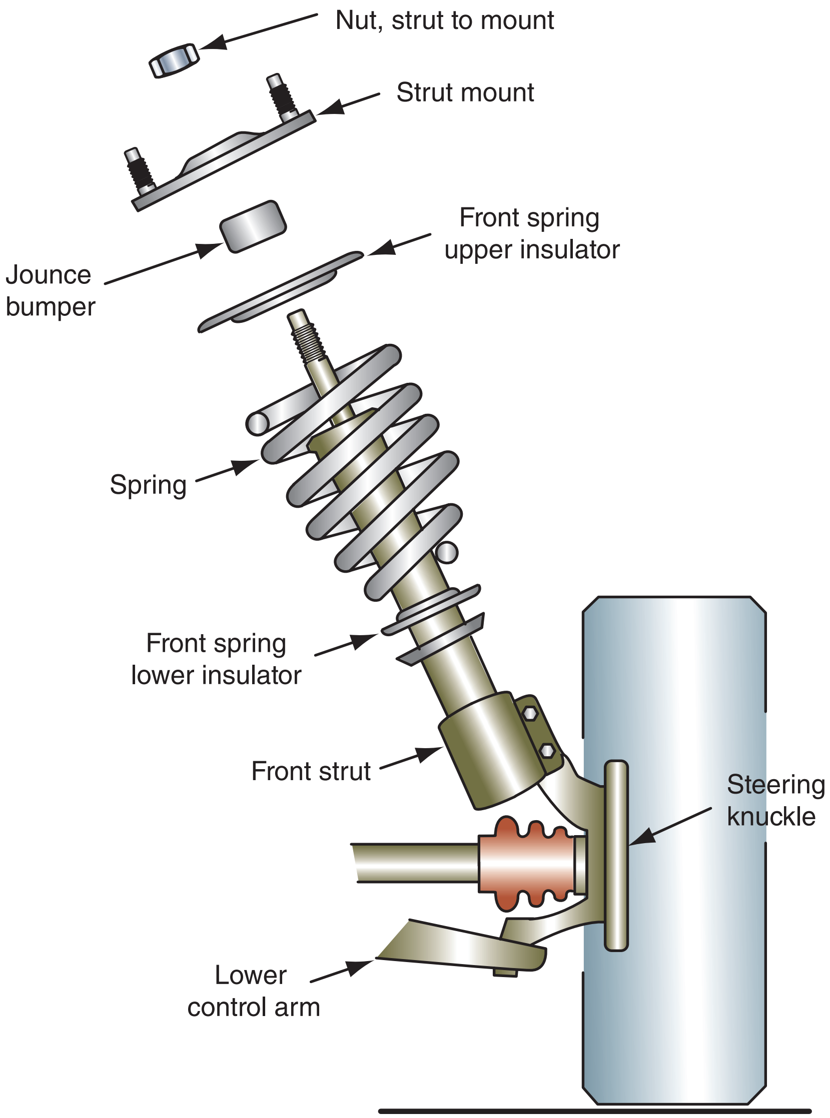


FIGURE 46–20 A complete MacPherson strut front suspension.

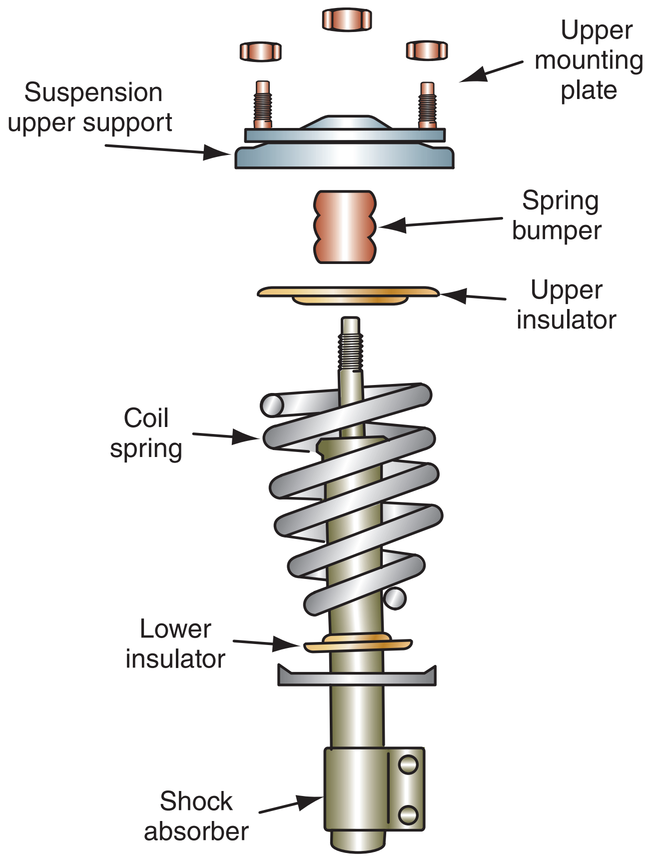


FIGURE 46–21 A MacPherson strut with a replaceable shock absorber cartridge.

FIGURE 46–22 A modified MacPherson suspension has the spring mounted separately from the strut.

minor road vibrations to be absorbed through the chassis rather than be fed back to the driver through the steering system. This system is called modified MacPherson suspension.

Struts

The core element of this type of suspension is the strut. With its cylindrical shape and protruding piston rod, it looks quite similar to the conventional shock absorber. In fact, the strut provides the damping function of the shock absorber, in addition to serving to locate the spring and to fix the position of the suspension.

The shock-damping function is accomplished differently on various types of struts. None of them uses a separate shock absorber as the traditional front suspension does. Some versions are designed so the damper can be independently serviced.

Struts fall into two broad categories: sealed and serviceable units. A sealed strut is designed so the top closure of the strut assembly is permanently sealed. There is no access to the shock absorber cartridge inside the strut housing and no means of replacing the cartridge. Therefore, it is necessary to replace the entire strut unit. A serviceable strut is designed so the cartridge inside the housing, which provides the shock-absorbing function, can be replaced with a new cartridge. Serviceable struts use a threaded body nut in place of a sealed cap to retain the cartridge.

The shock absorber device inside a serviceable strut is generally wet. This means the shock absorber contains oil that contacts and lubricates the inner wall of the strut body. The oil is sealed inside the strut by the body nut, O-ring, and piston rod seal. Servicing a wet strut with the equivalent components involves a thorough cleaning of the inside of the strut body, absolute cleanliness, and great care in reassembly (including replenishing the strut with oil).

Cartridge inserts were developed to simplify servicing wet struts. The insert is a factory-sealed replacement for the strut shock absorber. The replacement cartridge is simply substituted for the original shock absorber cartridge and retained with the body nut.

Most OE domestic struts are serviced by replacement of the entire unit. There is no strut cartridge to replace. Sealed OE units can also be serviced by replacement with an aftermarket unit that permits future servicing by cartridge replacement.

The use of the strut reduces suspension space and weight requirements. By mounting the bottom of the strut assembly to the steering knuckle, the upper

control arm and ball joint of the traditional suspension are eliminated. In place of the ball joint, the upper mount, which is bolted to the fender panel, is the load-carrying member on MacPherson suspensions.

Strut Mounts

A MacPherson strut has a mount between the top of the strut to the chassis where the strut is supported. These mounts are designed to dampen vibrations as well as secure the strut in position. Often the mounts include a bearing, although some use a bushing. Bearings are most commonly found in front suspensions because the suspension turns or pivots between left and right. Every application is different; however, most applications fall into one of three groupings **(Figure 46–23)**.

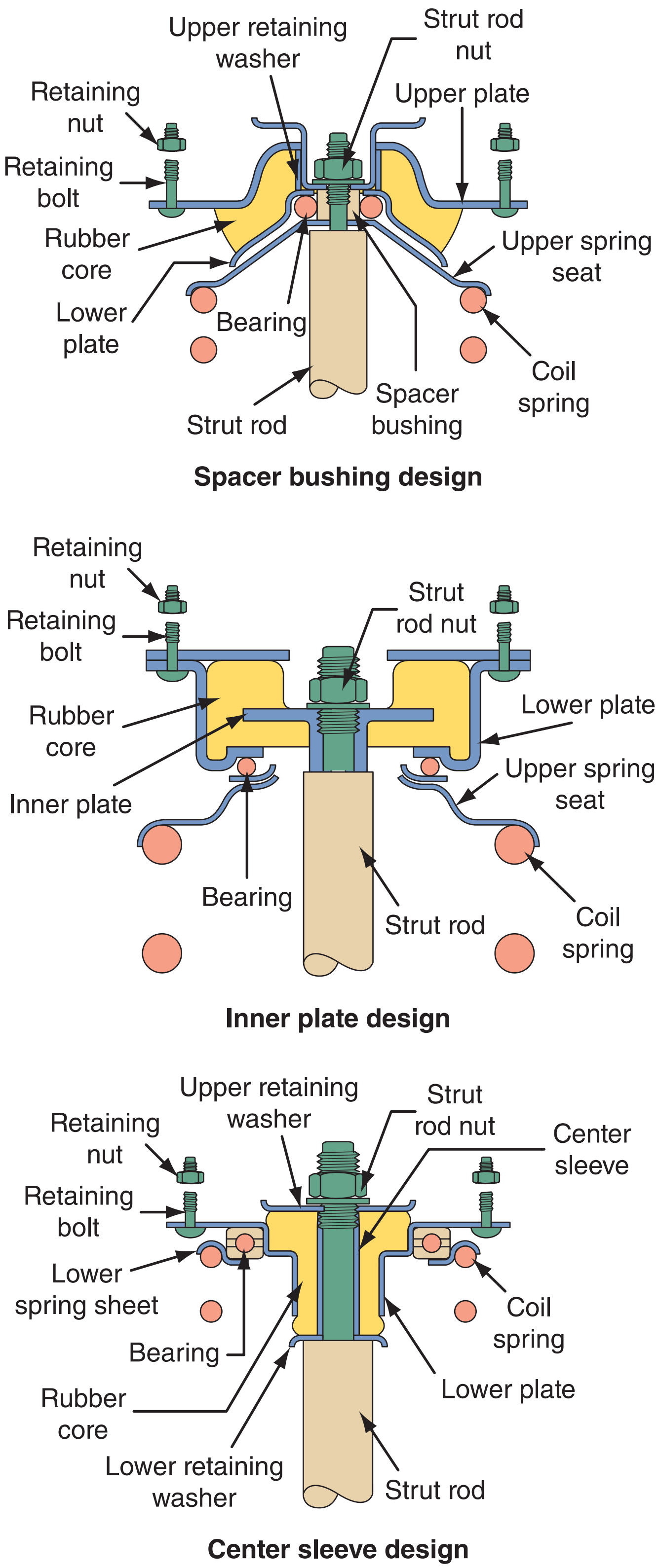


FIGURE 46–23 The different types of upper mounts for a strut.

Spacer Bushing This design has a bearing centered in the mount and a separate inner bushing. The bearing is pressed into the strut mount. The bearing, bushing, and upper plate support the piston. If the bushing is cracked or torn or if the bearing is binding or seized, the strut mount must be replaced.

Inner Plate The inner plate design has a rubber-encased inner plate placed between upper and lower surface plates. The plate prevents the strut piston rod from pushing through the upper or lower surface plate if the inner plate fails.

Center Sleeve The center sleeve design has a center sleeve molded to a rubber bushing. The stem of the strut passes through the sleeve. The bearing is not a part of the strut mount; rather it is a separate unit. To prevent the strut rod from pushing through the mount, upper and lower retainer washers are used. If there are cracks, tears, or other damage to the bushing, the mount should be replaced.

Mount Diagnosis and Service Worn or damaged strut mounts can cause the strut and the strut tower to move independently of one another. This can lead to abnormal noise, a bent or damaged strut, damage to the strut tower, and poor handling. A bad mount may cause a creaking or popping noise. This is caused by too much movement of the strut within the mount. Often the mount is replaced with the strut.

Lower Suspension Components

The lower end of the strut attaches to the steering knuckle, which is sometimes called the hub carrier. A common strut-to-knuckle connection uses mounting flanges that enclose the upper portion of the knuckle **(Figure 46–24A)**. These flanges are built into the strut body and are also used for attaching brake hoses

(A)

(B)

FIGURE 46–24 (A) A common strut-to-knuckle connection. (B) Clamping the strut into the knuckle.

and ABS wiring. The strut may bolt into an opening in the knuckle **(Figure 46–24B)**. Once inserted, a pinch bolt secures the strut tightly in place.

The suspension's lower mounting position continues to be the frame, as on the traditional suspension, because the lower control arm and ball joint are

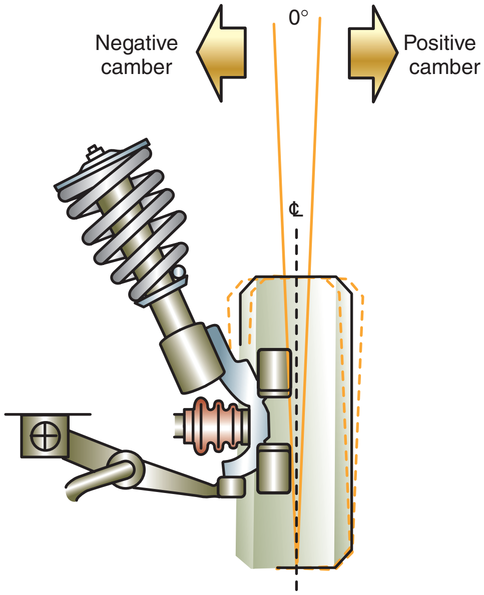


FIGURE 46–25 A front MacPherson strut assembly.

retained **(Figure 46–25)**. As on those suspensions, the control arm serves as the lower locator for the suspension.

MacPherson strut suspensions continue to use sway or stabilizer bars. On models with single-bushing control arms, strut rods or the sway bar can be fastened to the control arm to provide lateral stability.

The lower **ball joint** is a friction or steering ball joint and is used to stabilize the steering and to retard shimmy. The only exception is on modified MacPherson suspensions. In this design, the ball joint becomes the load bearer; the upper mount becomes the steering component. Some designs use two ball joints **(Figure 46–26)** to improve ride and handling.

FIGURE 46–26 Two lower ball joints connect to this steering knuckle.

Springs

Coil springs are used on all strut suspensions. A mounting plate welded to the strut serves as the lower spring seat. The upper seat is bolted to the strut piston rod. A bearing or rubber bushing in the upper mount permits the spring and strut to turn with the motion of the wheel as it is steered.

Short-Long Arm Suspension

The unequal length control arm or **short-long arm (SLA)** suspension system has been common on domestic-made vehicles for many years **(Figure 46–27)**. Each wheel is independently connected to the frame by a steering knuckle, ball joint assemblies, and short upper and longer lower control arms. Because the upper arm pivots in a shorter arc, the top of the wheel moves in and out slightly but the tire's road contact remains constant **(Figure 46–28)**.

One design of an SLA uses a narrow lower control arm, shaped like an "I" **(Figure 46–29)**. A strut rod is used to hold the control arm in place. The strut rod is attached to the control arm close to the steering knuckle and to the frame in front of the wheel assembly. Rubber bushings at the frame mounting allow the strut rod to move a little when the tire hits a bump. The bushing dampens the shock and prevents it from transmitting through the vehicle's frame.

The essential components of SLA systems are the wheel spindle or steering knuckle assembly, control arms, ball joints, shock absorbers, and springs, either coil or torsion bar.

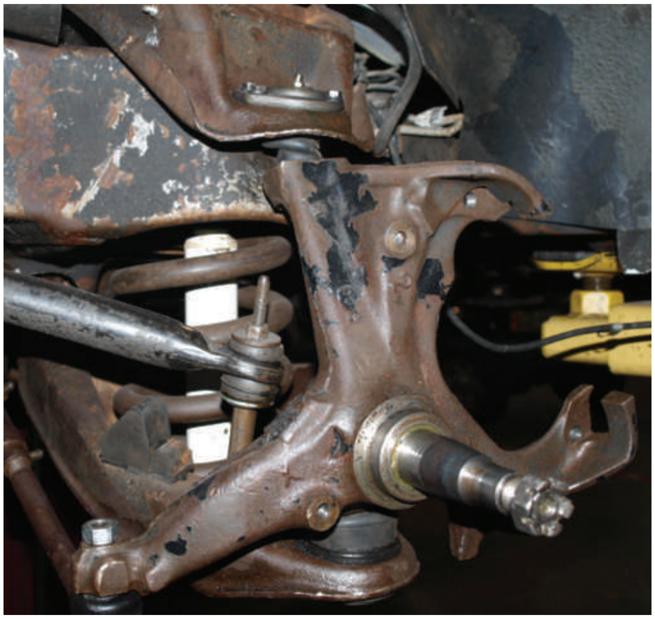


FIGURE 46-27 A typical SLA front suspension.

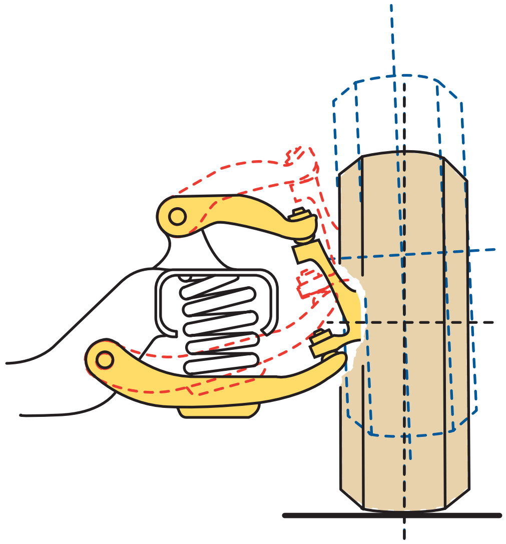


FIGURE 46-28 The movement of the wheel as a short-long arm suspension system moves up and down.

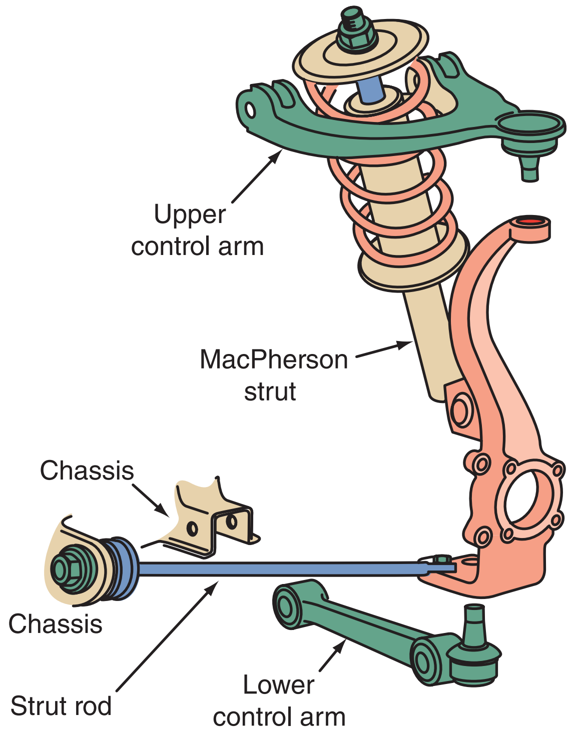


FIGURE 46-29 A FWD suspension system with a narrow lower control arm mounted on a single pivot.

Wheel Spindle A **wheel spindle** assembly consists of a wheel spindle and a steering knuckle. A wheel spindle is connected to the wheel through wheel bearings and is the point at which the wheel hub and wheel bearings are connected. A steering knuckle is connected to control arms. In most cases, a steering knuckle and wheel spindle are forged to form a single piece.

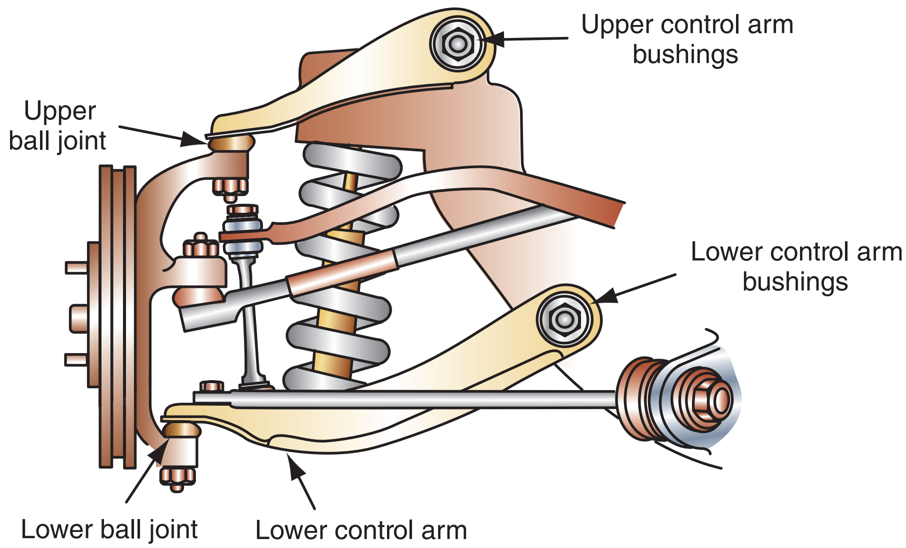


FIGURE 46-30 Ball joint locations in an SLA suspension.

Control Arms The upper and lower **control arms** on the traditional independent front suspension (IFS) function primarily as locators. They fix the position of the system and its components relative to the vehicle and are attached to the frame with bushings that permit the wheel assemblies to move up and down separately in response to irregularities in the road surface. The outer ends are connected to the wheel assembly with ball joints **(Figure 46–30)** inserted through each arm into the steering knuckle.

There are two types of control arms: the wishbone, or double-pivot, control arm and the single-pivot, or single-bushing, control arm **(Figure 46–31)**. The wishbone offers greater lateral stability than the single-pivot arm, which is lighter and requires less space than the wishbone but also requires modifications in suspension design to compensate for the reduced lateral stability. Those modifications are discussed further later in this chapter.

FIGURE 46-31 A front-suspension system with an upper control arm shaped like a "wishbone," which is what this type of suspension is called.

Ball Joints A ball joint **(Figure 46–32)** connects the steering knuckle to the control arm, allowing it to pivot on the control arm during steering. Ball joints also permit up-and-down movement of the control arm as the suspension reacts to road conditions. The ball joint stud protrudes from its socket through a rubber seal that keeps lubricating grease in the housing and keeps dirt out. Some ball joints require periodic lubrication, while most do not. These maintenance-free ball joints move in a prelubricated nylon bearing.

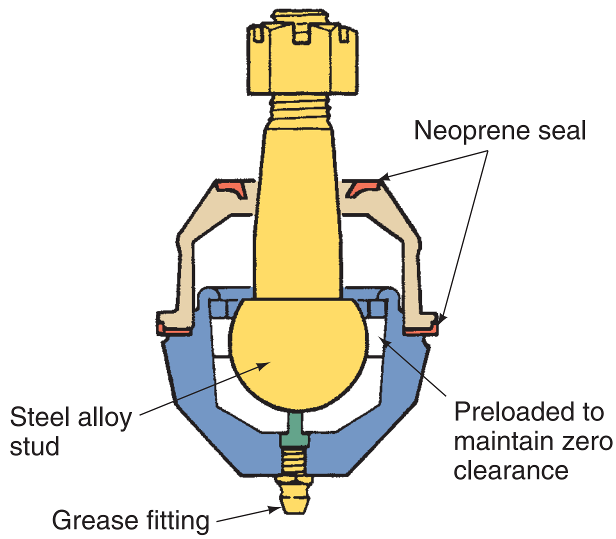


FIGURE 46-32 A typical ball joint.

Ball joints are either load carrying or are followers. A load-carrying ball joint supports the car's weight and is generally in the control arm that holds or seats the spring. Load-carrying joints can be called tension-loaded or compression-loaded ball joints **(Figure 46–33)**. The correct term depends on whether the force of the load tends to push the ball into the socket (compression) or pull it out of the socket (tension).

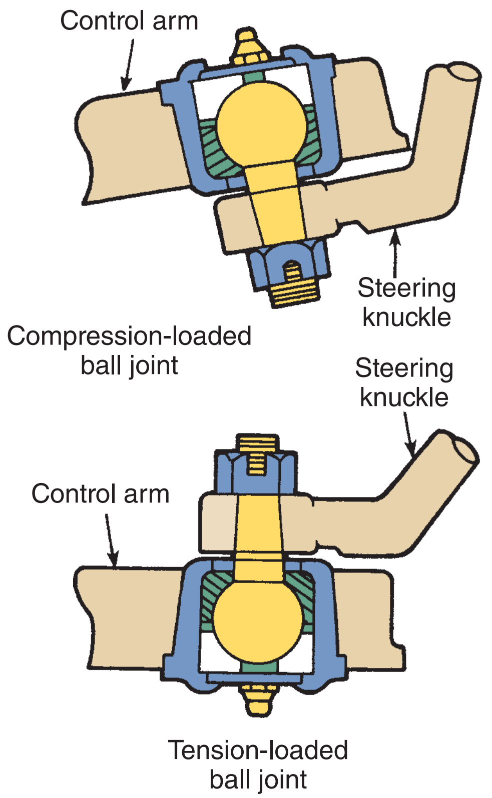


FIGURE 46–33 Two basic types of load-carrying ball joints.

Follower ball joints are often called friction-loaded ball joints. A follower ball joint mounts on the control arm that does not provide a seat for the spring. The follower does not support vehicle weight and does not get the same stress as the load carrier.

Depending on the location of the suspension system's spring, either the upper or lower ball joint will be the load-carrying joint. In a MacPherson strut suspension, there is usually only one ball joint on each side and it is typically a follower. In modified strut suspensions, the ball joint is a load-carrying joint because the spring is positioned between the frame crossmember and the lower control arm.

Some ball joints have wear indicators. As the joint wears, the grease fitting of the joint recedes into the housing. When the shoulder of the fitting is flush with the housing, the joint needs to be replaced **(Figure 46–34)**.

A ball joint is nothing more than a ball-in-socket joint. As long as the ball is firmly in the socket and the ball and/or socket is not worn, the joint will provide a solid connection. Once the ball or socket is worn, the connection becomes sloppy. How the ball is kept in its socket depends on the type of ball joint it is. Load-carrying ball joints rely on the vehicle's weight to keep the ball in the socket **(Figure 46–35)**. As weight is removed from the joint, the ball relaxes in the socket and will feel loose. Follower ball joints are held in place by friction inside the joint. A spring inside the joint typically keeps the ball tight in the socket but allows for some flexibility. This type of joint should never have any play.

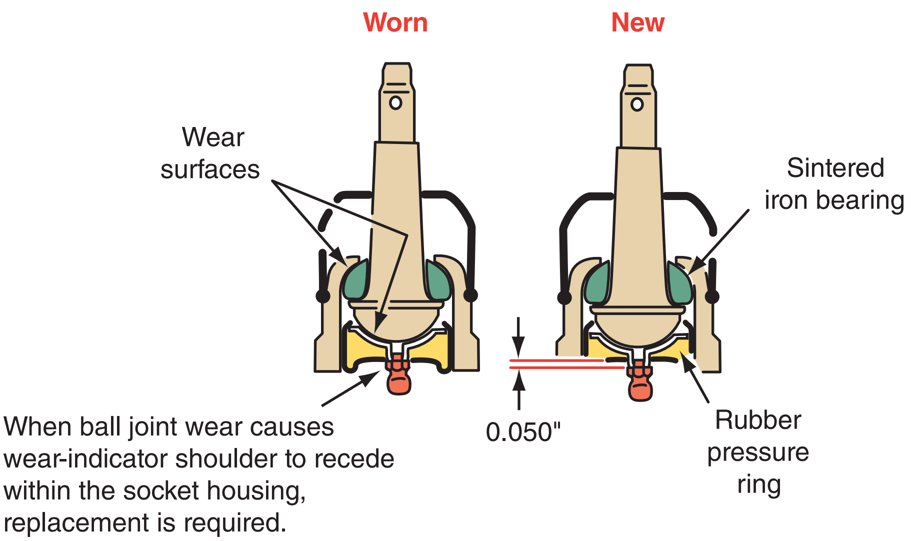


FIGURE 46–34 A wear indicator on a ball joint.

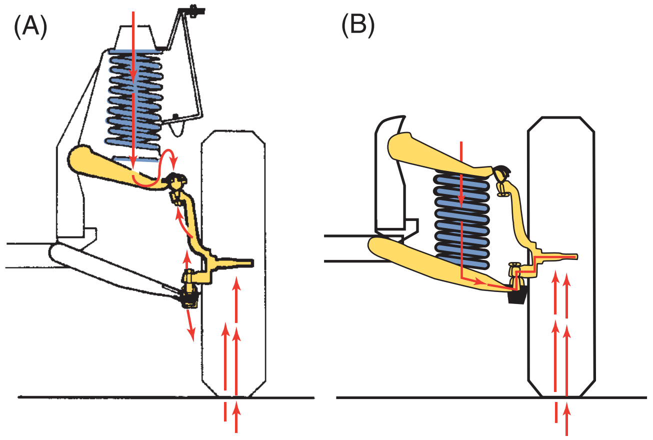


FIGURE 46–35 (A) The upper ball joint is the load-carrying joint. (B) The lower ball joint is the load-carrying joint in this system.

Four-Link or Multilink Front Suspension

A four-link front suspension, also called a multilink suspension, fixes the wheel with four rod-type control arms and the tie-rod **(Figure 46–36)**. The suspension strut supports the vehicle weight against the body via the load-bearing link. By separating wheel attachment and suspension elements, this suspension optimizes ride quality and movement. The influence of drive forces on the steering system is also minimal. This type of suspension is common on both RWD and FWD vehicles due to its compact design and neutral handling qualities.

FIGURE 46–36 A four-link front-suspension system.

FIGURE 46–37 An independent 4WD front-suspension.

Four-Wheel Drive Front Suspensions

Most modern four-wheel drive (4WD) trucks use an independent front suspension. The suspension may use short-long arms and a torsion bar or may use a multilink arrangement **(Figure 46–37)**. Mounting the front differential solidly to the frame and using two short drive axles allows for an independent suspension that improves ride quality compared to older, dependent suspensions. Older 4WD trucks and some new heavy-duty versions use a live axle. While very strong, using a live axle in the front suspension reduces ride quality and handling.

Basic Front-Suspension Diagnosis

Diagnosis of suspension problems should follow a logical sequence. The following procedure can be used on most vehicles; however, it is also best to follow the sequence given by the manufacturer for a specific vehicle.

PROCEDURE

To diagnose a suspension system:

STEP 1 Take the vehicle on a road test and verify the customer's concern.

STEP 2 Inspect the tires. Check their condition and air pressure. Also make sure that the sizes of the tires and wheels are correct.

STEP 3 Inspect the chassis and underbody. Remove any excessive accumulation of mud, dirt, or road deposits. Then:

- Inspect all parts to identify any aftermarket modifications that may have been made.
- Check vehicle attitude for evidence of overloading or sagging. Be sure the chassis height is correct.
- Raise the vehicle off the floor. Grasp the upper and lower surfaces of the tire and shake each front wheel to check for worn wheel bearings.
- Look for loose or damaged front- and rear-suspension parts.
- Check loose, damaged, or missing suspension bolts.
- Check the ball joints for looseness and wear.
- Check the condition of the struts' upper mounts.
- Check the shock absorbers and struts for signs of fluid leakage **(Figure 46–38)** and damage.
- Check all of the mountings for the shocks and struts.
- Check all suspension bushings for looseness, splits, cracks, misplacement, and noises.
- Check the steering mounts, linkages, and all connections for looseness, binding, or damage.
- Check for damaged or sagging springs.
- Check the drive axles for damage and looseness.

STEP 4 If the cause of the customer's concern was found, make the repair as necessary and verify that the repair fixed the problem.

STEP 5 If the cause of the concern was not found, refer to the symptom chart given in the service information and conduct all applicable checks. Then make the repair as necessary and verify that the repair fixed the problem.

SHOP TALK

Often the steering behavior of a vehicle is stated as having oversteer or understeer. Although the terms refer to handing, they actually refer to traction while a vehicle is turning. Oversteer occurs when the vehicle turns more than the driver intends. It occurs when the rear wheels lose traction before the front wheels do. This can result from sudden and hard acceleration or a quick weight transfer to the front during a sudden lift of the accelerator pedal, a stab on the brakes or too much steering input. Understeer occurs when the vehicle turns less than the movement of the steering wheel and it turns wider than the intended path, this happens when the front wheels lose traction before the rear wheels. These characteristics are part of the design of the car and are very difficult to correct; however, they can be corrected.

FIGURE 46–38 Check the shock absorbers for signs of fluid leakage.

Shock Absorber or Strut Bounce Test

With the vehicle on the ground, a quick check, called the bounce test, can be performed to check the operation of the shocks and struts. When the bounce test is performed, the bumper is pushed two or three times downward with considerable weight applied on each corner of the vehicle. The bumper is released after each push and the vehicle should oscillate about 1½ cycles and then settle. One free upward bounce should stop the vertical chassis movement if the shock absorber or strut provides proper spring control. If the vehicle's bumper does more than 1½ free upward bounces, the shock absorber or strut is defective.

A shock that does not bounce excessively in the shop still may not respond properly during operation on the road. A test drive should be performed over various road conditions to fully evaluate the dampening ability of the shock.

Excessive Body Roll

If a vehicle leans or rolls excessively during corners, the sway bar links are likely broken. Broken links can also cause noise over bumps and while turning.

Noises

Abnormal noises from the suspension system can be caused by a number of problems. Tire noise varies with road surface conditions, whereas differential noise is not affected when various road surfaces are encountered. Uneven tread surfaces may cause tire noises that seem to originate elsewhere in the vehicle. These noises may be confused with differential noise. Differential noise usually varies with acceleration and deceleration, whereas tire noise remains more constant in relation to these forces. Tire noise is most pronounced on smooth asphalt road surfaces at speeds of 15 to 45 mph (24 to 72 km/h).

Rattling on road irregularities can be caused by worn shock absorber bushings or grommets, worn spring insulators, a broken coil spring or broken spring insulators, worn control arm bushings, worn stabilizer bar bushings, and worn strut rod grommets, worn leaf spring shackles and bushings, and worn torsion bars, anchors, and bushings. Dry or worn control arm bushings may cause a creaking or squeaking noise on irregular road surfaces.

Chatter while cornering can be caused by worn upper strut mounts. Front strut noise on sharp turns or during suspension jounce may be caused by interference between the coil spring and the strut tower **(Figure 46–39)** or between the coil spring and

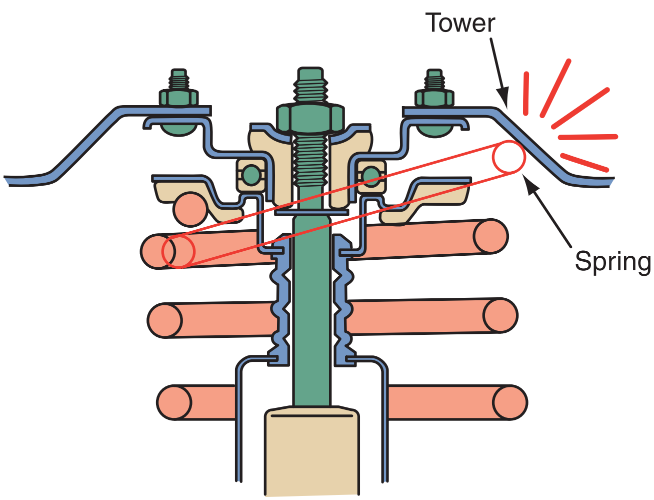


FIGURE 46–39 Coil spring to strut tower interference.

SHOP TALK

Before visual inspection or suspension height measurements can be performed, the vehicle must be on a level surface. Tires must be at recommended pressures; gas tank must be full; and there should be no passenger or luggage compartment load. Beginning at the rear bumper, jounce the car up and down several times. Proceed to the front bumper and repeat, releasing during same cycle as rear jounce.

the upper mount. Worn upper strut mounts or bearings can also cause binding and poor steering return.

Knocking noises can be caused by broken sway bar links, worn and loose ball joints, worn control arm, strut rod, or radius arm bushings. Severely worn struts or shocks can also cause knocking sounds, especially over very bumpy roads.

Chassis Height Specifications

A quick overall visual inspection detects any obvious sag from front to rear or from side to side. Under the car, at the level of the two ends of the control arms, check for out-of-level, damaged, or worn rubber bumpers, or shiny or worn spring coils. All indicate weak coil springs.

USING SERVICE INFORMATION

For the most accurate measurement of chassis height, use the service information to check against the manufacturer's recommendations for the specific model. Photo Sequence 42 shows the typical procedure for checking vehicle ride height. Be careful. The measurement points vary from one model to another even if manufactured by the same company. When coil-spring wear is suspected, it might be necessary to load the vehicle to the manufacturer's suggested capacities and measure at the designated points.

A more accurate inspection reveals less obvious problems by measuring heights at specific points on each side of the suspension system.

Front-Suspension Component Servicing

Each major component of the suspension system needs to be carefully checked. Each has its own procedure for doing this as well as the service procedures. The only maintenance required on suspension systems is a periodic chassis lubrication. If the owner has failed to have this done, many problems can result. Very few vehicles require any periodic chassis lubrication any more as nearly all suspension and steering components are sealed and greased for life. However, if a vehicle has had components replaced, such as ball joints or steering sockets, these parts will likely need to be greased.

GO TO Chapter 8 for details on how to lubricate the chassis.

Coil Springs

Coil springs require no adjustments and are basically trouble-free. However, the constant compression and extension of the spring can lead to a loss of elasticity and cause spring sag. Coil springs then need to be replaced. A weak spring upsets vehicle trim height, which can cause incorrect wheel alignment, abnormal steering, poor headlight aim, poor braking, increased tire wire, reduced traction, and a decrease in the service life of U-joints and shocks.

Coil springs can also break. This is often due to vehicles being overloaded or rusted. When a vehicle carries more weight than it was designed to carry, the springs can break from being overly compressed.

A vital step in replacing a coil spring is to identify the correct replacement. Begin by looking for the OEM part number, which is normally on a tag wrapped around a coil. Often, this tag falls off before replacement is necessary. If a set of aftermarket springs has been installed, the part number might be stamped on the end of the coil. Next, determine what types of ends the coils springs have. There are three types of ends used in automotive applications: full wire open, tapered wire closed, and pigtail. Springs with full wire open ends are cut straight off and sometimes flattened or ground into a D or

Measuring Front and Rear Curb Riding Height

P42-1 Check the trunk for extra weight.

P42-2 Check the tires for normal inflation pressure.

P42-3 Park the car on a level shop floor or alignment rack.

P42-4 Find the vehicle manufacturer's specified curb riding height measurement locations in the service information.

P42-5 Measure and record the right front curb riding height.

P42-6 Measure and record the left front curb riding height.

P42-7 Measure and record the right rear curb riding height.

P42-8 Measure and record the left rear curb riding height.

P42-9 Compare the measurement results to the specified curb riding height in the service information.

Caution! The coil spring exerts a tremendous force on the control arm. Before you disconnect either control arm from the knuckle for any service operation, contain the spring with a spring compressor to prevent it from flying out and causing injury.

square shape. Tapered wire closed ends are wound to ensure squareness and ground into a taper at the ends. Pigtail ends are wound into a smaller diameter at the ends.

The final step is to check all available service information. To do this, it is necessary to know the make, year, model, body style, and engine size, and if the vehicle is equipped with air conditioning. In some cases, it is also good to know the type of transmission, seating capacity, and other specifics that add extra weight to the vehicle. In most parts catalogs, springs are listed by vehicle and VIN in two sections: front and rear. Springs should always be replaced in pairs.

Removing a Spring To remove a coil spring, raise and support the vehicle by its frame. Let the control arm hang free. Remove wheels, shock absorbers, and stabilizer links. Disconnect the outer tie-rod ends from their respective arms. Remove the brake caliper and support it with a wire or bungee cord so it does not hang on the brake hose.

Unload the ball joints with a roll-around floor jack. Jack under the lower control arm from the opposite side of the vehicle. This allows the jack to roll back when the control arm is lowered. Position the jack as close to the lower ball joint as possible for maximum leverage against the spring.

The spring is ready for the installation of the spring compressor **(Figure 46–40)**. There are many different types of spring compressors. One type uses a threaded compression rod that fits through two plates, an upper and lower ball nut, a thrust washer, and a forcing nut. The two plates are positioned at either end of the spring. The compression rod fits through the plates with a ball nut at either end. The upper ball nut is pinned to the rod. The thrust washer and forcing nut are threaded onto the end of the rod. Turning the forcing nut draws the two plates together and compresses the spring.

In some cases, it is necessary to break the tapers of both upper and lower ball joints so the steering knuckle can be moved to one side **(Figure 46–41)**. If the vehicle is equipped with a strut rod, this must be disconnected at the lower control arm. Push the control arm down until the spring can be removed. If necessary, a pry bar can be used to remove the spring from its lower seat. Remove the spring and compressor.

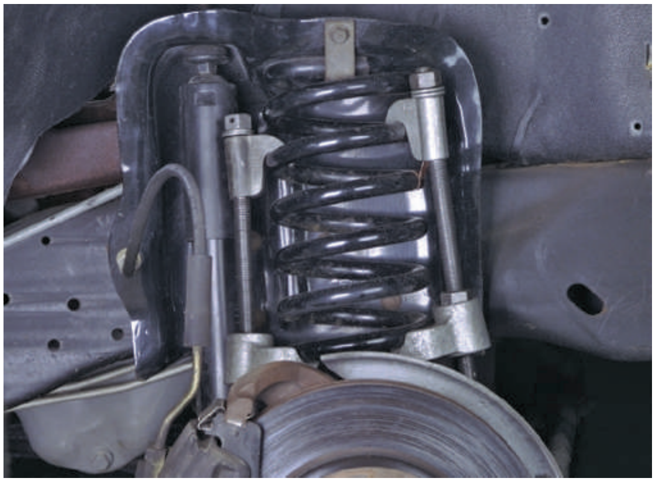


FIGURE 46–40 A coil-spring compressor is used to compress the spring before disconnecting some suspension parts.

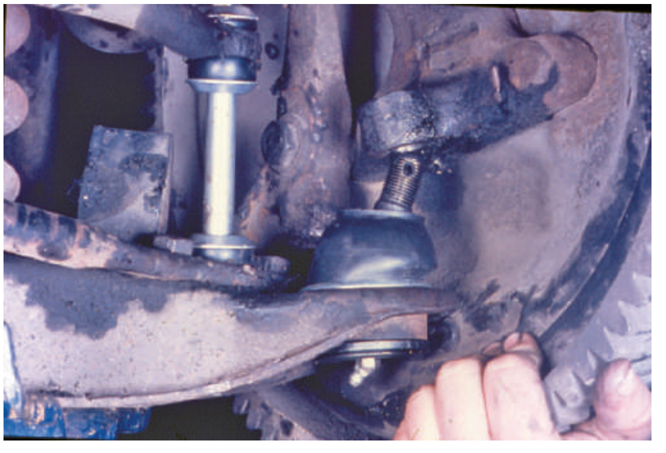


FIGURE 46–41 At times the steering knuckle must be disconnected from the lower and/or ball joint in order to remove a spring.

If the same spring is to be reinstalled, leave the compressor in position. If a new spring is to be used, slowly release the pressure on the tool by backing off the forcing nut. Compress the new spring prior to installing it.

Torsion Bars

Torsion bars are subjected to many of the same conditions affecting coil springs. Periodic adjustment of the torsion bars is necessary to maintain the proper height. Replacement is sometimes necessary because of breakage. It should be noted that the bars are not interchangeable from side to side.

FIGURE 46–42 A torsion bar adjuster.

Removing a torsion bar often requires a special tool used to unload the bar. Begin by lifting and supporting the vehicle by the frame. Remove any covers or plates covering the torsion bar adjuster **(Figure 46–42)**. Measure and record or mark the adjuster bolt before loosening it. This measurement will be used when installing the bar and setting the tension. Install the torsion bar tension relief tool and tighten the tool until the torsion bar adjuster is loose. Remove the adjuster and loosen the tool until tension is off of the bar. Remove the tool and then remove the torsion bar from the control arm.

Install the new torsion bar and apply tension using the tool. Tighten until the new adjustment bolt can be installed and set the bolt at the depth measured on the old bolt before removal. Loosen and remove the tool. Once the torsion bar is installed, set the vehicle back on the ground, bounce it several times to settle the suspension, and measure the ride height. Height inspection and measurements for vehicles with torsion bar suspensions are often the same for coil springs. Procedures for adjusting torsion bars are given in the service information. If ride height is incorrect, adjust the torsion bar until the height is within specifications. Once ride height is correct, check the wheel alignment.

Ball Joints

Begin your inspection of a ball joint by checking to see if the ball joint has a wear indicator on it. If it does, check the placement of the grease fitting. If it is recessed, the ball joint is worn and should be replaced. On some vehicles it is recommended that you check to see if the grease fitting can wiggle in the ball joint. If it does, the ball joint should be replaced. Always check the service information when checking ball joints.

Look carefully at the joint's boot. A damaged boot or joint seal will allow lubricant to leak out and allow dirt to enter and contaminate the lubricant. If the boot is damaged, the ball joint should be replaced.

If no boot damage is evident, gently squeeze the boot. If the boot is filled with grease, it will feel somewhat firm. If the joint has a grease fitting and appears not to be filled with grease, use a grease gun and refill the joint. Fill the joint until fresh grease is seen flowing out of the boot's vent. If too much grease is forced into the joint or it is forced in too quickly, the boot can unseat or tear.

Ball joints should be checked for excessive wear. Load-carrying joints may have some slop when the weight of the vehicle is taken off them. Follower joints should never have play. To check a load-carrying joint, it must be unloaded.

When the coil spring is on the lower control arm, raise the vehicle by jacking under the control arm as close to the ball joint as possible. This gives the maximum amount of leverage against the spring. The ball joint is unloaded when the upper strike out bumper is not in contact with the control arm or frame. A quick check for looseness can be made by using a pry bar between the tire and the ground. To find out if the ball joint is loose beyond manufacturer's specifications, use an accurate measuring device. The following checking procedures demonstrate the use of a dial indicator. The dial indicator is a precision instrument and should be handled carefully to prevent damage. The mounting procedure for the checking tool might vary depending on the style of ball joint used on the vehicle. Manufacturer's tolerances can be axial (vertical), radial (horizontal), or both. To conduct these checks, follow these procedures.

Typical Radial Check For a radial check, attach a dial indicator to the control arm of the ball joint being checked. Position and adjust the plunger of the dial indicator against the edge of the wheel rim nearest to the ball joint being checked. Slip the dial ring to the zero marking. Move the wheel in and out and note the amount of ball joint radial looseness registered on the dial **(Figure 46–43)**. The procedure for checking the radial movement of a lower ball joint on a MacPherson strut front suspension is shown in Photo Sequence 43.

Typical Axial Check For an axial check, first fasten the dial indicator to the control arm, then clean off the flat on the spindle next to the ball joint studnut. Position the dial indicator plunger on the flat of the spindle and depress the plunger approximately 0.350 inch. Turn the lever to tighten the indicator in

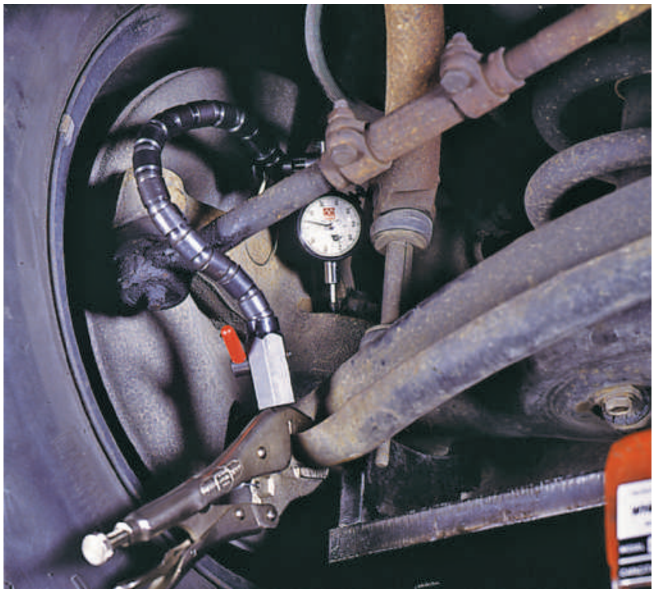
Courtesy of Federal-Mogul Corporation.

FIGURE 46–43 A typical mounting of a dial indicator for a radial check.

place. Pry the bar between the floor and tire. Record the reading **(Figure 46–44)**.

If the ball joint looseness reading on the dial indicator exceeds manufacturer's specifications, the ball joint should be replaced.

When the load-carrying ball joints are on the upper control arm (spring mounted on the upper arm), place a steel wedge between the bottom of the upper control arm and the frame. Next, raise the vehicle by its frame to unload the ball joints and hold them in their normal position. Pry up on the tire to check for play in the load-carrying joint. To determine the condition of the non-load-carrying (or follower) ball joint, vigorously push and pull on the tire, while watching the ball joint for signs of movement. Refer to the manufacturer's specifications for tolerances.



Courtesy of Federal-Mogul Corporation.

FIGURE 46–44 A typical mounting of a dial indicator for an axial check.

Rotational Torque Test

Ball joints on many Toyota products have a specification for the rotational tightness of the ball joint. To check, move the stud back and forth several times, turn the stud by hand, then attach a torque wrench to the stud **(Figure 46–45)**. Rotational torque is then compared to specifications. Typical specs are less than 31 in-lbs.

Inspection of Wear Indicators Wear-indicator-type ball joints must remain loaded to check for wear. The vehicle should be checked with the suspension at curb height. The most common type has a small-diameter boss, which protrudes from the center of the lower housing. As wear occurs internally, this boss recedes very gradually into the housing. When it is flush with the housing, the ball joint should be replaced. To remove and install a ball joint, follow the procedure given in the service information.

Replacing Ball Joints

Ball joints are mounted to the control arm in one of four basic ways: rivets, bolts, press fit, and threaded. To replace a ball joint, safely raise and support the vehicle. Depending on the vehicle and spring location, you may need to support the control arm. In most cases, remove the brake caliper and support it using a wire or bungee cord. Next, remove the ball joint to steering knuckle nut and separate the knuckle from the joint. Once the knuckle is out of the way, you will have access to the ball joint.

Many ball joints are riveted in place at the factory. Replacing these joints requires drilling or cutting out the rivets. Once the rivets are removed, the new ball joint is bolted in the control arm. Bolted in ball joints are removed by simply removing the bolts and nuts securing it to the arm. Once the new joint is installed, torque the bolts and nuts to specifications.

The most common method is press fit. Some manufacturers require you to replace the entire control-arm assembly if a ball joint is to be replaced. In these cases, the ball joint and control arm are made as a single assembly and individual parts are not available.

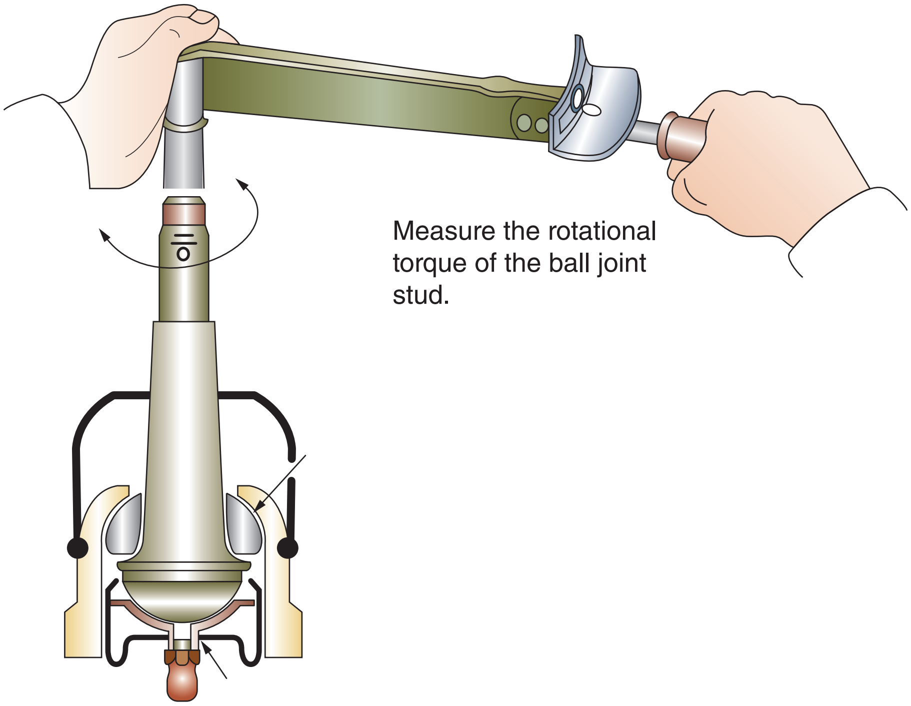


FIGURE 46-45 Checking rotational torque.

Press-fit ball joints are typically removed and installed using a special ball joint press **(Figure 46–46)**. While pressing the ball joint out of or into the control arm, make sure you do not damage the arm.

A few vehicles use threaded ball joints. In this style, external threads are formed in the outside of the ball joint housing. The joint threads into the control arm. To replace it, remove the steering knuckle and unscrew the ball joint. Install the new joint and torque it to specifications.

Once the new ball joints are installed, reinstall the steering knuckle and torque the ball joint nut to specifications. If a castle nut is used and the hole in the ball joint stud does not align with the hole in the nut, tighten the nut until the two align. Install a new cotter pin and bend one or both prongs so that the pin cannot back out of the joint.

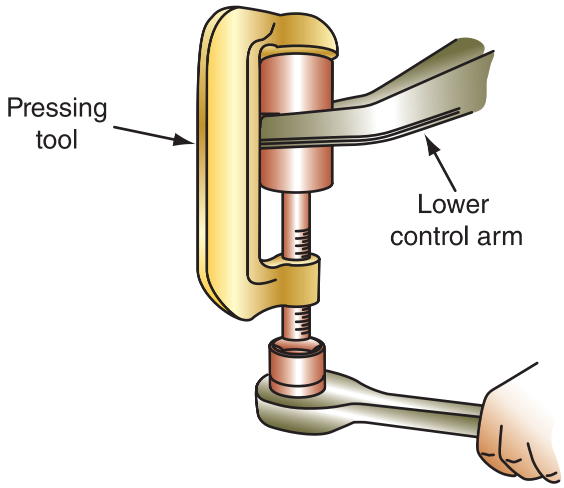


FIGURE 46-46 Pressing in a new ball joint.

Warning! Never use heat to remove a ball joint.

Control Arm Bushings

Visually inspect each rubber bushing for signs of distortion, movement, off-center condition, and presence of heavy cracking. Check metal bushings for noise and loose seals.

To remove the control arm bushings, raise the vehicle and support the frame on safety jack stands. Remove the wheel assembly. Install a spring compressor on the coil spring.

Disconnect the ball joint studs from the steering knuckle as described previously. Remove the bolts attaching the control-arm assembly to the frame and remove the control arm.

Bushings are pressed in and out of their bores by using special tools. A special tool is installed over the bushing **(Figure 46–47)** after the correct size adapter for the tool has been selected. Tightening

PHOTO SEQUENCE 43

Measuring the Lower Ball Joint Radial Movement on a MacPherson Strut Front Suspension

P43-1 Raise the front suspension with a floor jack and place jack stands under the chassis at the vehicle's lift points.

P43-2 Grasp the front tire at the top and bottom and rock the tire inward and outward while a coworker visually checks for movement in the front wheel bearing. If there is movement, adjust or replace the wheel bearing.

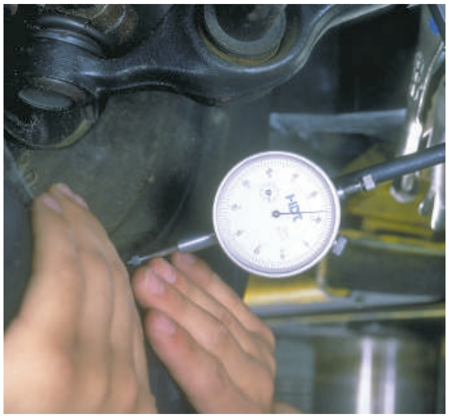
P43-3 Position a dial indicator against the inner edge of the rim at the bottom. Preload and zero the dial indicator.

P43-4 Grasp the bottom of the tire and push outward.

P43-5 With the tire held outward, read the dial indicator.

P43-6 Pull the bottom of the tire inward and be sure the dial indicator reading is zero. Adjust the dial indicator as required.

P43-7 Grasp the bottom of the tire and push outward.



P43-8 With the tire held in this position, read the dial indicator.

P43-9 If the dial indicator reading is more than specified, replace the lower ball joint. Before doing this, make sure that the wheel bearing and hub are good.

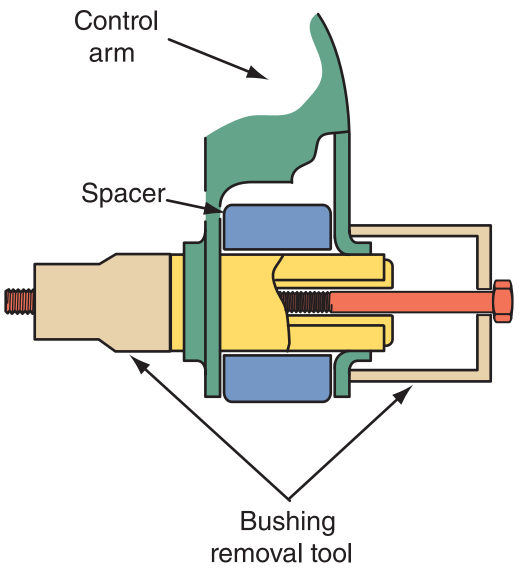


FIGURE 46–47 Removing a control-arm bushing.

the tool pushes the bushing out of the control arm. The same process is used to press a new bushing into the control arm. As the special tool is tightened, the bushing moves into its bore. When installing new bushings, make sure they stay straight while they are being pressed in.

Once the new bushings are started into the control arm, measure and mark the center between mounting holes and center the control arm. Now, alternately press in the bushings on each side, keeping the reference marks aligned. This ensures the shaft is not off center, causing binding. End cap nuts or bolts should not be torqued until the vehicle is at curb height and the suspension has been bounced and allowed to settle out.

Rebolt the control arm and tighten the bolts to specifications, then install the coil spring into position. Install the ball joint studs into the control arms. Remove the coil-spring compressor. Install the wheel assembly and lower the car. Road test the car, retighten all bolts, and set wheel alignment.

Strut Rod Bushings

Except in the case of accidental damage, the strut rod itself is rarely replaced. Rather, it is the bushing that wears, deteriorates, and needs replacement. To replace the bushings, remove the nuts and bolts securing the strut rod to the frame and control arm. Remove the bushings and washers and replace with new and in the correct order. Torque all the fasteners to specifications. Depending on the suspension arrangement, removing and replacing the strut rod bushings require checking and adjusting caster.

Sway Bar Bushings and Links

These bushings anchor the sway bar securely to the vehicle frame and the control arms on each side. The condition of the bushings affects the performance of the bar. Visual inspection of mounting bushings indicates if the bushings are worn, have taken a permanent set, or are possibly missing. Also check the sway bar links. Any damage indicates that they should be replaced.

Sway bar links on older vehicles typically use a long bolt, washers, bushings, a spacer, and a nut. The link is assembled between the control arm and sway bar **(Figure 46–48)**. Over time, the links rust and break. Install a sway bar link kit, making sure the bushings and washers are installed in the correct positions. Tighten the bolt and nut to specifications to prevent overtightening and collapsing the bushings.

FIGURE 46–48 A broken sway bar link.

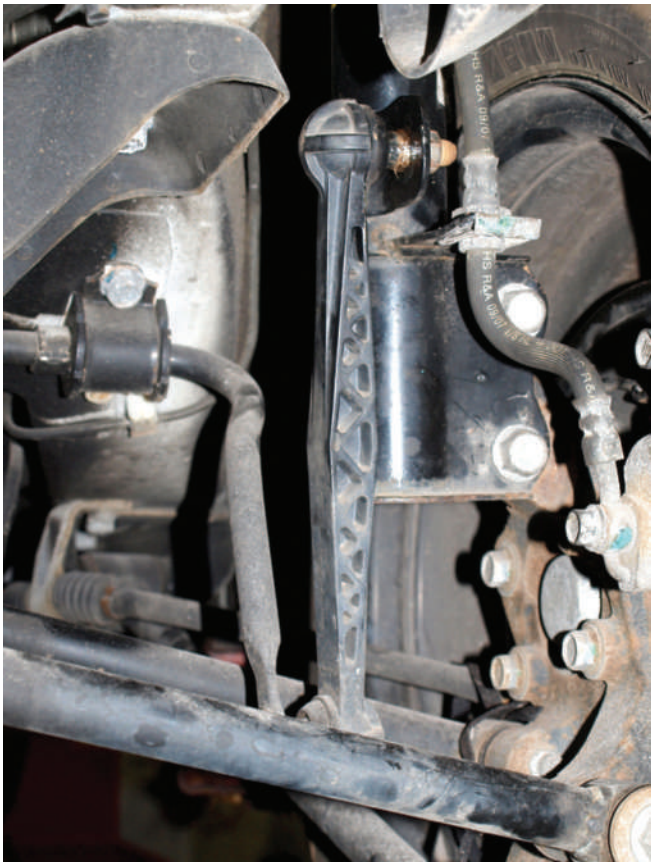


FIGURE 46–49 An example of a sway bar link.

Most vehicles now use plastic or metal links with ball socket joints on the ends. The ball sockets connect the link to the sway bar and control arm or strut **(Figure 46–49)**. This type of link typically does not come without destroying the ball socket. This means that if the link needs to be removed, such as when replacing a strut, the link will likely need to be replaced also as the ball sockets do not usually separate without damage.

Shock Absorbers

A shock absorber that is functioning properly ensures vehicle stability, handling, and rideability. Most motorists fail to notice gradual changes in the operation of their cars as a result of worn shock absorbers. Some common indications of shock absorber failure follow:

- Steering and handling are more difficult.
- Braking is not smooth.
- Bouncing is excessive after bumps and stops.
- Tire wear patterns are unusual, especially cupping.
- Springs are bottoming out.

Warning! Gas-pressurized shock absorbers will extend on their own and can create a dangerous situation. Never apply heat or flame to the shock absorbers during removal; the heat will cause the gas to expand and the shock will quickly extend. Before disposing of used gas-pressurized shocks and struts, refer to the manufacturer's service information regarding the release of gas pressure. This usually requires drilling a small hole in a specific location in the shock body to release the pressure.

Shock absorbers should be inspected for loose mounting bolts and worn mounting bushings. If these components are loose, they will rattle, and replacement of the bushings and bolts is necessary. The upper mounts of struts should also be carefully checked.

In some shock absorbers, the bushing is permanently mounted in the shock, and the complete unit must be replaced if the bushing is worn. When the mounting bushings are worn, the shock absorber will not provide proper spring control.

Vibrations set up by a worn shock absorber can cause premature wear in many of the undercar systems. They can cause wear in the front and rear component parts of the suspension system, the linkage component parts of the steering system, and the U-joints and motor or transmission mounts of the driveline. Also, vibrations can cause unnatural wear patterns on the tires.

When replacing shocks, refer to the service information. Some rear shocks are mounted into the passenger compartment or trunk, requiring extra caution during replacement. For most front shocks, remove the shock's lower mounting bolt(s) and then remove the upper mount. If the shock mount uses bushings, install the new bushings on the shock to prevent metal-on-metal contact. Install the shock and torque all fasteners to specs.

Rear shock replacement may require using a jack to support the rear axle or suspension but the replacement procedure is basically the same as for front shock replacement. If the old shocks are gas-pressurized, refer to the procedures for releasing the gas before disposing of the shock.

A shock absorber can be bench tested. First, turn it up in the same direction it occupies in the vehicle. Then extend it fully. Next, turn it upside down and fully compress it. Repeat this operation several times. Install a new shock absorber if a lag or skip occurs near mid-stroke of the shaft's change in travel direction, or if the shaft seizes at any point in its travel, except at the ends. Also, install a new shock absorber if noise, other than a switch or click, is encountered when the stroke is reversed rapidly, if there are any leaks, or if action remains erratic after purging air.

MacPherson Strut Suspension

The MacPherson strut suspension system is based on a triangular design. The strut shaft is a structural member that does away with the upper control arm bushings and the upper ball joint. Since this shaft is also the shock absorber shaft, it receives a tremendous amount of force vertically and horizontally. Therefore, this assembly should be inspected very closely for leakage, bent shaft, and poor damping.

To remove and replace the MacPherson strut, proceed as shown in Photo Sequence 44.

During the disassembly of the strut, make sure you check the strut pivot bearing **(Figure 46–50)**. Move the bearing with your hand. If the bearing is hard to move or seems to bind, it must be replaced. When replacing the bearing, make sure the correct side is up. Manufacturers normally mark the up side with paint or some other marking. Make sure you check all rubber insulators for deterioration and other damage and replace them if necessary. Also make sure you mark the eccentric camber bolts before loosening them. Returning the bolts in the same location will help maintain the correct camber angle after reassembly. Also replace all cotter pins in the suspension and align the wheels after everything is reassembled.

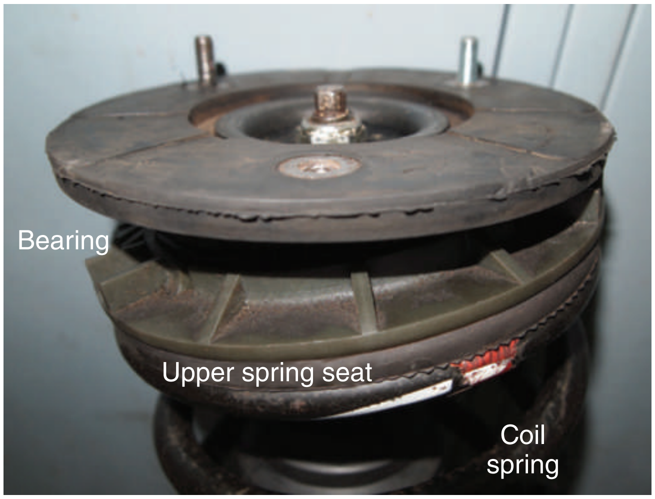


FIGURE 46–50 Check the strut's pivot bearing for free movement.

Rear-Suspension Systems

There are three basic types of rear suspensions: live-axle, semi-independent, and independent. There are distinct designs of each, but the types of components and the principles involved are the same as on front-suspension systems described earlier in this chapter. Live-axle suspensions are found on rear-wheel drive (RWD) cars, trucks, vans, and the front of many four-wheel drive (4WD) trucks. Semi-independent systems are used on front-wheel drive (FWD) vehicles. Independent suspensions can be found on both RWD and FWD vehicles, as well as 4WD cars.

Live-Axle Rear-Suspension Systems

This traditional rear-suspension system consists of springs used in conjunction with a live-axle (one in which the differential axle, wheel bearings, and brakes act as a unit). The springs are either of leaf or coil type. Air springs are used on some older vehicles.

Leaf Spring Live-Axle System Two springs—either multiple-leaf or monoleaf—are mounted at right angles to the axle and along with the shock absorbers, are positioned below the rear-axle housing. The front of the two springs is attached to brackets on the vehicle's frame by a bolt and bushing inserted through the eyes of the springs. While the bushing allows the spring to move, it isolates the rest of the vehicle from noisy road vibrations.

The center of each leaf spring is connected to the rear axle housing with U-bolts. Rubber bumpers are located between the rear-axle housing and frame or unit body to dampen severe shocks. The rear eye pivot bushings are held to the frame with shackles, which attach to the springs by a bolt and bushing **(Figure 46–51)**.

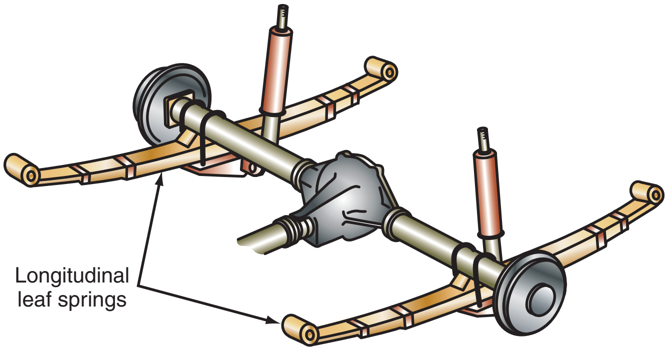


FIGURE 46–51 A typical rear suspension with a live axle.

There are some disadvantages to the live-axle suspension system. First, this design has a large amount of unsprung weight. Another drawback is the instability caused by the use of a solid axle. Since both rear wheels are connected to the same axle, movement up or down by one wheel affects the other. Consequently, poor traction results because both wheels are pushed out of alignment with the road. Under severe acceleration, this type of suspension is subject to axle tramp, a rapid up-and-down jumping of the rear axle due to the torque absorption of the leaf springs. This condition can break spring mounts and shock absorbers and cause premature wear of wheel bearings. Axle tramp is reduced by mounting shock absorbers on the opposing sides (front and back) of the axle. Some heavy-duty vehicles have two-stage springs that allow the vehicle to ride comfortably with both a light or heavy load.

Coil-Spring Live-Axle System Some vehicles use two coil springs at the rear with a live rear axle. Because coil springs can only support weight and have little axle-locating capability, such vehicles need forward and lateral control arms or links. This type of suspension is called the link-type rigid axle.

The coil springs, located between the brackets on the axle housing and the vehicle body or frame, are held in place by the weight of the vehicle and sometimes by the shock absorbers **(Figure 46–52)**. The control arms are usually made of channeled steel and mounted with rubber bushings. Accelerating, driving, and braking torque are transmitted through three or four control arms, depending on the design. Two forward links are always used, but either one or two lateral links can be found on individual models. Trailing arms mount to the underside of the axle, and run forward at a 90-degree angle to the axle to brackets on the car frame. Rubber bushings

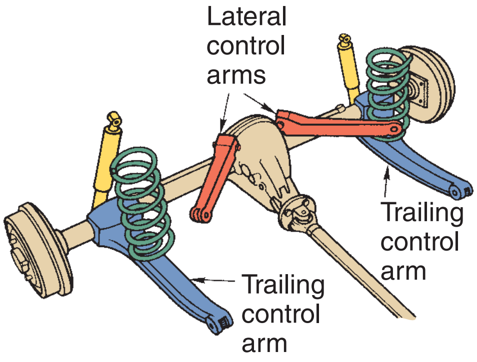


FIGURE 46–52 A typical live-axle suspension with coil springs.

are used at mounting locations to permit up-and-down movement of the arms and to reduce noise and the effect of shock.

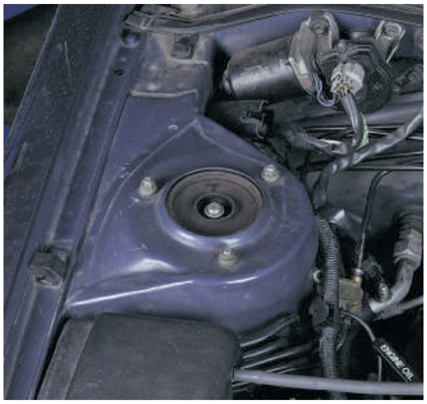
Some rear-axle assemblies are connected to the body by two lower control arms and a track bar. A single torque arm is used in place of upper control arms and is rigidly mounted to the rear-axle housing at the rear and through a rubber bushing to the transmission at the front. A few manufacturers are using Watts links in their rear suspensions **(Figure 46–53)**. A Watts link is used to limit rear-axle motion from side to side.

Live-Axle Suspension System Servicing Typical service to both coil-spring and leaf-spring systems include the replacement of shock absorbers or springs. Bushings, shackles, or control arms do not need replacement frequently. Always follow the procedures outlined in the service information whenever servicing the rear suspension.

FIGURE 46–53 A Watts link used to limit rear-axle movement.

PHOTO SEQUENCE 44

Removing and Replacing a MacPherson Strut



P44-1 The top of the strut assembly is mounted directly to the chassis of the car.

P44-2 Prior to loosening the strut chassis bolts, scribe alignment marks on the strut bolts and the chassis.

P44-3 With the top strut bolts or nuts removed, raise the car to a working height. It is important that the car be supported on its frame and not on its suspension components.

P44-4 Remove the wheel assembly. The strut is accessible from the wheel well after the wheel is removed.

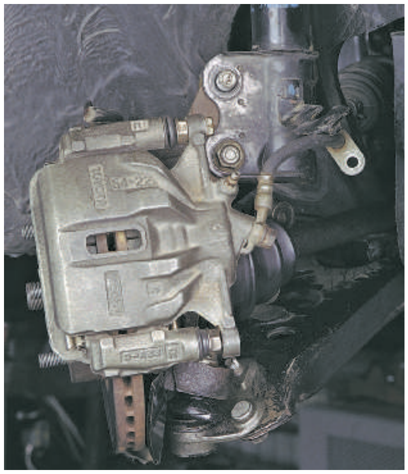
P44-5 Remove the bolt that fastens the brake line or hose to the strut assembly.

P44-6 Remove the strut's two steering knuckle bolts.

P44-7 Support the steering knuckle with wire and remove the strut assembly from the car.

P44-8 Install the strut assembly into the proper type of spring compressor. Then compress the spring until it is possible to safely loosen the retaining bolts.

P44-9 Remove the old strut assembly from the spring and install the new strut. Compress the spring to allow for reassembly and tighten the retaining bolts.



P44-10 Reinstall the strut assembly into the car. Make sure all bolts are properly tightened and in the correct locations.

Semi-Independent Suspension

A semi-independent suspension system is used on many front-wheel drive models. On some, the suspension position is fixed by an axle beam, or crossmember, running between two trailing arms. Although there is a solid connection between the two halves of the suspension because of the axle beam, the beam twists as the wheel assemblies move up and down. The twisting action not only permits semi-independent suspension movement, but it also acts as a stabilizer. Frequently, a separate shock and spring trailing arm system is also used. In either an integrated or separate shock system, each rear wheel is independently suspended by a coil spring.

A coil spring and shock absorber–strut assembly are ordinarily used with this suspension system. The bottom of the strut is mounted to the rear end of the trailing arm. The top is mounted to the reinforced inner fender panel. Braking torque is transmitted through the trailing control arms and struts. The arms and struts also maintain the fore and aft, and lateral positioning of the wheels. A track bar is also used on some trailing arm suspension systems. The track bar helps to reduce sideways movement of the axle.

Semi-Independent Suspension System Servicing

As in most rear-system servicing, the first step is to remove the shock absorber. It is important to remember not to remove both shock absorbers at one time unless the axle is supported. Suspending the rear axle at full length could result in damage to the brake lines and hoses. The servicing of a semi-independent suspension system usually involves the removal and reinstallation of shock absorbers, springs, insulators, and control arm bushings. Follow the procedures given in the vehicle's service information.

Warning! When removing the rear springs, do not use a twin-post hoist. The swing arc tendency of the rear-axle assembly when certain fasteners are removed might cause it to slip from the hoist. Perform this operation on the floor if necessary.

Independent Suspension

Independent suspensions can be found in large numbers on FWD, RWD, AWD, and even 4WD vehicles. The introduction of independent rear suspensions was brought about by the same concerns for improved traction ride that prompted the introduction of independent front suspensions. If the wheels can move separately on the road, traction and ride are improved.

Independent coil-spring rear suspensions can have several control arm arrangements. For example, A-shaped control arms are sometimes employed. When the wide bottom of a control arm is toward the front of the car and the point turns in to meet the upright, they are called trailing arms **(Figure 46–54)**. When the entire A-shaped control arms are mounted at an angle, they are known as semitrailing control arms or multilink suspensions. Coil springs are used between the control arm and the vehicle body. The control arms pivot on a crossmember and are attached at the other end to a spindle. A shock absorber is attached to the spindle or control arm.

Some vehicles use a rear-suspension system that uses a lower control arm and open driving axles. A crossmember supports the control arms, while the tops of the shock absorbers are mounted to the body. The springs are set in seats at the bottom and top of the crossmember.

A few cars use only lower control arms, but substitute a wishbone-shaped subframe for the upper control arms. Two torque arms transfer the rear-end torque to the subframe. In fact, many cars are now featuring rear double-wishbone suspension **(Figure 46–55)**. Torque loads create bushing and control arm deflection during braking, cornering, acceleration, and deceleration. It is

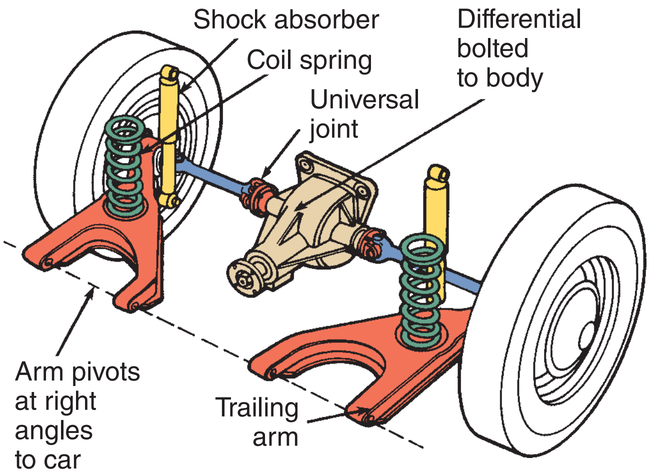


FIGURE 46–54 Trailing arms are often used with independent rear suspensions.

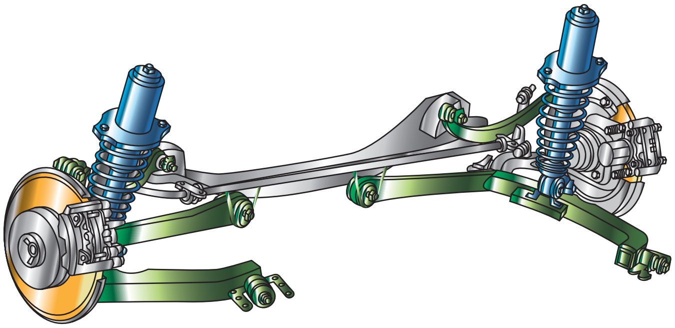


FIGURE 46–55 A double wishbone rear suspension.

interesting to note this rear-suspension system allows for a small amount of toe-in change to enhance straight line stability. The toe-in change during cornering leads to quicker and more responsive turning. The rear-suspension system can also be tuned to ensure minimal dive under braking and minimal squat under acceleration.

Currently, struts are replacing conventional shock absorbers in rear independent-suspension systems. One of the latest strut rear-suspension designs used by car manufacturers is shown in **Figure 46–56**.

On this type of system, the spindle is used to secure the strut, the outer ends of two of the four control arms, the rear ends of the tie-rods, and a rear wheel. The control arms contain bushings of different sizes at their outer ends. The ends with the smaller bushings attach near the body centerline. The ends with the larger bushings attach at the spindle. (When replacing control arms, it is mandatory that offsets at their outer ends and the flanges on the arms face in the direction prescribed in the manufacturer's service information.) This system is also called the nonmodified MacPherson strut system.

FIGURE 46–56 A strut-based rear-suspension system.

The modified MacPherson strut rear suspension is common for vehicles with front-wheel drive. The major components on each side of the vehicle are a modified MacPherson shock strut, lower control arm, tie-rod, and wheel spindle. A coil spring mounts between the lower control arm and the body crossmember/side rail. The spindle, in addition to supporting the rear wheel, is used as an attaching location for the outer end of the control arm and the rear end of the tie-rod. The inner end of the control arm attaches to the crossmember. The forward end of the tie-rod attaches to the side rail.

Another rear strut design uses a Chapman strut that is similar to the modified MacPherson strut. The difference between the two struts is that the MacPherson strut is involved directly in the car's steering system. The Chapman strut is not. In addition, the Chapman strut can be used with conventional springs, often a leaf-type spring. It frees the Chapman strut of load-carrying duties so it can concentrate on providing exact wheel location and shock absorbing functions.

Rear leaf-spring suspension systems are used on many vehicles with conventional rear drives. These leaf springs are generally mounted longitudinally in the same manner as described earlier in this chapter for live-axle systems. A few leaf-spring systems, however, employ springs mounted transversely. Both multiple-leaf and monoleaf, or single-leaf, can be used. The transverse-leaf spring is mounted to the differential housing rather than the vehicle frame as in the longitudinal installation. The transversely mounted spring's eyes are connected to the wheel spindle assemblies.

Rear shock absorbers or shock struts have the same service limitations as those used on the front of the vehicle. They cannot be adjusted, refilled, or repaired. The procedure for inspecting rear shocks or shock struts is similar to previously mentioned front-end parts inspection. Repetition is not necessary.

Multilink Rear Suspension

A multilink rear suspension uses several control arms to guide the wheel **(Figure 46–57)**. Different models feature different types of multilink rear suspensions that satisfy the varying demands of vehicle dynamics, ride comfort, and space requirements. These include the double-wishbone rear suspension, trailing-link double-wishbone rear suspension, and trapezoidal-link rear suspension.

In the double-wishbone suspension, the wheel is guided by two triangulated lateral control arms (the

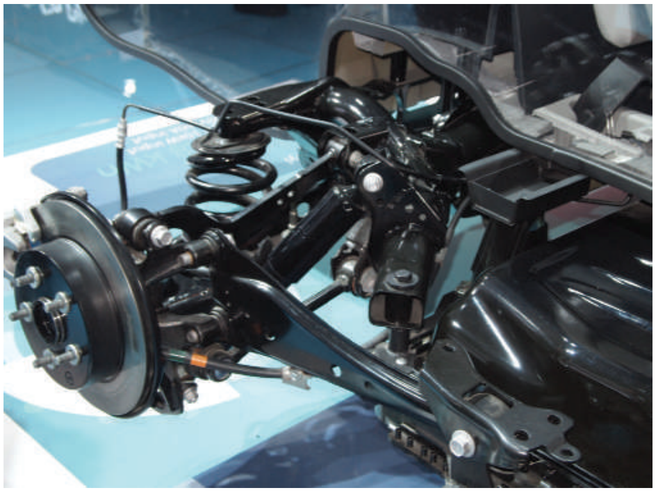


FIGURE 46–57 A multilink rear suspension.

wishbones) and a tie rod. The suspension strut is attached to the lower wishbone to provide vertical support.

The trailing-link double-wishbone suspension has a trailing link that also carries the wheel and upper and lower wishbones. The spring is located on the trailing link ahead of the center of the wheel; the shock absorber is behind it.

The trapezoidal-link rear suspension permits excellent performance, handling, and comfort. The rear wheel is fixed by an upper lateral control arm and a trapezoidal lower link with a tie rod behind it. For reduced weight, the trapezoidal link and upper control are hollow aluminum castings.

Servicing Independent Suspension Systems

Most of the servicing techniques for rear independent suspension systems—except coil, control arm, and strut removal and installation—are similar to other front- and rear-suspension parts. They have been covered earlier in this chapter. Of course, check the service information for all inspection and repair techniques of the vehicle's independent rear system.

Servicing Rear Coil Spring Raise the vehicle on a frame contact hoist or position jack stands under the frame forward of the rear-axle assembly. This allows the shock absorbers to fully extend. Place a floor jack under the center of the rear-axle housing and support the weight of the rear axle, but do not lift the vehicle off the jack stands. Disconnect the lower end of the shock absorber. Then, lower the floor jack until all of the coil-spring force is relieved. If a coil-spring positioner is used, remove it from the center of the coil spring. The coil spring can usually be removed from the vehicle at this time by lifting it from its spring seat. If the springs are to be used again, mark or tag each one so it can be returned to its original location. When a replacement is needed, always replace coil springs in pairs. This ensures equal height.

To install a spring, place the insulator on top of the coil spring and position the spring on the spring seat. The end of the top coil must be positioned to line up with the recess in the spring seat. Jack up the rear-axle housing so the spring is properly seated at the lower end and the shock absorbers line up. Reconnect the shock absorbers.

There are some definite advantages to working on one spring at a time. First of all, the assembled side of the vehicle helps support the disassembled side. It also keeps the parts aligned and eliminates the possibility of putting the parts on the wrong side of the vehicle.

Servicing Rear Struts

The biggest difference with replacing rear struts is the location of the upper mounts. In many cars, the upper strut mount may be located in the trunk, under the parcel shelf, or behind the rear seat cushion **(Figure 46–58)**. Determine how to access the upper

FIGURE 46–58 Disassembling the rear passenger area to replace the rear struts.

mount before you start in case you have to disassemble the interior of the car. Support the lower control arm with a jack and remove the lower strut connections. Once you have access to the upper mount, remove the fasteners and remove the strut from the car. Torque all fasteners once reinstalled and make sure all the interior pieces are clean.

Servicing Rear Control Arms To remove the upper rear control arms from the vehicle, remove the bolts passing through the control arms at the frame and at the axle ends. Usually the rear coil spring does not have to be removed for this. Service one side of the vehicle at a time. This simplifies realigning the parts during assembly. On a serviceable control arm, replace the control arm bushings by removing the defective bushing with an appropriate puller. Properly position the new bushing and press it into place in the same manner as is done on front suspensions. Position the repaired control arm on the vehicle and loosely install the bolts. Repeat the service on the other control arm if necessary. Properly torque the nuts and bolts once the vehicle's entire weight is on the springs again.

The coil springs must be removed to service the lower rear control arms. Again, one side of the vehicle should be serviced at a time. Once the vehicle is properly supported and the springs are dismantled, remove the nuts and bolts that pass through the control arm. Remove the control arm from the vehicle and service it in the same way as the upper control arm.

Check the service information to see if there is an adjustment for the driveline working angle. If none is specified, torque the control arm bolts to specification while the full vehicle weight is on the rear axle. This sets neutral bushing tension at normal curb height.

When there is a driveline working angle adjustment, adjust the angle before torquing the control arm bolts. After the rear suspension has been serviced, always check the working angle of the universal joints on the drive shaft. This minimizes the possibility of driveline vibration.

Some independent rear-suspension systems have ball joints that perform a function similar to the front ball joints, and they should be inspected in the same way.

Although very few cars have rear wheels that steer, some independent suspension systems have components that would normally be seen only on vehicles with four-wheel steering. Components such as tie-rod ends may appear to serve the same purpose as if they were on the front suspension. They are used to adjust the angle of the wheels for stable straight ahead performance. These suspension and steering items are covered in greater detail in Chapters 47 and 48 of this book.

Electronically Controlled Suspensions

All of the suspension systems covered up to this point are known as passive systems. Vehicle height and damping depend on fixed nonadjustable coil springs, shock absorbers, or MacPherson struts. When weight is added, the vehicle lowers as the springs are compressed. Air-adjustable shock absorbers may provide some amount of flexibility in ride height and ride firmness, but there is no way to vary this setting during operation. Passive systems can be set to provide a soft, firm, or compromise ride. Vehicle body motion and tire traction vary due to road conditions and turning and braking forces. Passive systems have no way of adjusting to these changes.

Advances in electronic sensor and computer control technology have led to a new generation of suspension systems. The simplest systems are level control systems that use electronic height sensors to control an air compressor linked to air-adjustable shock absorbers.

More advanced adaptive suspensions are capable of altering shock damping and ride height continuously. Electronic sensors **(Figure 46–59)** provide input data to a computer. The computer adjusts air spring and shock damping settings to match road and driving conditions.

The most advanced computer-controlled suspension systems are true active suspensions. Some use forward-looking cameras to scan the road ahead and adjust the suspension before hitting bumps and dips in the road. These systems are usually hydraulically, rather than air, controlled. They use high-pressure hydraulic actuators to carry the vehicle's weight rather than conventional springs or air springs. However, some systems, such as AIRMATIC from Mercedes-Benz, use electronically controlled air springs to carry weight and control ride quality.

The unique feature of an active suspension is that it can be programed to respond almost perfectly to various operating conditions. For example, some late-model Ford Fusions have a unique computer-controlled shock absorber system that provides continuously controlled damping. In effect, the system softens the blow when a tire falls into a pothole on the road. It detects the pothole and then stops the tire from dropping all the way into it, which means the tires won't strike the opposite side of the pothole as harshly. This reduces the jarring felt by the vehicle's passengers.

The system uses 12 sensors and active dampers that can adjust the shock absorbers every

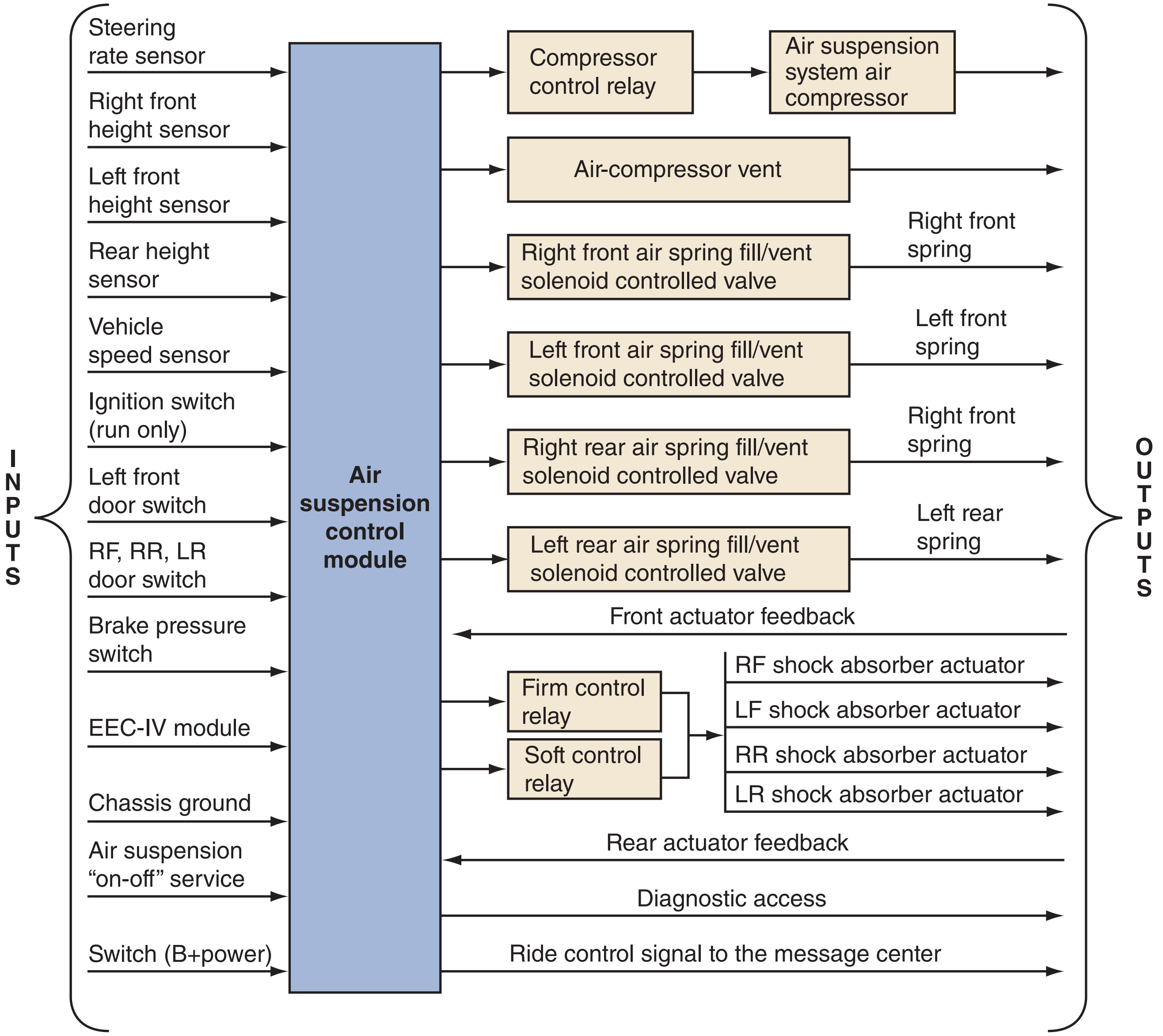


FIGURE 46–59 The various inputs and outputs for an electronic suspension system.

2 milliseconds. The rear suspension can respond faster; signals from the front wheel provide warning signals for the rear wheel before it reaches the pothole. The system can also be used in Sport mode to improve handling and cornering.

Active systems using hydraulic actuators are presently used on a limited number of high-performance vehicles. Most manufacturers are introducing various adaptive suspension systems that rely on pneumatically actuated air springs and dampers.

Some late-model pickups and SUVs offer air suspension systems. These systems are added to existing leaf-spring suspensions. The air spring is positioned between the center of the leaf spring and the frame of the truck. The air spring serves as an adjustable and additional spring at each end of the axle.

Adaptive Suspensions

Adaptive suspensions use electronic shock absorbers with variable valving. In some cases, variable air spring rates are used to adapt the vehicle's ride characteristics to the prevailing road conditions or driver demands.

Electronic sensors monitor factors such as vehicle height, vehicle speed, steering angle, braking force, door position, shock damping status, engine vacuum, throttle position, and ignition switching. A computer is used to analyze this input and switch the suspension into a preset operating mode that matches existing conditions. Some systems are fully automatic. Others allow the driver to select the ride mode.

At present, adaptive suspensions are less costly and complicated than hydraulically controlled active suspensions. However, they do have some limitations. Although they can reduce body roll, adaptive suspensions cannot eliminate it like true active systems. Adaptive systems also experience a slight delay in their reaction time, although some systems can change shock valving in as little as 150 microseconds.

System Components There are many different designs and components used by the manufacturers to accomplish the same task. Some systems use adjustable shocks, while others use air springs at each side of the axles. The air spring membrane is similar to a tire in construction. A solenoid valve and filter assembly allows clean air to be added or released from the air spring. Adding or removing air changes the ride height of the vehicle.

The airflow to the springs is controlled by the interaction of the air compressor, system sensors, computer control module, and solenoid valves. All of the air-operated parts of the system are connected by nylon tubing.

Compressor. The compressor supplies the air pressure for operating the entire system. It is often a positive displacement single piston pump powered by a 12-volt DC motor. A regenerative air dryer is attached to the compressor output to remove moisture from the air before it is delivered to the air springs. The compressor is operated through the use of an electric relay controlled by the computer module.

Sensors. Vehicle height sensors can be rotary Hall-effect sensors that enable the computer to more accurately measure ride height as well as to compensate for road variations **(Figure 46–60)**. This prevents the vehicle from bottoming out when crossing over railroad tracks or similar road irregularities.

FIGURE 46–60 A sensor used for ride and stability control systems.

Advanced systems also read the steering angle by using a photo diode and shutter location inside the steering column. This allows the system to firm up the suspension when the vehicle is turning. The system also reads engine vacuum or throttle position to stiffen the suspension when the vehicle is accelerating. A brake sensor allows the system to compensate for front nosedive during hard braking. Some systems use a special G-sensor to sense sudden acceleration or braking. Other adaptive systems use a yaw sensor to pick up body roll when cornering.

Electronic Shock Absorbers. Many adaptive suspension systems use electronically controlled shock absorbers that feature variable shock damping. The degree of damping is controlled by the computer based on input from the vehicle speed, steering angle, and braking sensors. As explained earlier in this chapter, variable shock damping is accomplished by varying the size of the metering orifices inside the shock. A small actuating motor mounted on top of the shock absorber rotates a control rod that alters the size of the metering orifices.

A recent advancement in adaptive suspension technology is the use of real-time shock damping. These systems use solenoid-actuated shocks rather than the motor driven shocks. Solenoids allow almost instantaneous valving changes. This means the suspension can react to bumps and body motions as they happen. Real-time adaptive systems deliver most of the handling advantages of a full active suspension without increased vehicle weight and power drain. With these systems, changes to shock valving in as little as 10 milliseconds are possible when bumps are encountered.

Electronic Struts. Some systems use an electronically controlled strut in place of the air spring and shock absorber **(Figure 46–61)**. Design and operation is similar to electronic shock absorbers. A valve selector or variable orifice located inside the strut controls fluid pressure in the suspension system based on input from many sensors and commands from the system's control module.

Some variable damping suspension systems use air or gas rather than a fluid. At speeds up to 40 mph (65 km/h), the orifice is fully open and provides full flow. From 40 to 60 mph (65 to 100 km/h), the orifice is in the normal position and flow is restricted. At speeds more than 60 mph (100 km/h), or when the vehicle is accelerating or braking, the variable orifice is shifted to the firm position.

The use of a variable orifice in the damper control, coupled with the deflected disc valving, provides optimum fluid flow control for both rebound and jounce strokes. In the comfort mode, the selector is

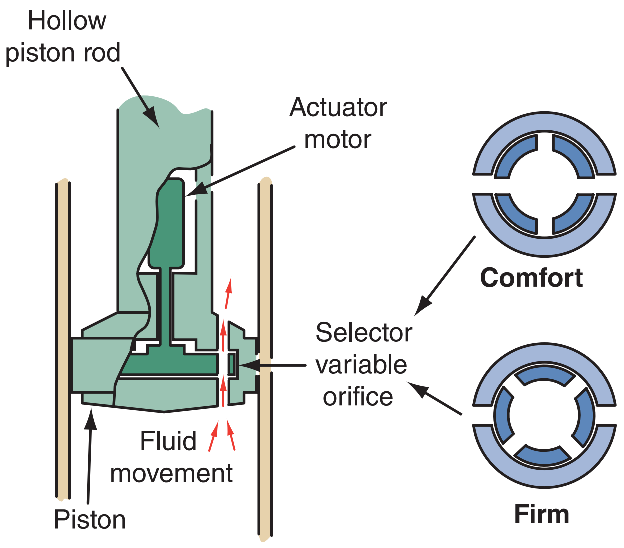


FIGURE 46-61 Computer command ride strut. Four electronically controlled struts are used on many adaptive suspension systems. Based on input from the computer, the valving selector shifts the variable by-pass orifice to a comfort, normal, or firm setting.

set to allow fluid flow primarily through the large selector orifice to achieve minimum damping forces. While in the normal mode, the unit is set to balance fluid flows between the small selector orifice and the deflected disc valving to provide moderate damping forces. Under conditions in which the firm mode is needed, the selector is rotated to its firm or blocked position and fluid flows entirely through the deflected disc valving.

The damper control also can raise or lower the vehicle's height. This action also improves the car's aerodynamic characteristics at highway speed. As speed increases, the suspension reduces the vehicle's height and the front end angles downward. This action tends to reduce wind resistance for greater stability and better gas mileage. As the vehicle slows, the suspension brings the body up to its normal height and level position.

Computer Control Module. An electronic module controls the air compressor motor (through a relay), the compressor vent solenoid, and the four air spring solenoids. The computer module also controls operation of electronic shock absorber actuating motors and electronic strut valving selectors. The control module receives input from all system sensors.

The computer module also has the capability of performing diagnostic tests on the system. It has a preprogrammed routine for properly fitting air springs after servicing. The module also controls the dash-mounted system warning light.

Electrical power to operate the basic air suspension system is distributed by the main body wiring harness. Each wiring harness involved has a special function in the typical air suspension system.

Warning! The compressor relay, compressor vent solenoid, and all air spring solenoids have internal diodes for electrical noise suppression and are polarity sensitive. Care must be taken when servicing these so as not to switch the battery feed and ground circuits, or component damage will result. When charging the battery, the ignition switch must be in the off position if the air suspension switch is on, or damage to the air compressor relay or motor may occur. However, use of a battery charger while performing the diagnostic test or air spring fill option is acceptable. Set it to a rate to maintain but not damage the vehicle battery.

Electronic Leveling Control. Adaptive suspension systems are capable of adjusting the suspension system during operation. Less complicated electronic level-control systems are used on many large and mid-size vehicles.

These systems do not use a computer module. In most cases, height sensors are the only types of sensors used. These height sensors sense when passenger weight or cargo is added to or removed from the vehicle **(Figure 46–62)**. The height sensors control two basic circuits. The compressor relay coil grounds circuits that activate the compressor. The exhaust solenoid coil grounds circuits that vent air from the system.

To prevent falsely actuating the compressor relay or exhaust solenoid circuits during normal ride motions, the sensor circuitry provides an 8- to 15-second delay before either circuit can be completed.

In addition, the typical sensor electronically limits compressor run time or exhaust solenoid energized time to a maximum of approximately 3½ minutes. This time limit function is necessary to prevent continuous compressor operation in a case of a solenoid malfunction. Turning the ignition off and on resets the electronic timer circuit to renew the

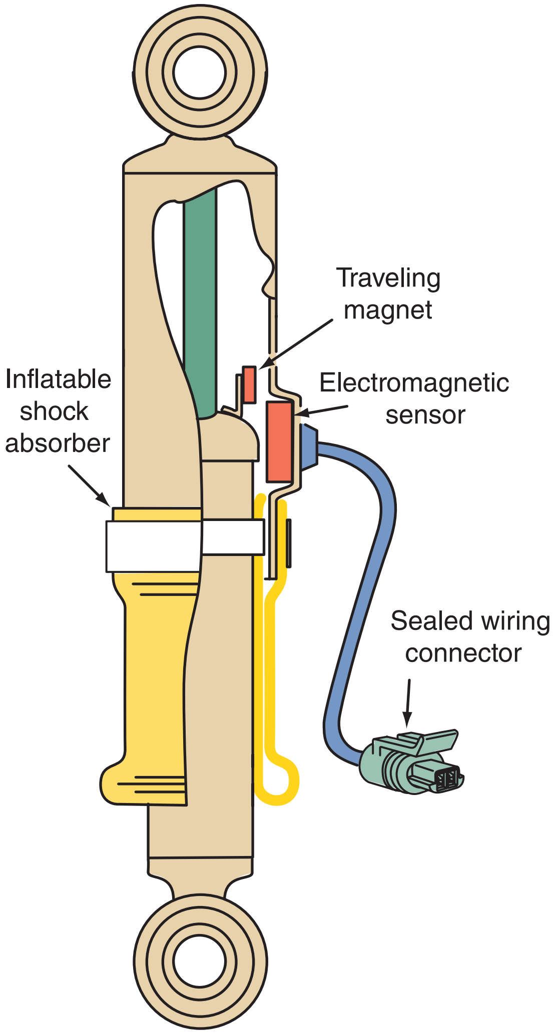


FIGURE 46–62 A load-sensing shock absorber.

3½-minute maximum run time. The height sensor is mounted to the frame crossmember in the rear. The sensor actuator arm is attached to the rear upper control arm by a link. The link should be attached to the metal arm when making any trim adjustment.

When the air line is attached to the shock absorber fittings or compressor dryer fitting, the retainer clip snaps into a groove in the fitting, locking the air line in position. To remove the air line, spread the retainer clip, release it from the groove, and pull on the air line.

Adjustable Pneumatic Suspension Adjustable pneumatic suspension at the front and rear wheels is a feature on some AWD vehicles. By varying the vehicle's ground clearance, it can be used off-road but also performs and handles well on the highway. There are four ride-height positions that can be selected either manually or automatically, with a total range of over 8 inches (203 mm) of ground clearance. At highway speeds, the vehicle's ground clearance is 5.6 inches (142 mm). Urban mode raises it a full inch. For moderate off-road and local driving, ground clearance is 7.6 inches (193 mm). For severe off-road conditions at speeds under 25 mph (40 km/h), maximum clearance is 8.2 inches (208 mm). The vehicle will adjust to the desired height based on vehicle speed, or the driver can temporarily override the setting by depressing a button.

MagneRide

MagneRide is a semiactive suspension system, which features shocks or struts with no electromechanical valves or small moving parts. Instead of valve-controlled orifices, MagneRide regulates the flow of fluid by a variable magnetic field produced by a small electric coil mounted in the shock **(Figure 46–63)**. The shocks are filled with magneto-rheological (MR) fluid. MR fluid consists of magnetically soft particles, such as iron, suspended in synthetic hydrocarbon fluid.

The action of the shock forces the MR fluid through a magnetized opening in each shock. When the shock is in its off state, the fluid is not magnetized and flows freely through the orifice. When current is sent to the coil, the fluid becomes magnetized and its viscosity changes instantly **(Figure 46–64)**.

FIGURE 46–63 A magneto-rheological fluid-based strut.

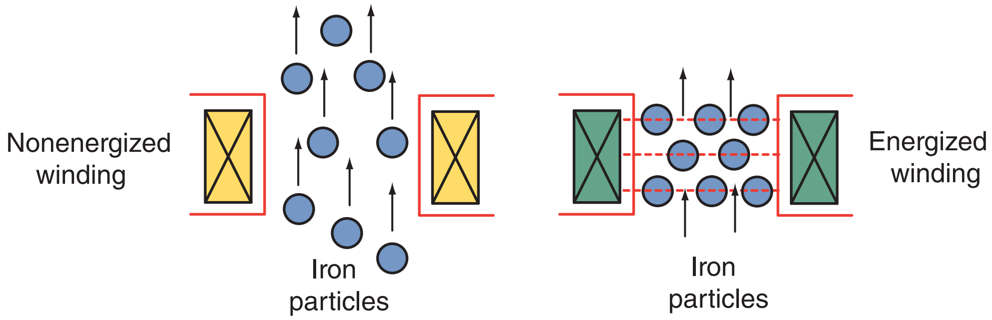


FIGURE 46-64 The iron particles in the MR fluid align themselves when they pass through the magnetic field, causing the fluid to stiffen.

The material changes from a fluid state to a semisolid state that is directly proportional to the magnetic field applied to it. With little or no electrical current, the iron particles are randomly distributed, and the fluid passes freely through the piston orifice. When a strong electrical current is applied to the coil, the resulting magnetic field aligns the iron particles so that the fluid stiffens and the flow is resisted. This condition causes heavy damping. The resulting damping force is proportional to the viscosity, which is proportional to the strength of the magnetic field.

Sensors monitoring wheel position, lateral acceleration, vehicle speed, steering wheel angle, and brake pedal angle are inputs to the control module that sends current to the coil in the shocks. This system provides extremely quick response time, typically about 5 ms, and the fluid is capable of reacting 30,000 times per second.

Servicing Electronic Suspension Components

Most electronic suspension servicing requires the removal and replacement of a component. The correct procedures for doing this are given in the manufacturer's service information. Serviceable items include the air compressor, mounting brackets, height sensors, air springs, air lines and connections, gas struts, strut mounts, control arm components, shock absorbers, and stabilizer bars.

Attention to fasteners is extremely important when serving all suspension systems, especially electronic systems. Failure to adhere to the advice given about fasteners can result in a sudden failure of the air spring or suspension system. Suspension fasteners can affect performance of vital components and systems or could result in additional service expenses. All fasteners must be replaced with fasteners of the same part number or with an equivalent part. Never use a replacement part of lesser quality or substitute design. All fasteners must be tightened to the specified torque. New fasteners must be installed whenever the originals are loosened or removed and when new components are installed.

Diagnosis

A scan tool and/or a special electronic tester is used to diagnose most electronic suspension systems. These can only retrieve DTCs; they may also be able to activate various actuators in the system. The exact procedures and available data from the vehicle's computer will vary with manufacturer and the system found on the vehicle. Always refer to the correct service information when diagnosing electronic systems.

Diagnosis should begin with gathering as much information as possible from the customer. Make sure you know exactly what the concern is and the conditions at the time the malfunction occurred. Verify the customer's concern by attempting to duplicate the conditions during a road test.

Check the voltage at the battery. If the voltage is below 11 volts, recharge or replace the battery before continuing with diagnostics. Check the fuses, connectors, and wiring harnesses for the suspension system and repair them as necessary. Start the engine and allow it to warm up. Then connect the scan tool or tester. Retrieve all DTCs from the system. If the scan tool or tester is unable to communicate with the vehicle's computer, diagnose the cause of this before proceeding.

GO TO Chapter 22 for the procedures for retrieving DTCs and CAN communication problem diagnostic procedures.

Check the DTC charts to see if the DTCs match the symptoms exhibited by the vehicle. If they do, proceed

to follow the troubleshooting chart related to each DTC. If the DTCs do not match the symptoms, clear them and recheck for trouble codes after your diagnosis of the suspension system has been completed.

If there are no DTCs related to the problem, record the PIDs and compare them to specifications **(Figure 46–65)**. If the cause of the problem is still not evident, refer to the symptoms chart provided by the manufacturer. Check those areas identified as possible causes of the problem. If the tester has the capability of activating the system's actuators, do this now. In many cases, the tester can cause action at one wheel at a time. The suspension of one wheel can be manually energized and the vehicle will tilt. The actuator can then be de-energized and the vehicle will return to its original position. This procedure should

PID	DESCRIPTION	EXPECTED VALUES
4X4_HIGH	4X4 High Input	IN, OUT
4X4_LOW	4X4 Low Input	IN, OUT
AS_COMP	Compressor Relay Status	ON---, ONO--, ON-B-, ON--G, OFF---, OFFO--, OFF-B-, OFF--G
AS_GATE	Front Gate Solenoid Status	ON---, ONO--, ON-B-, ON--G, OFF---, OFFO--, OFF-B-, OFF--G
AS_VENT	Vent Solenoid Status	ON---, ONO--, ON-B-, ON--G, OFF---, OFFO--, OFF-B-, OFF--G
BOO_ARC	Brake Pedal Position Switch Input	ON, OFF
CCNTARC	Number of Continuous DTCs Counted by the ARC Module	one count per bit
DR_OPEN	Door Ajar Input	OPEN, CLOSED
F_FILL	Front Fill Solenoid Status	ON---, ONO--, ON-B-, ON--G, OFF---, OFFO--, OFF-B-, OFF--G
FHGTSEN	Front Height Sensor	#, ## VDC
HGTSENS	Height Sensor	ON, OFF
IGN_RUN	Detection of Ignition Switch in the RUN Position	RUN, not RUN
LFSHK_E	Left Front Shock Encoder Status	SOFT, FIRM
LRSHK_E	Left Rear Shock Encoder Status	SOFT, FIRM
OFFROAD	Vehicle Off Road Status	ON, OFF
OPSTRAT	Operational Strategy	ARC
PCM_ACC	Acceleration Signal from the Powertrain Control Module (PCM)	YES, NO
R_FILL	Rear Fill Solenoid Status	ON---, ONO--, ON-B-, ON--G, OFF---, OFFO--, OFF-B-, OFF--G
RASGATE	Rear Gate Solenoid Status	ON---, ONO--, ON-B-, ON--G, OFF---, OFFO--, OFF-B-, OFF--G
RFSHK_E	Right Front Shock Encoder Status	SOFT, FIRM
RHGTSEN	Rear Height Sensor	#, ## VDC
RRSHK_E	Right Rear Shock Encoder Status	SOFT, FIRM
STEER_A	Steering Rotation Sensor A	LOW, HIGH

FIGURE 46–65 Typical PIDs for an electronic suspension system.

be completed at each wheel. If the suspension does not respond correctly to these commands, the corner of the suspension that did not should be thoroughly checked. If all corners responded as they should, the problem is most likely not caused by something in the electronic system, and diagnosis should continue with checks of the conventional suspension parts.

Once the cause is identified, it should be replaced or repaired; then the repair ought to be confirmed. Drive the vehicle under the same conditions during which the concern was present. Also recheck the system for any new DTCs.

Warning! NEVER remove an air spring when there is pressure in the air spring. Do not remove any components supporting an air spring without either exhausting the air or providing support for the air spring. When servicing any air suspension component, power to the air system must be shut off by turning the air suspension switch (in the luggage compartment) off or by disconnecting the battery. Most air suspension systems are equipped with a warning light. The light comes on if there is a problem, or when servicing the system.

Vehicle Alignment

Aligning a vehicle with an electronic suspension system is essentially the same as the aligning procedure described in Chapter 48, with one notable exception—curb height.

Curb height is an important dimension because it affects the other alignment angles. Caster is the most obvious one that is affected, but front camber and toe can also be included. Curb height is especially critical when checking rear camber and toe on independent rear suspensions. With electronic suspension, the ride can vary depending on various circumstances. The only way to guarantee the suspension is at the correct curb height is to preset it. Setting the vehicle up properly to check and set the alignment often requires following the manufacturers' service information exactly and using a scan tool to put the system into service mode. Do not attempt to check or set wheel alignment on a vehicle with an active suspension unless you have the right information and equipment.

Active Suspensions

Some of the advanced adaptive suspension systems may be called **active suspensions**. In this text, active suspensions refer to those controlled by double-acting hydraulic cylinders or solenoids (usually called actuators) that are mounted at each wheel.

CUSTOMER CARE

Because the technician is seldom present when a vehicle requires towing, it is important to advise the customer of the proper procedures so the tow operator does not damage the electronic suspension system. You must also know the proper hoist lifting and jacking restrictions.

When towing, it must be remembered that when the ignition is off, the automatic leveling suspension is still on. Before lifting the vehicle, be sure the ignition switch is turned off and the trunk switch deactivated. When towed from the front, towing should not exceed a speed of 35 mph (60 km/h) or a distance of 50 miles (80 km/h). When the car is towed from the rear, speeds should not exceed 50 mph (80 km/h) (or 35 mph [60 km/h] on bumpy pavement).

A body hoist is usually the only type of lift recommended. Most manufacturers warn against using a suspension hoist. The proper sequence is to position the car over the lift, shut off the ignition, and then deactivate the system.

If a body hoist is not available, a floor jack and jack stands will do. Lift the car by the front cross-member and the rear jacking points that are just in front of the rear wheel wells. Jack stands should be used to support the car.

In all situations, the lifting theory is the same. The suspension should be free to hang down while the car is in the air. This allows the wheels to be supported by the struts in the front and the shocks at the rear, both in their full extension (rebound) positions. Thus, the membrane of each air spring retains its proper shape while the car is in the air.

Each actuator maintains a sort of hydraulic equilibrium with the others to carry the vehicle's weight, while maintaining the desired body attitude. At the same time, each actuator serves as its own shock absorber, eliminating the need for yet another traditional suspension component.

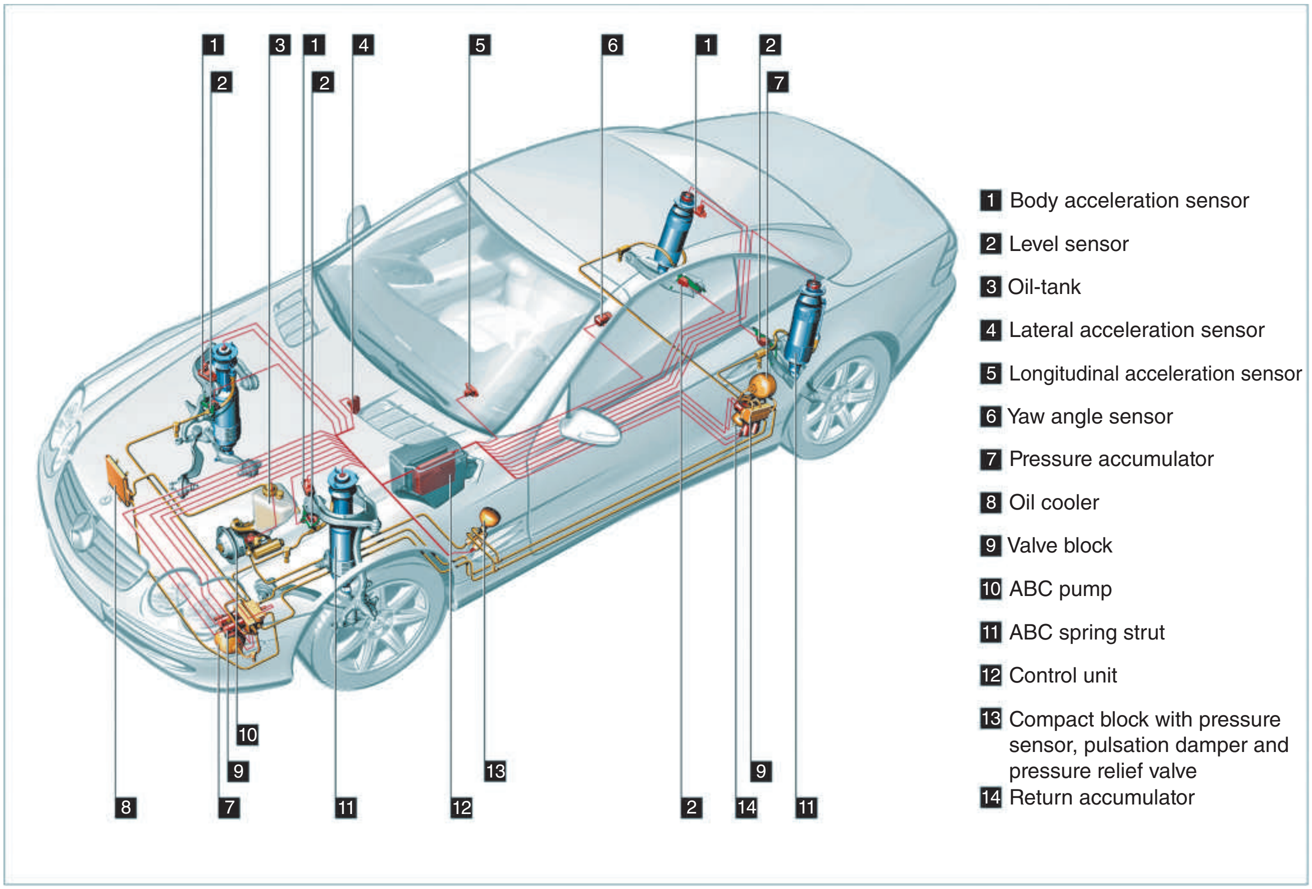
In other words, each hydraulic actuator acts as both a spring (with variable-rate damping characteristics) and a variable-rate shock absorber. This is accomplished in an active suspension system by varying the hydraulic pressure within each cylinder and the rate at which it increases or decreases. By bleeding or adding hydraulic pressure from the individual actuators, each wheel can react independently to changing road conditions.

The components that make such a system possible are the actuator control valves, various sensors, and the chassis computer **(Figure 46–66)**. Feeding information to a computer are a number of specialized sensors. Each actuator has a linear displacement sensor and an acceleration sensor to keep the computer informed about the actuator's relative position. This enables the computer to track the extension and compression of each actuator, and to know when each wheel is undergoing jounce or rebound. There are also load sensors and hub acceleration sensors in each wheel to measure how heavily each wheel is loaded.

A steering angle sensor is used to signal the computer when the vehicle is turning. To monitor body motions, a roll sensor and lateral acceleration and G-sensors are used. The computer also monitors hydraulic pressure within the system and the speed of the pump monitor.

Once it has all the necessary inputs, the computer can then regulate the flow of hydraulic pressure within each individual actuator according to any number of variables and its own built-in program. Another nice feature of a suspension such as this is that it can be programmed to behave in a variety of unique and currently impossible ways: leaning or rolling into turns, for example, or even raising a flat tire on command in order to change the tire without using a separate jack.

When the wheel of an active suspension hits a bump, the sensors detect the sudden upward deflection of the wheel. The computer recognizes the change as a bump, and instantly opens a control valve to bleed pressure from the hydraulic actuator. The rate at which pressure is bled from the actuator



Chrysler LLC.

FIGURE 46–66 An active suspension system.

determines the cushioning of the bump and the relative harshness or softness of the ride. The rate can be varied at any point during jounce or rebound to produce a variable spring rate effect. In other words, the feel of the suspension can be programmed to respond in an almost indefinite variety of ways. Once the bump has been absorbed by the actuator, pressure is forced back into it to keep the wheel in contact with the road and to maintain the suspension's desired ride height.

During hard braking with a conventional suspension system, there is a tendency for a vehicle to make a dive. The weight of the vehicle seemingly pushes the front of the car downward and the back upward. During hard braking, the active suspension increases air pressure in the front actuators and reduces air pressure in the rear actuators. These actions minimize dive to keep the vehicle level and make it easier for the driver to control. After braking, valves operate to equalize air pressures in front and rear air actuators and level the vehicle again.

Frequently, when a driver depresses the accelerator quickly during hard acceleration, the front end of the vehicle tends to lift up, while the rear end lowers. The action is known as squat. With an active suspension system, squat is controlled by the operating valve's solenoids, which increase the air pressure in rear wheel actuators and reduce air pressure in front wheel actuators. When the vehicle is no longer accelerating quickly, the control system operates valves to equalize air pressures and level the vehicle. Thus, an active suspension changes the height of the front, rear, or either side of the vehicle to counteract tilting, rolling, and leaning. These active attitude control functions improve vehicle stability and increase tire traction and driver control.

The power required for a totally active system is only 3 to 5 horsepower (about the same as a typical power steering pump). Power consumption is lowest when the system is least active, as when driving on a smooth road. Rough roads and hard maneuvers, on the other hand, put more of a demand on the system. The hydraulic pump works harder and thus requires more power.

Power consumption can be reduced by going with a semiactive suspension that uses small springs with the hydraulic actuators. The springs help to support the vehicle's weight, which reduces the load on the actuators. Smaller actuators that require less hydraulic power can then be used, which reduces the bulk and weight of the system. The addition of springs also adds a certain margin of safety to the system to keep it from going flat should the hydraulics spring a leak.

Although not as widely used as electronic leveling or adaptive suspension systems, hydraulic active suspensions are sure to become more common.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2010	**Make:** GMC	**Model:** Acadia	**Mileage:** 140,951	**RO:** 19261
Concern:	Noise over bumps, ride is rougher, and the body seems to move around more.			
The technician performs a test drive and notes several noises, including knocking and creaking sounds. He also notes the body leans a lot on right turns and the ride is rougher than normal. Back at the shop he performs a visual inspection and a shock bounce test.				
Cause:	Found one broken sway bar link, two leaking front struts, and one rear shock broken at the lower mount.			
Correction:	Replaced sway bar links, front struts and rear shocks.			

KEY TERMS

Active suspension
Adaptive suspension
Antisway bar
Ball joint
Control arm
Dampers
Jounce
Linear rate
MacPherson strut
Rebound
Shock absorber
Short-long arm (SLA)
Sway bar
Torsion bar
Variable rate
Wheel spindle

SUMMARY

- Four types of springs are used in suspension systems: coil, leaf, torsion bar, and air.
- Springs take care of two fundamental wheel actions: jounce and rebound.
- Common coil-spring materials include carbon steel, carbon boron, steel, and alloy steels. Alloy steels, such as those containing chromium and silicon, improve the coil's resistance to relaxation.
- Two basic designs of coil springs are used in vehicles: linear rate and variable rate.
- Leaf springs are made of steel or a fiber composite.
- In torsion suspension, the bar may run either from front to rear or side to side across the chassis.
- Air springs are generally only used in computer-controlled suspension systems.
- Shock absorbers damp or control motion in a vehicle. A conventional shock absorber is a velocity-sensitive hydraulic damping device. The faster it moves, the more resistance it has to the movement.
- Shock absorbers can be mounted either vertically or at an angle. Angle mounting of shock absorbers improves vehicle stability and dampens accelerating and braking torque.
- There are two basic adjustable air shock systems: the manual fill type and the automatic or electronic load-leveling type.
- MacPherson struts provide the damping function of a shock absorber. In addition, they serve to locate the spring and to fix the position of the suspension.
- Domestic struts have taken two forms: a concentric coil spring around the strut itself and a spring located between the lower control arm and the frame.
- Independent front suspension (IFS) must keep the wheels rigidly positioned and at the same time allow them to steer right and left. In addition, because of weight transfer during braking, the front-suspension system absorbs most of the braking torque. When accomplishing this, it must provide good ride and stability characteristics.
- The unequal length arm or short-long arm (SLA) suspension system is most commonly used on domestic vehicles.
- Live-axle is the traditional rear-suspension system and consists of springs used in conjunction with a live-axle (one in which the differential axle, wheel bearings, and brakes act as a unit). The springs are either of leaf or coil type.
- Semi-independent suspension is used on many front-wheel-drive models.
- Three strut designs are frequently used in IFS systems: the conventional MacPherson strut, the modified MacPherson strut, and the Chapman strut.
- The two basic types of computer suspension systems are adaptive and active.
- Electronically controlled suspensions can be either simple load-leveling systems, adaptive systems, or fully active systems. Adaptive and systems are computer controlled.
- Adaptive suspensions can alter vehicle ride height and shock absorber damping while the vehicle is in motion. Such systems use air springs and electronic shock absorbers or struts.
- Active suspensions are hydraulically operated actuators to control up-and-down and side-to-side movement. They can be programmed to respond to certain road conditions and turning forces.

REVIEW QUESTIONS

Short Answer

1. Describe how a stabilizer bar works.
2. Explain the difference between sprung and unsprung weight.
3. What are two reasons for using an air spring?
4. Explain the action of the conventional shock absorber on both compression (jounce) and rebound strokes.
5. Describe the action of the independent front wheel suspension system.
6. Describe the common complaints caused by faulty shock absorbers.
7. The core of any suspension system is the ___.

Multiple Choice

1. What occurs when a wheel hits a dip or hole and moves downward?
   a. Jounce
   b. Free length
   c. Deflection
   d. Rebound

2. Which of the following is part of the sprung weight of a vehicle?
   a. Steering linkage
   b. Tires
   c. Engine
   d. All of the above
3. What occurs when a wheel hits a dip or hole and moves upward?
   a. Jounce
   b. Free length
   c. Deflection
   d. Rebound
4. The modified MacPherson rear strut suspension is common in ___.
   a. FWD vehicles
   b. RWD vehicles
   c. pickup trucks
   d. station wagons
5. What is used to control the movement of a vehicle as it goes around corners?
   a. Struts
   b. Shock absorbers
   c. Stabilizer bar
   d. Control arms
6. The coil springs of the vehicle ___.
   a. support the weight of the vehicle
   b. provide axle location
   c. stabilize the up-and-down movement
   d. all of the above
7. SLA systems in common use today are used in the ___.
   a. coil spring suspension
   b. torsion bar suspension
   c. strut and control arm suspension
   d. all of the above
8. A multilink front suspension contains which of the following?
   a. Strut
   b. Control arms
   c. Ball joints
   d. All of the above

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that the use of firmer, urethane bushings in the suspension improves the vehicle's road-holding ability and handling. Technician B says that firmer bushings help eliminate torque steer in some FWD vehicles. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Technician A says that load-carrying ball joints should always have some play in them. Technician B says that follower ball joints should never have some play in them. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. Technician A says that a weak suspension spring can cause a loss of traction during acceleration. Technician B says that a weak suspension spring can cause poor braking power. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. Technician A says that leaf spring-type rear suspensions are subject to axle tramp. Technician B says that an antisway bar is designed to limit wheel tramp. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. Technician A says that shock absorbers should be inspected for loose mounting bolts and worn mounting bushings. Technician B says that shock absorbers and struts should be inspected for oil leakage. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

6. While discussing types of coil springs: Technician A says that linear-rate coil springs have equal spacing between the coils. Technician B says that a variable-rate spring may have a cylindrical shape with unequally spaced coils. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. When the front wheels are turned on a vehicle equipped with front struts, the left front coil spring provides a chattering action and noise: Technician A says that the strut has internal defects and strut replacement is necessary. Technician B says that the upper strut bearing and mount are defective. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. Technician A says that the suspension switch must be turned off before raising any corner of a car with an electronic air suspension. Technician B says that the ignition switch must not be turned on while any corner of a car with electronic air suspension is raised. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. While conducting a bounce test: Technician A says that the bumper should be pushed two or three times downward with considerable weight applied on each corner of the vehicle. Technician B says that one free upward bounce should stop the vertical chassis movement if the shock absorber or strut provides proper spring control. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. Technician A says that rattling on road irregularities can be caused by worn shock absorber bushings or grommets. Technician B says that dry or worn control arm bushings may cause a squeaking noise on irregular road surfaces. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 47

STEERING SYSTEMS

The purpose of the steering system seems simple—turn the front wheels. However, as vehicles have changed through the years, so have the requirements of the steering system. In addition to turning the front wheels, and in some cases also the rear wheels, the steering system is now integrated with driver assistance technology such as self-parking, lane departure control, and semiautonomous operation. Until recently, few cars had stability control systems or electric steering assist; today all new vehicles have some type of stability control and most vehicles have electrically assisted steering **(Figure 47–1)**. Until vehicles have purely electronic steering, mechanical steering components will still be the foundation of the steering system.

OBJECTIVES

- Identify the typical steering system components and their functions.
- Identify the basic types of steering linkage systems.
- Identify the components in a rack and pinion steering arrangement and describe the function of each.
- Describe the function and operation of a steering gearbox and the steering column.
- Describe the service to the various power-steering designs.
- Perform general power-steering system checks.
- Inspect and service steering linkage components.
- Inspect and service power steering pumps.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2007	**Make:** Chevy	**Model:** Cobalt	**Mileage:** 130,753	**RO:** 19357
Concern:	Customer states car darts to right or left after hitting a bump.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

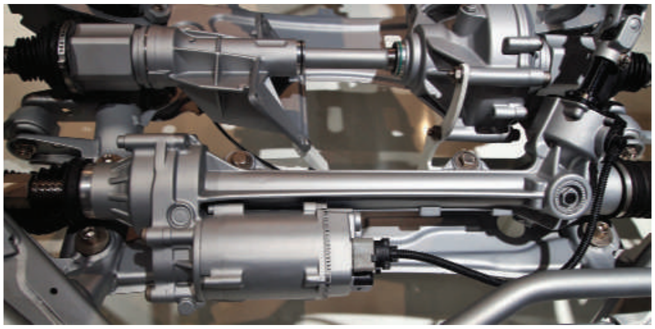


FIGURE 47–1 Modern electric power assisted steering.

Mechanical Steering Systems

The steering system is composed of three major subsystems: the steering linkage, steering gear, and steering column and wheel. As the steering wheel is turned by the driver, the steering gear transfers this motion to the steering linkage. The steering linkage turns the wheels to control the vehicle's direction. Although there are many variations to this system, these three major assemblies are in all steering systems.

Steering Linkage

The term steering linkage is applied to the system of pivots and connecting parts placed between the steering gear and the steering arms that are attached to the front or rear wheels that control the direction of vehicle travel. The steering linkage transfers the motion of the steering gear output shaft to the steering arms, turning the wheels to maneuver the vehicle. The steering arms are the part of the steering knuckle that curve in toward the center of the vehicle and connect to the steering linkage.

The type of front-wheel suspension (independent wheel suspension as compared with a solid front axle) greatly influences steering geometry. Most passenger cars, light trucks, and recreational vehicles have independent front-wheel suspension systems. Therefore, a steering linkage arrangement that tolerates relatively large wheel movement must be used.

Parallelogram Steering Linkage

A parallelogram type of steering linkage arrangement was at one time the most common type used on passenger cars. It is used with the short-long arm suspension and a recirculating ball steering gearbox. Parallelogram steering linkage can be placed behind the front-wheel suspension **(Figure 47–2A)** or ahead of the front-wheel suspension **(Figure 47–2B)**. The components in a parallelogram steering linkage arrangement are the Pitman arm, idler arm, links, and tie-rods.

Pitman Arm The **Pitman arm (Figure 47–3)** connects the linkage to the steering gear located at the base of the column. It transmits motion from the gear to the linkage, causing the linkage to move left or right to turn the wheels in the appropriate direction. It also serves to maintain the height of the center link. This ensures that the tie-rods are able to be parallel to the control arm movement and avoid unsteady toe settings or **bump steer**. *Toe*, a critical alignment factor, is a term that defines how well the tires point to the direction of the vehicle.

Idler Arm The **idler arm** or idler arm assembly **(Figure 47–4)** is normally attached, on the opposite side of the center link, from the Pitman arm and to the car frame, supporting the center link at the correct height. A pivot built into the arm or assembly permits sideways movement of the linkage. On some linkages, such as those on a few light-duty trucks, two idler arms are used.

Links Links, depending on the design application, can be referred to as **center links**, drag or steering links **(Figure 47–5)**. Their purpose is to control sideways linkage movement, which changes the wheel's direction. Because they usually are also mounting locations for tie-rods, they are very important for maintaining correct toe settings. If they are not mounted at the correct height, toe is unstable and a condition known as the toe change or bump steer is produced. Center links and drag links can be used either alone or in conjunction with each other, depending on the particular steering design. On some vehicles, a steering damper may be attached to the center link and to

SHOP TALK

A linkage component can be a wear or nonwear component. If the part has a ball joint socket, it is considered a wear component. If the part only has a bore for the ball joint stud of another component to connect it to, it is considered a nonwear part. If a center link is nonwear, the Pitman arm is normally a wear arm. If the link is wear, the Pitman arm is usually nonwear. Idler arm assemblies are always subject to wear.

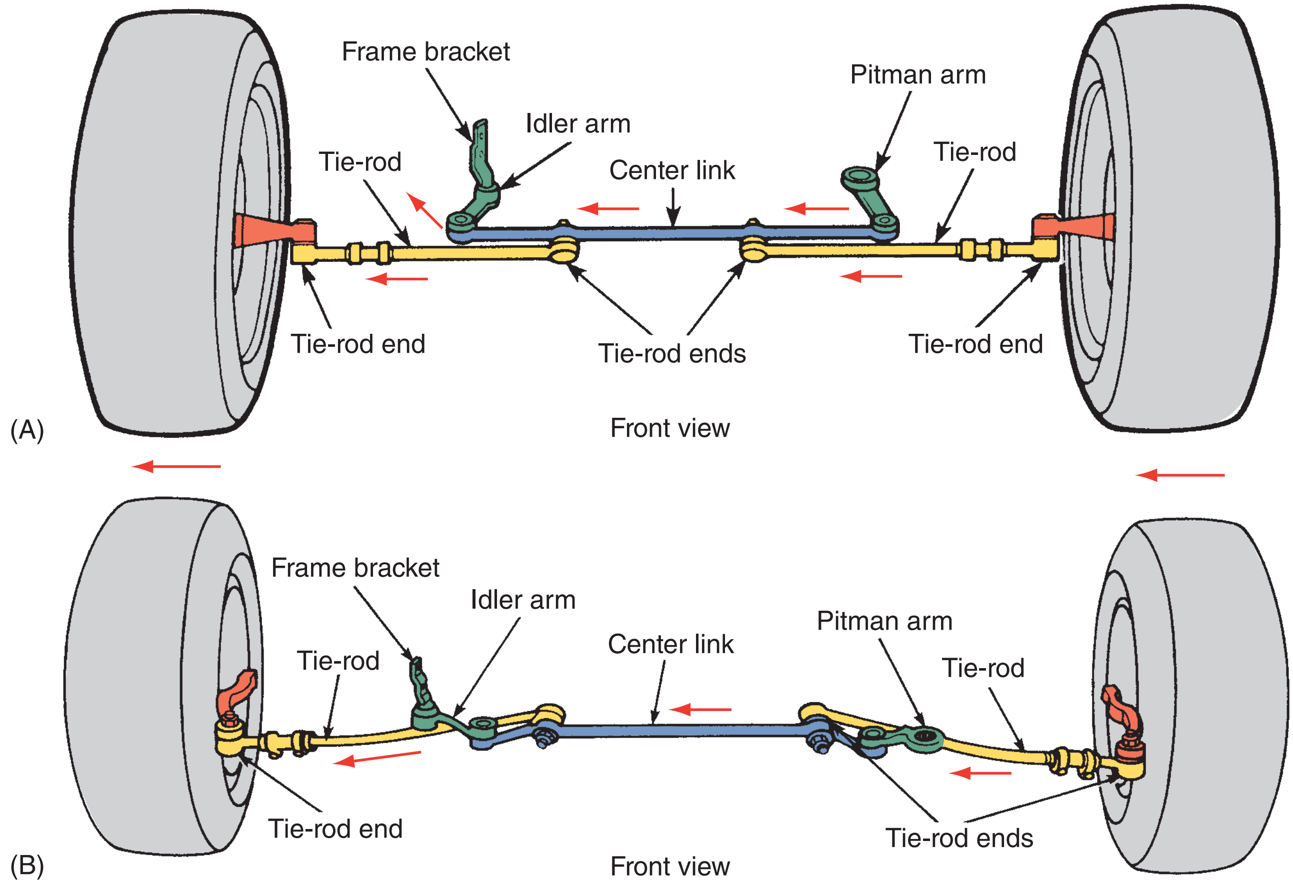


FIGURE 47–2 Parallelogram steering system mounts (A) behind the front suspension, and (B) ahead of the front suspension.

FIGURE 47–3 A typical Pitman arm. It connects the steering column to the center link.

FIGURE 47–4 A typical idler arm. It supports the center link and it is mounted to the frame.

FIGURE 47–5 A typical center link.

the frame. The damper reduces the effects of road induced vibrations on the steering wheel.

Tie-Rods **Tie-rods** and tie-rod assemblies make the final connections between the steering linkage and steering knuckles. In a parallelogram steering linkage, the tie-rods have ball socket assemblies at each end. One end is attached to the steering arm and the other end to the center link. Tie-rod assemblies consist of inner tie-rod ends, which are connected to the opposite sides of the center link; outer tie-rod ends, which connect to the steering knuckles; and adjusting sleeves or bolts, which join the inner and outer tie-rod ends, permitting the tie-rod length to be adjusted for correct toe settings **(Figure 47–6)**.

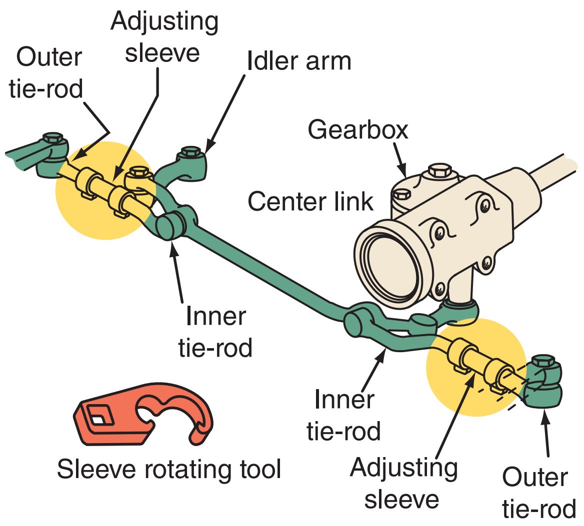


FIGURE 47-6 A tie-rod assembly.

Cross Steer and Haltenberger Linkages

Vehicles with solid front axles, front live axles, or twin I-beam suspensions typically use either a cross steer or Haltenberger linkage **(Figure 47–7)**. These linkage arrangements use long tie-rods, often called drag links, and a Pitman arm, instead of parallelogram linkage. These linkages allow for the movement of the front suspension without causing bump steer.

Steering Damper

The purpose of a steering damper is simply to reduce the amount of road shock that is transmitted up through the steering column. Steering dampers are found mostly on 4WD, especially those fitted with large tires. The damper serves the same function as a shock absorber but is mounted horizontally to the steering linkage—one end to the center link and the other to the frame.

Rack and Pinion Steering Linkage A **rack and pinion** is lighter in weight and has fewer components than parallelogram steering **(Figure 47–8)**. Tie rods are used in the same fashion on both systems, but the resemblance stops there. Steering input is received from a pinion gear attached to the steering column. This gear moves a toothed rack that is attached to the tie-rods.

In the rack and pinion steering arrangement, there is no Pitman arm, idler arm assembly, or center link. The rack performs the task of the center link. Its movement pushes and pulls the tie-rods to change the wheel's direction. The tie-rods are the only steering linkage parts used in a rack and pinion system.

Most rack and pinion assemblies **(Figure 47–9)** are composed of a tube in which the steering rack can slide. The rack is a rod with gear teeth cut along its length. The inner tie-rods attach either to the ends of the rack gear or bolt to its center. When the tie-rods thread onto the ends of the rack gear it is called an end take-off rack. When the tie-rods bolt to the center of the rack gear it is called a center take-off rack.

The rack meshes with the teeth of a small pinion gear. The pinion gear is at the end of the steering column. The two inner tie-rod ends, which are attached to the rack gear, are covered by rubber bellows boots that protect the rack from contamination. The inner tie-rods connect to outer tie-rod ends, which connect to the steering arms. The rack and pinion housing is fastened to the vehicle at two or three points. Typically, the rack is mounted on rubber bushings. Like the parallelogram linkage, it can be mounted in front of or behind the suspension.

In some cases, the rack and pinion steering gear on unibody cars is bolted directly to a body panel, like a cowl. This is common with center take-off racks **(Figure 47–10)**. When this is done, the body

FIGURE 47-7 A cross link system on a 4WD truck.

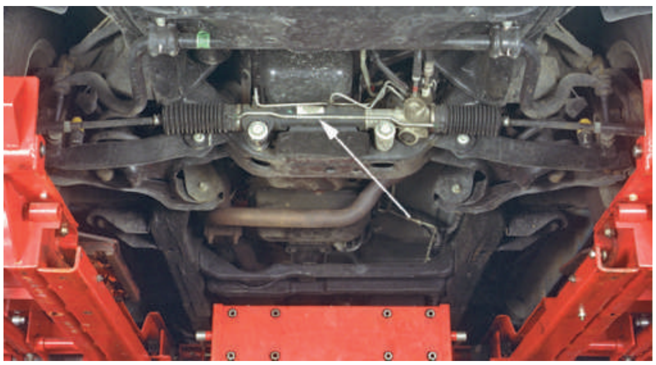


FIGURE 47-8 A rack and pinion steering system.

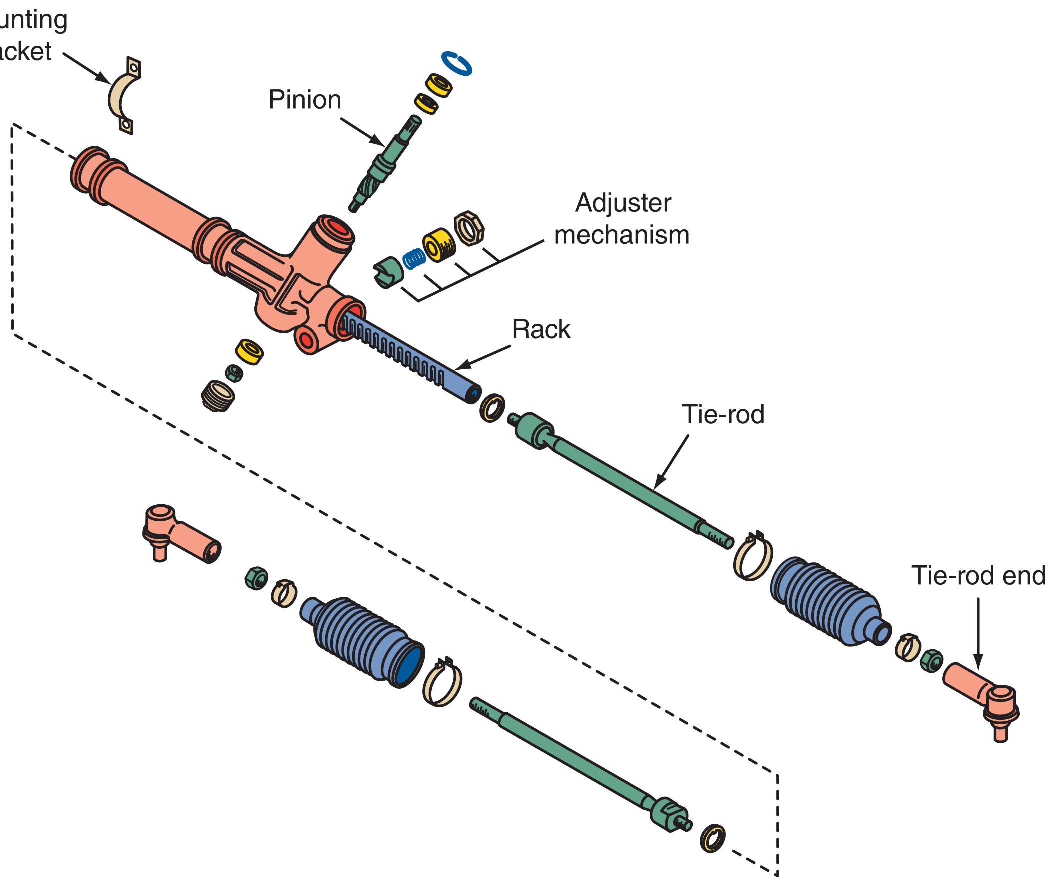


FIGURE 47–9 A disassembled view of a manual rack and pinion steering gear.

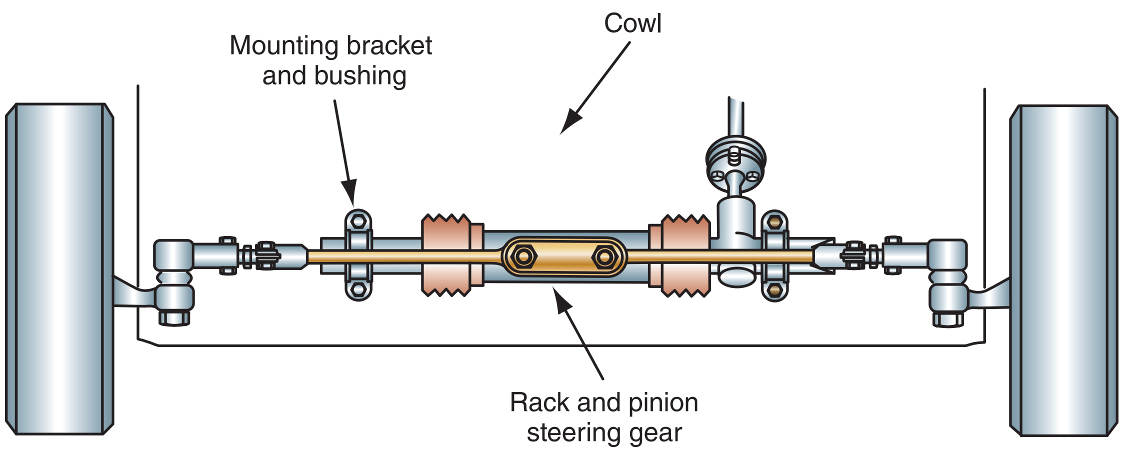


FIGURE 47–10 A center take-off rack and pinion.

panel must hold the steering gear in its correct location. The unibody structure must maintain the proper relationship of the steering and suspension parts to each other. Along with other advantages, the rack and pinion steering system combined with the MacPherson strut suspension system is found in most front-wheel-drive unibody vehicles because of their weight- and space-saving feature.

The driver gets a greater feeling of the road with rack and pinion because there are fewer friction points. Fewer friction points can also reduce the system's total ability to isolate and dampen vibrations.

Rack The rack is a toothed bar contained in a metal housing. The rack maintains the correct height of the

steering components so that the tie-rod movement is able to parallel control arm movement.

The rack is similar to the parallelogram center link in that its sideways movement in the housing is what pulls or pushes the tie-rods to change wheel directions.

Pinion The pinion is a toothed or worm gear moved by the steering wheel. The pinion gear meshes with the teeth in the rack so that the rack is propelled sideways in response to the turning of the pinion.

Yoke Adjustment The rack-to-pinion lash, or preload, affects steering harshness, feedback, and noise. It is set according to the manufacturer's specifications. An adjustment screw, plug, or shim pack are located on the outside of the housing at the junction of the pinion and rack to correct or set the yoke lash **(Figure 47–11)**.

Tie-Rods Tie-rods in rack and pinion systems are very similar to those used on parallelogram systems. They consist of inner and outer ends. Typically, the rod of the inner tie-rod threads into the outer tie-rod. This allows for changing the length of the tie-rod assembly, which changes wheel position and the toe angle **(Figure 47–12)**. The inner tie-rod ends on rack and pinion units are usually spring-loaded ball sockets that screw onto the rack ends **(Figure 47–13)**. They are preloaded and protected against contaminant entry by rubber bellows or boots.

Manual-Steering Gear

The purpose of the steering gear is to change the rotational motion of the steering wheel to a reciprocating motion to move the steering linkage. In addition, the steering gear also reduces the effort needed to turn the wheels. This is done by using gears of different sizes. The steering gearbox ratio is determined by the total number of degrees of steering wheel rotation divided by the total degrees of movement of the front tires **(Figure 47–14)**. Gearboxes with high numerical ratios, such as 20:1, provide easier but less precise steering. Lower ratios, such as 15:1, provide better driver feedback and feel but at increased effort. A modern full-size truck may have a 20:1 steering ratio and a small sports car, such as the Mazda Miata, around 15.5:1.

There are three styles: the recirculating ball, worm and roller, and the rack and pinion. The latter gear assembly incorporates the already described rack and pinion linkage system and steering gear as a single unit.

The recirculating ball, as shown in **Figure 47–15**, contains a sector shaft, wormshaft, and ball nut. A ball nut is used that has threads that mate to the threads of the wormshaft via continuous rows or ball bearings between the two. Ball bearings recirculate

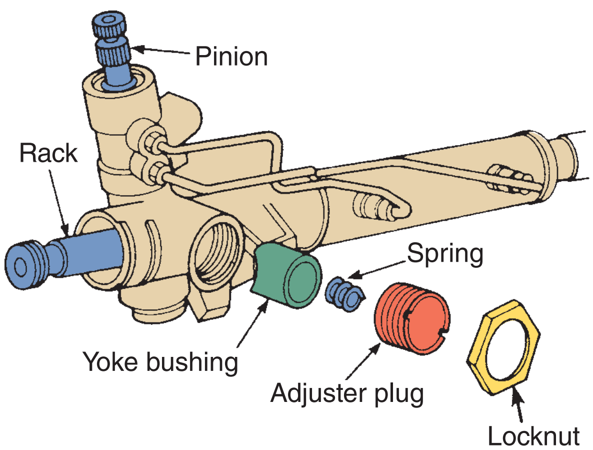


FIGURE 47–11 The rack preload (yoke lash) is adjusted by a screw, plug, or shim pack.

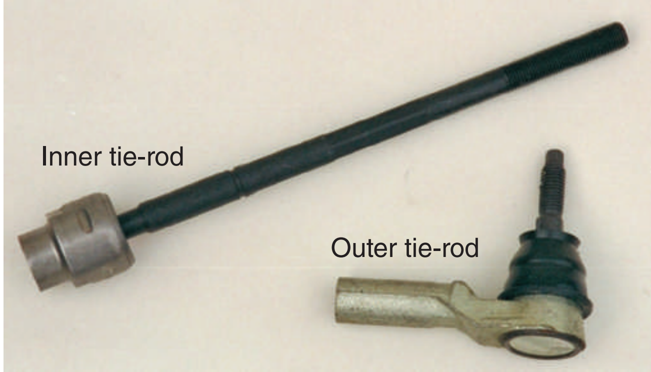


FIGURE 47–12 Rack and pinion inner and outer tie-rods.

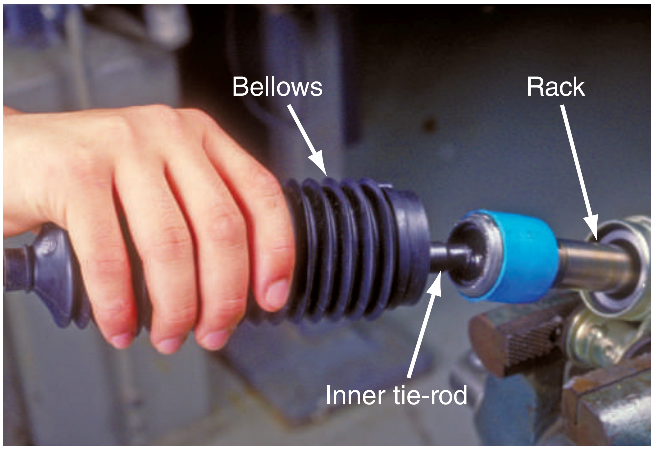


FIGURE 47–13 The inner tie-rod is a spring-loaded ball socket in a rack and pinion steering box.

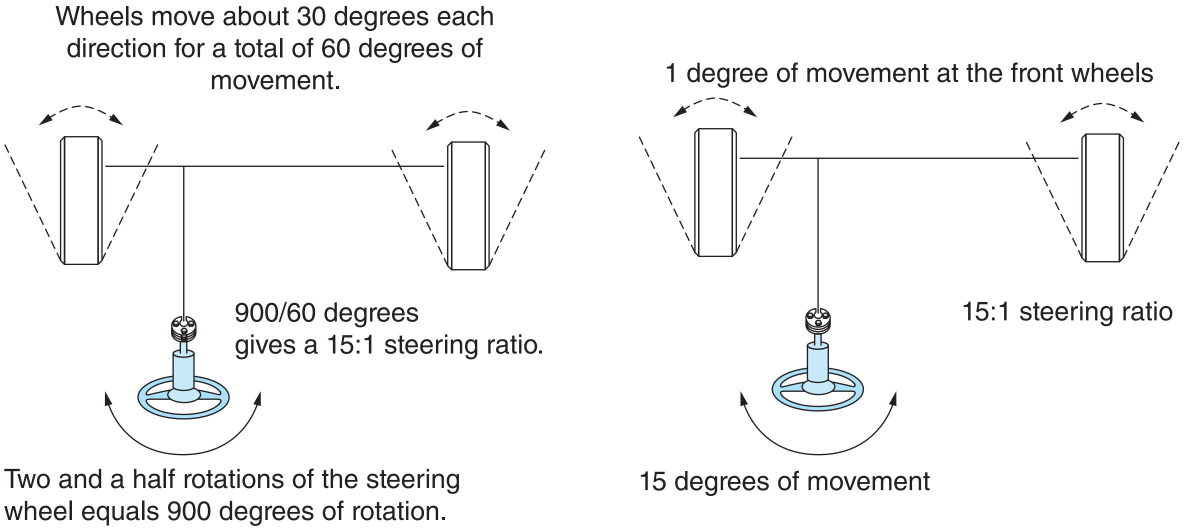


FIGURE 47–14 Steering gearbox ratio.

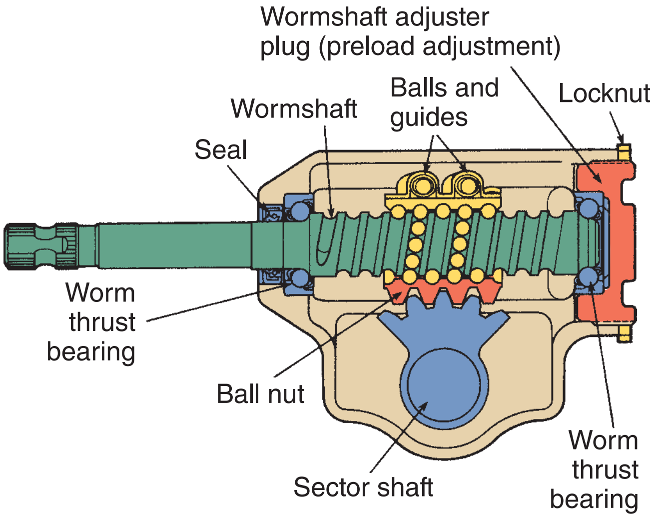


FIGURE 47–15 A top cutaway of a manual recirculating ball steering gear.

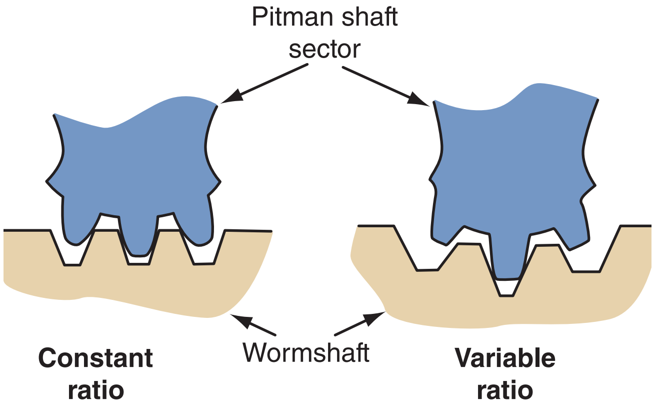


FIGURE 47–16 Constant and variable ratio steering gears.

through two outside loops, referred to as ball return guide tubes. The ball nut has gear teeth cut on one face that mesh with gear teeth on the sector shaft. As the steering wheel is rotated, the wormshaft rotates, causing the ball nut to move up or down the wormshaft. Since the gear teeth on the ball nut are meshed with the gear teeth on the sector shaft, the movement of the nut causes the sector shaft to rotate and swing the Pitman arm.

Variable Steering The number of input turns per output turn of the steering gearbox is called the gearbox ratio. Steering gears can have a constant or a variable ratio. The sector teeth in a constant ratio unit are identical in size and shape, while the sector of a variable ratio unit has larger center teeth **(Figure 47–16)**. This makes the steering faster in turns than in a straight direction. Variable ratio is normally used only in power-steering units.

Steering Wheel and Column

The purpose of the steering wheel and column is to produce the necessary force to turn the steering gear. The exact type of steering wheel and column depends on the year and the car manufacturer. The steering column, also called a steering shaft, relays the movement of the steering wheel to the steering gear. An electric motor, used to provide power steering assist, may be part of the steering column.

Major parts of the steering wheel and column are shown in **Figure 47–17**. The steering wheel is

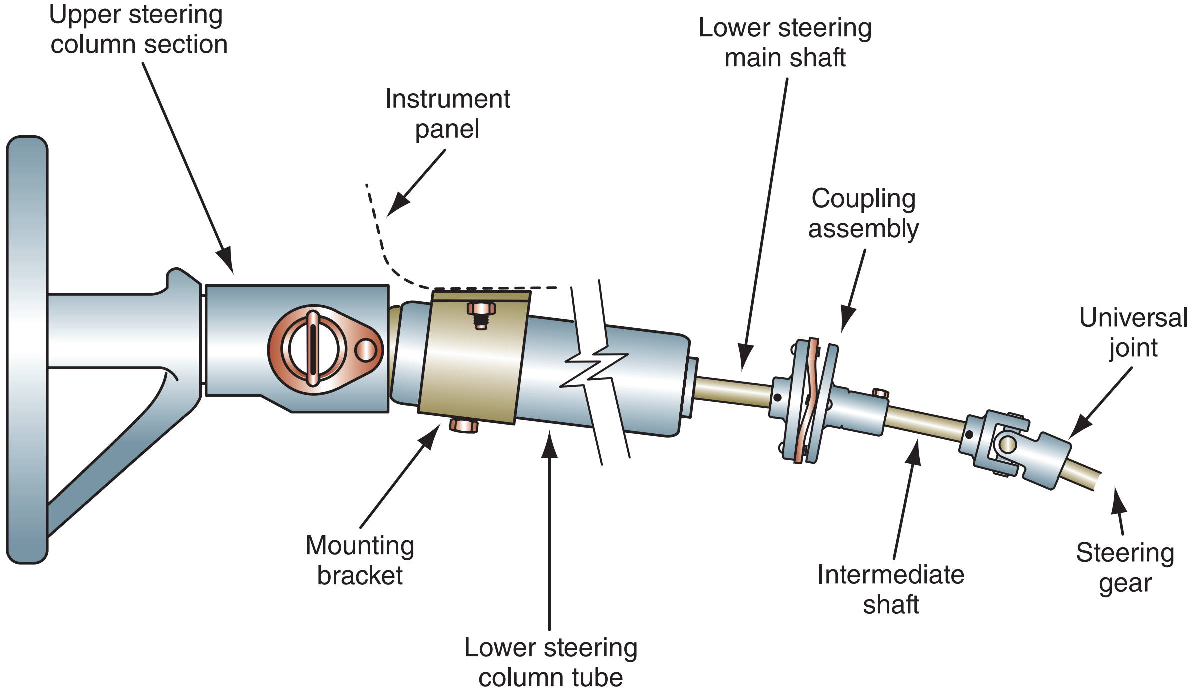


FIGURE 47–17 Typical steering column components. The steering wheel is splined to the shaft that extends through the column and down to the steering gearbox.

used to produce the turning effort. The lower and upper covers conceal parts. The universal joints rotate at angles to connect the steering shaft to the steering gear. Support brackets are used to hold the steering column in place. Assorted screws, nuts, bolt pins, and seals are used to make the steering wheel and column perform correctly. Since 1968, all steering columns have a collapsible feature that allows the column to fold into itself on impact. This feature prevents injury to the driver.

In vehicles equipped with a driver's side air bag, the air bag assembly is contained in the center portion of the steering wheel. This assembly must be disarmed and removed before the steering wheel can be removed.

Warning! **Always follow the manufacturer's service procedures to disarm an air bag before beginning to remove an air bag assembly. Failure to do this may result in accidental air bag deployment. (See Chapter 48 of this textbook.) Air bag service precautions vary depending on the vehicle.**

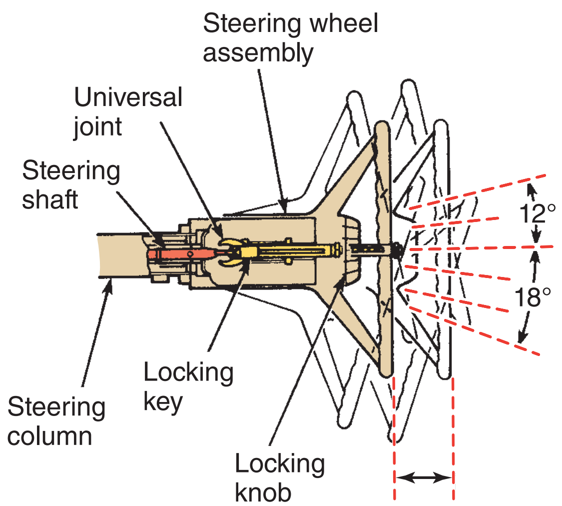


FIGURE 47–18 Tilt steering column operation.

Differences in steering wheel and column designs include fixed column, telescoping column, tilt column, manual transmission, floor shift, and automatic transmission column shift. The tilt columns **(Figure 47–18)** may feature preset detents that have at least five driving positions (two up, two down, and a center position). Many tilt systems allow for setting the position of the column

anywhere between a fixed upper and lower limit. A feature on newer cars and trucks is power tilt and telescoping steering columns. Two small electric motors are used to move the column and wheel into the driver's desired position. One motor is used for tilt while the other motor is for the telescoping function. Powered columns are common on vehicles with programmable memory or personality presets for different drivers.

Most columns contain a multifunction switch, which operates the emergency warning flasher control, turn signal switch, lights (high/low beams), horn, windshield wipers, and washers. Vehicles that use an ignition key often house the key lock cylinder and an antitheft device that locks the steering system in the column. The antitheft device may be a rod, cable, or electric motor used to lock the steering shaft from turning until the key is turned to unlock the column. On automatic-transmission-equipped vehicles, the transmission linkage locks also.

Late-model vehicles with stability control and/or electric power steering assist also have steering sensors located in the column. These sensors are used to determine steering angle and torque and are used as inputs into the electronic power-steering control module and vehicle stability control system.

Methods used to lock the shaft to the tube include a breakaway plastic capsule or a series of inserts or steel balls held in a plastic retainer that allow the shaft to roll forward inside the tube. There is also collapsible steel mesh **(Figure 47–19)** or accordion-pleated devices that give way under pressure. After the vehicle has been in an accident, the steering column should be checked for evidence of collapse. Although the car can be steered with a collapsed column that has been pulled back, the collapsed portion must be replaced. All service information provides explicit instructions for doing this.

Steering wheels often house controls for the audio system, cruise control, communication system, and other systems. The steering wheel is usually held in place on the steering shaft by either a bolt or nut.

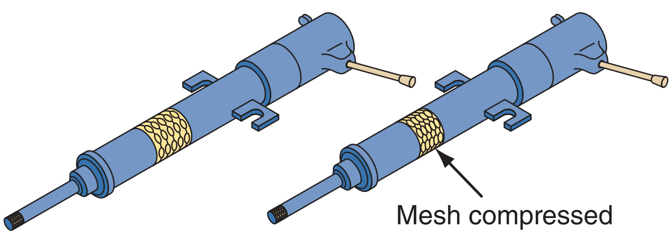


FIGURE 47–19 This figure shows the condition of the collapsible mesh of a steering column before and after an accident.

Power-Steering Systems

The power-steering unit is designed to reduce the amount of effort required to turn the steering wheel. It also reduces driver fatigue on long drives and makes it easier to steer the vehicle at slow road speeds, particularly during parking.

Power steering can be broken down into two design arrangements: conventional and nonconventional or electronically controlled. In the conventional arrangement, hydraulic power is used to assist the driver. In the nonconventional arrangement, an electric motor and electronic controls provide power assistance in steering.

There are several power-steering systems in use on passenger cars and light-duty trucks. The most common ones are the integral-piston, and power-assisted rack and pinion system **(Figure 47–20)**.

Integral Piston System

The integral piston system is used in conventional recirculating ball power-steering systems. It consists of a power-steering pump and reservoir, power-steering pressure and return hoses, and steering gear. The power cylinder and the control valve are in the same housing as the steering gear.

On some model cars and light trucks, instead of the conventional vacuum-assist brake booster, the hydraulic fluid from the power-steering pump is also used to actuate the brake booster. This brake system is called the hydro-boost system **(Figure 47–21)**.

Components

The manual-steering parts described earlier in this chapter, such as the steering linkage, are used in conventional power-steering systems. The components that have been added for power steering provide the hydraulic power that drives the system. They are the power-steering pump, flow control and pressure relief valves, reservoir, hydraulic hose lines, spool valves, and power pistons.

Power-Steering Pump The steering pump is used to develop hydraulic flow, which provides the force needed to operate the steering gear. The pump is belt driven from the engine crankshaft, providing flow

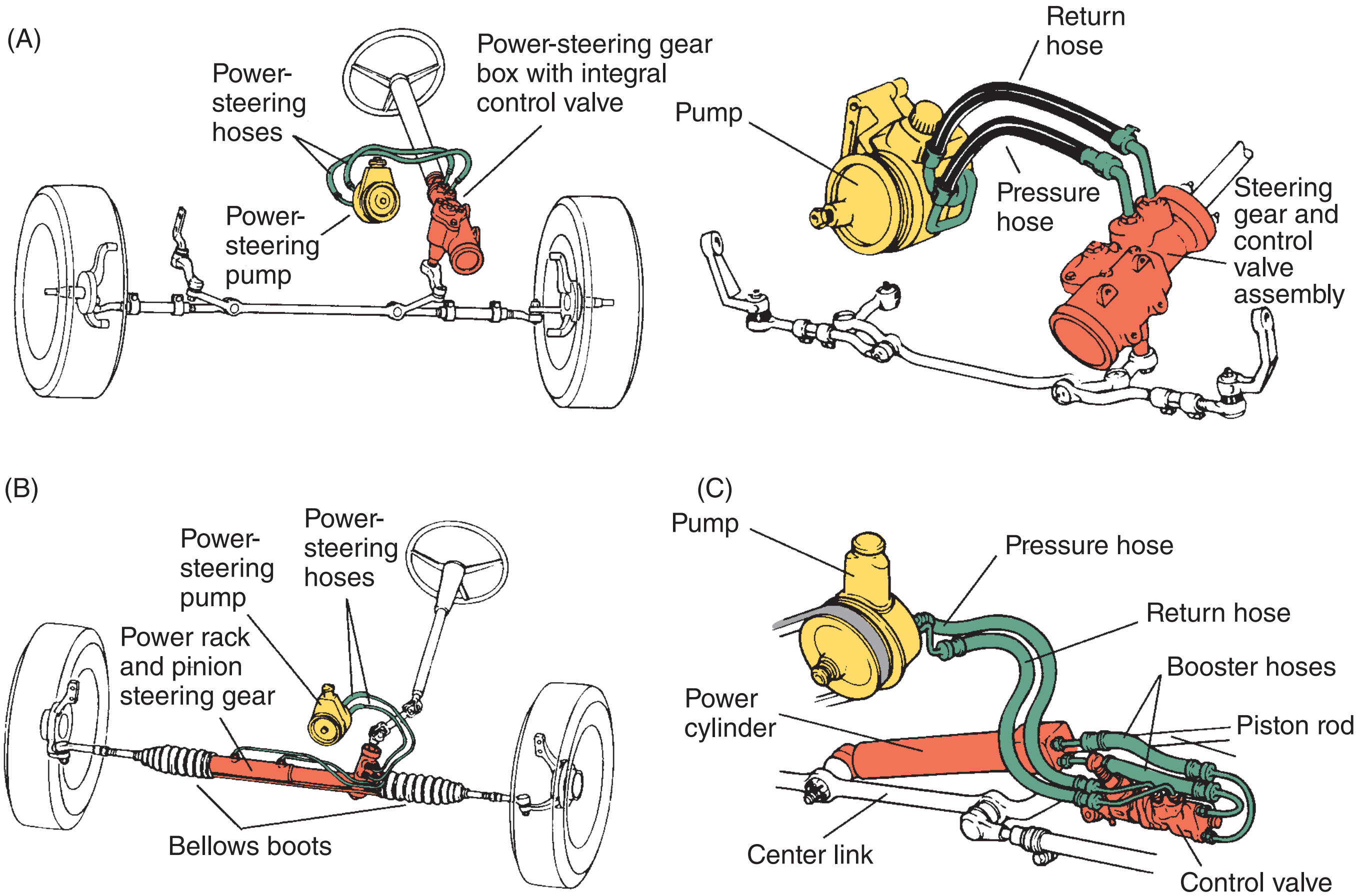


FIGURE 47–20 The three common power-steering systems: (A) Integral-piston linkage. (B) Rack and pinion. (C) External-piston linkage.

any time the engine is running. It is usually mounted near the front of the engine **(Figure 47–22)**. The pump assembly includes a reservoir and an internal flow control valve. The drive pulley is normally pressed onto the pump's shaft.

There are four general types of power-steering pumps: roller, vane **(Figure 47–23A)**, slipper, and gear. Vane pumps are common because of their low internal friction and quiet operation. In a vane pump, the rotor is driven by the pulley when the engine is running. The vanes move outward from the rotor against the inside of the cam ring. Fluid flows into the spaces between the rotor, vanes, and cam ring. As the rotor turns, fluid is trapped in a progressively smaller area. This pressurizes the fluid before it leaves the discharge ports **(Figure 47–23B)**.

Functionally, all pumps operate in the same basic manner. Hydraulic fluid for the power-steering pump is stored in a reservoir. Fluid is routed to and from the pump by hoses and lines. Excessive pressure is controlled by a relief valve.

Power-Steering Pump Drive Belts Many power-steering pumps are driven by a belt that connects the crankshaft pulley to the power-steering pump pulley. Nearly all late-model vehicles use a serpentine belt. This belt may be used to drive all the belt-driven components. Most serpentine belts have a spring-loaded automatic belt tensioner that eliminates periodic belt tension adjustments. The smooth backside of the drive belt may also be used to drive some of the components. Older vehicles use a V-belt to drive the accessories, including the power-steering pump. Regardless of the type of belt, the belt tension is critical. A power-steering pump will never develop full pressure if the belt is slipping.

Electric Power Steering Pump A few vehicles use electrically operated power steering pumps. The advantage is that the pump can be turned off when not actually needed, such as when stopped at a traffic light. This saves fuel and reduces the power drain on the engine.

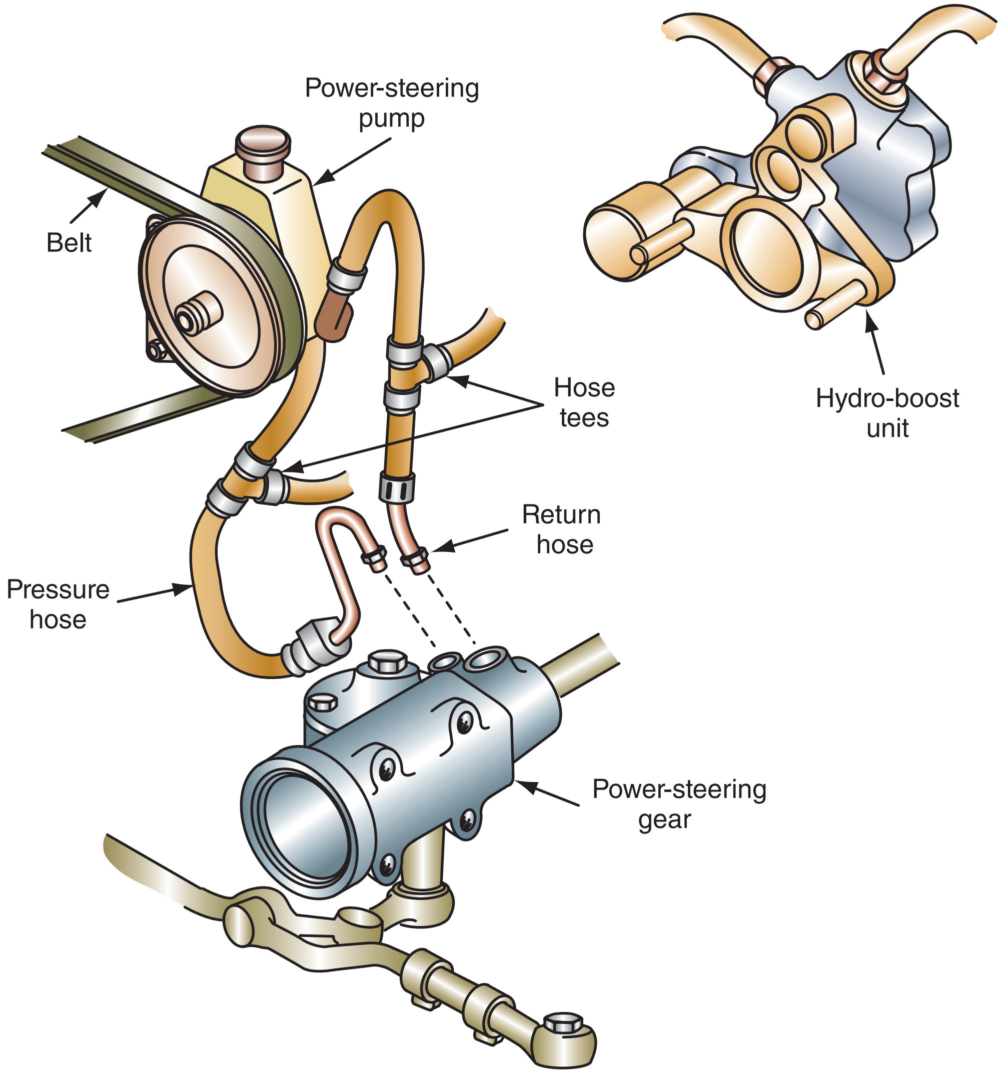


FIGURE 47–21 A typical hydro-boost system that uses the power-steering pump to power assist brake applications.

Courtesy of Visteon Corporation™.

FIGURE 47–22 A power-steering pump.

Flow Control and Pressure Relief Valves A pressure relief valve controls the pressure output from the pump. This valve is necessary because of the variations in engine rpm and the need for consistent steering ability in all ranges from idle to highway speeds. It is positioned in a chamber that is exposed to pump outlet pressure at one end and supply hose pressure at the other **(Figure 47–24)**. A spring is used at the supply pressure end to help maintain a balance.

As the fluid leaves the pump rotor, it passes the end of the flow control valve and is forced through an orifice that causes a slight drop in pressure. This reduced pressure, aided by the springs, holds the flow control valve in the closed position. All pump flow is sent to the steering gear.

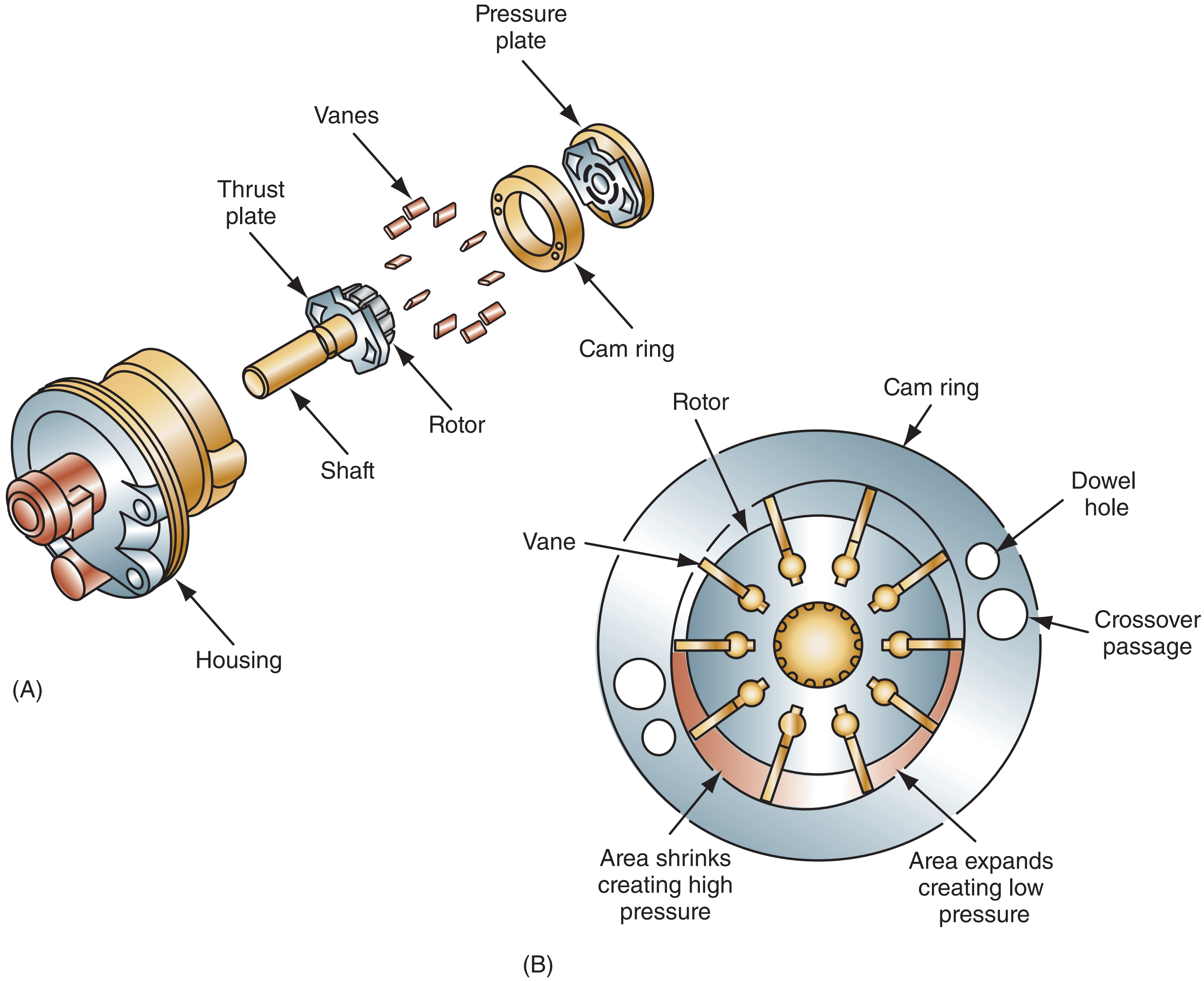


FIGURE 47–23 (A) A vane-type power-steering pump. (B) The basic operation of a vane-type pump.

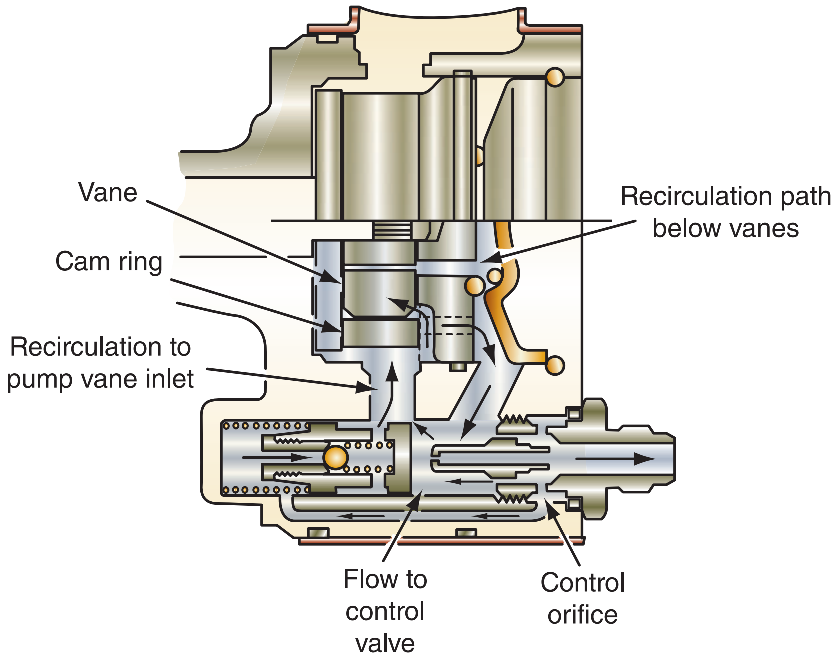


FIGURE 47–24 The flow control valve limits output pressure.

When engine speed increases, the pump can deliver more flow than is required to operate the system. Since the outlet orifice restricts the amount of fluid leaving the pump, the difference in pressure at the two ends of the valve becomes greater until pump outlet pressure overcomes the combined force of supply line pressure and spring force. The valve is pushed down against the spring, opening a passage that returns the excess flow back to the inlet side of the pump.

A spring and ball contained inside the flow control valve are used to relieve pump outlet pressure. This is done to protect the system from damage due to excessive pressure when the steering wheel is held against the stops. Since flow in the system is severely restricted, the pump would continue to build pressure until a hose ruptured or the pump destroyed itself.

When outlet pressure reaches a preset level, the pressure relief ball is forced off its seat, creating a greater pressure differential at the two ends of the flow control valve. This allows the flow control valve to open wider, permitting more pump pressure to flow back to the pump inlet and pressure is held at a safe level.

Some vehicles electronically control the fluid flow from the pump **(Figure 47–25)**. These variable effort systems can decrease fluid flow to increase steering firmness and improve steering feel based on vehicle speed. When vehicle speed is reduced, flow is increased to allow for easier steering.

Power-Steering Gearbox A power-steering gearbox is basically the same as a manual recirculating ball gearbox with the addition of a hydraulic assist. A power-steering gearbox is filled with hydraulic fluid and uses a control valve.

An integral power-steering system has the spool valve and a power piston integrated with the recirculating ball gearbox. The spool valve directs the oil pressure to the left or right power chamber to steer the vehicle. The spool valve is actuated by a lever or a small torsion bar **(Figure 47–26)**.

In parallelogram linkage systems, the control valve is connected directly to the steering linkage through the Pitman arm on the steering gear. Any movement of the steering wheel and the Pitman arm compresses the centering spring and moves the valve spool. This opens and closes a series of ports directing fluid under pressure from the pump to one side or the other of the power cylinder piston **(Figure 47–27)**.

Power-Assisted Rack and Pinion System

Power-assisted rack and pinion components are basically the same as for manual rack and pinion steering except for the hydraulic control housing. The power-assisted rack and pinion system are also similar to the integral system because the power cylinder and the control valve are in the same

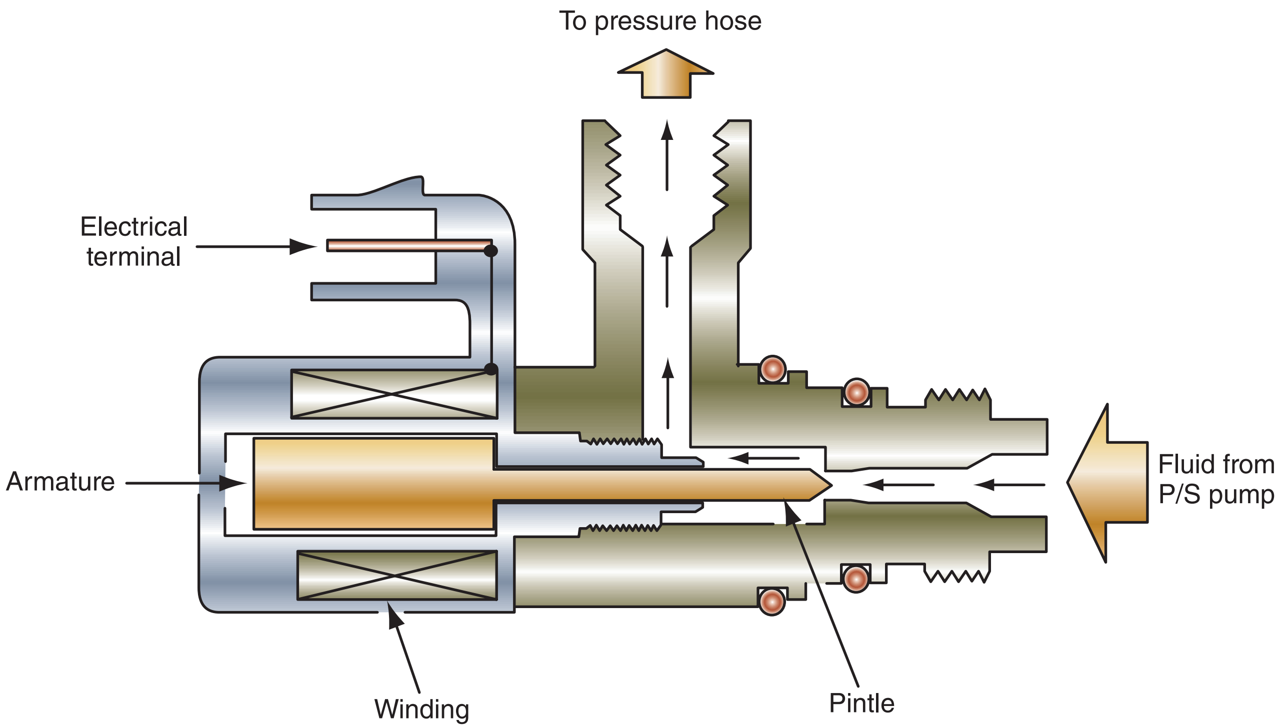


FIGURE 47–25 Electrohydraulic variable effort steering.

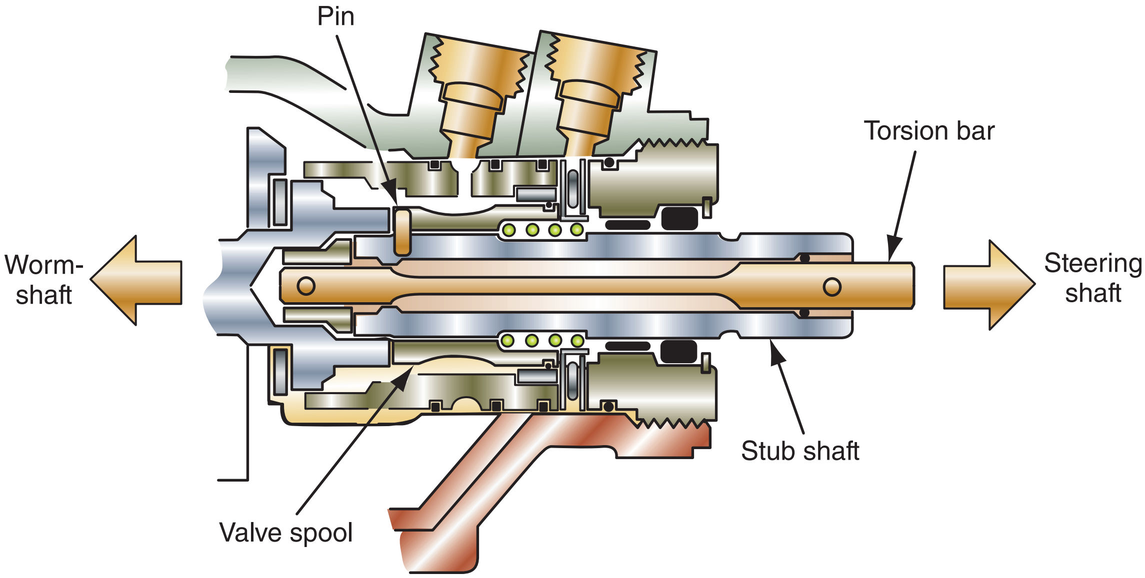


FIGURE 47–26 A torsion bar moves the spool valve to direct the oil flow to the piston.

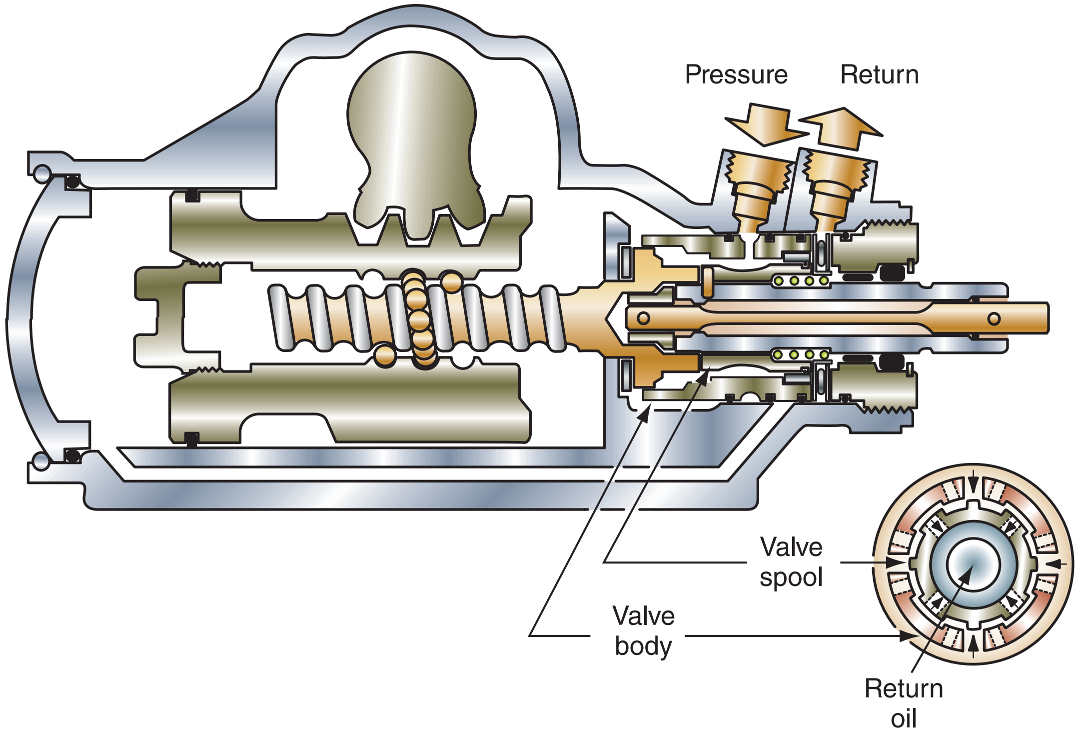


FIGURE 47–27 The spool valve with the wheels straight ahead.

housing. The rack housing acts as the cylinder and the power piston is part of the rack. Control valve location is in the pinion housing **(Figure 47–28)**. Turning the steering wheel moves the valve, directing pressure to either end of the back piston. The system utilizes a pressure hose from the pump to the control valve housing and a return line to the pump reservoir. This type of steering system is common in modern vehicles.

In a power rack and pinion gear, the piston is mounted on the rack, inside the rack housing. The rack housing is sealed on either side of the rack piston to form two separate hydraulic chambers for the left and right turn circuits **(Figure 47–29A)**. When the wheel is turned, the rotary valve creates a pressure differential on either side of the rack piston **(Figure 47–29B)**. This causes the rack to move toward the lower pressure and reduces the total effort required to turn the wheels.

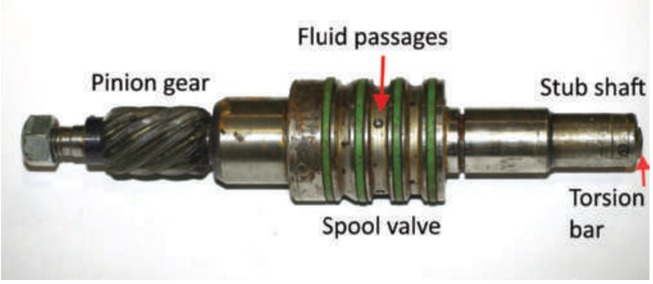


FIGURE 47–28 A pinion gear and spool valve assembly.

Power-Steering Hoses The primary purpose of power-steering hoses is to transmit power (fluid under pressure) from the pump to the steering gearbox, and to return the fluid ultimately to the pump reservoir. Hoses also, through material and construction, function as additional reservoirs and act as sound and vibration dampers.

Hoses are generally a reinforced synthetic rubber (neoprene) material coupled to metal tubing at the connecting points. The pressure side must be able to handle pressures up to 1,500 psi (10,342 kPa). For that reason, wherever there is a metal tubing to a rubber connection, the connection is crimped. Pressure hoses are also subject to surges in pressure and pulsations from the pump. The reinforced construction permits the hose to expand slightly and absorb changes in pressure.

Two internal diameters of hose **(Figure 47–30)** may be used on the pressure side; the larger diameter or pressure hose is at the pump end. It acts as a reservoir and as an accumulator, absorbing pulsations. The smaller diameter or return hose reduces the effects of kickback from the gear itself.

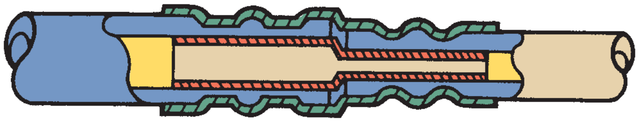


FIGURE 47–30 Power-steering hoses may have two internal diameters.

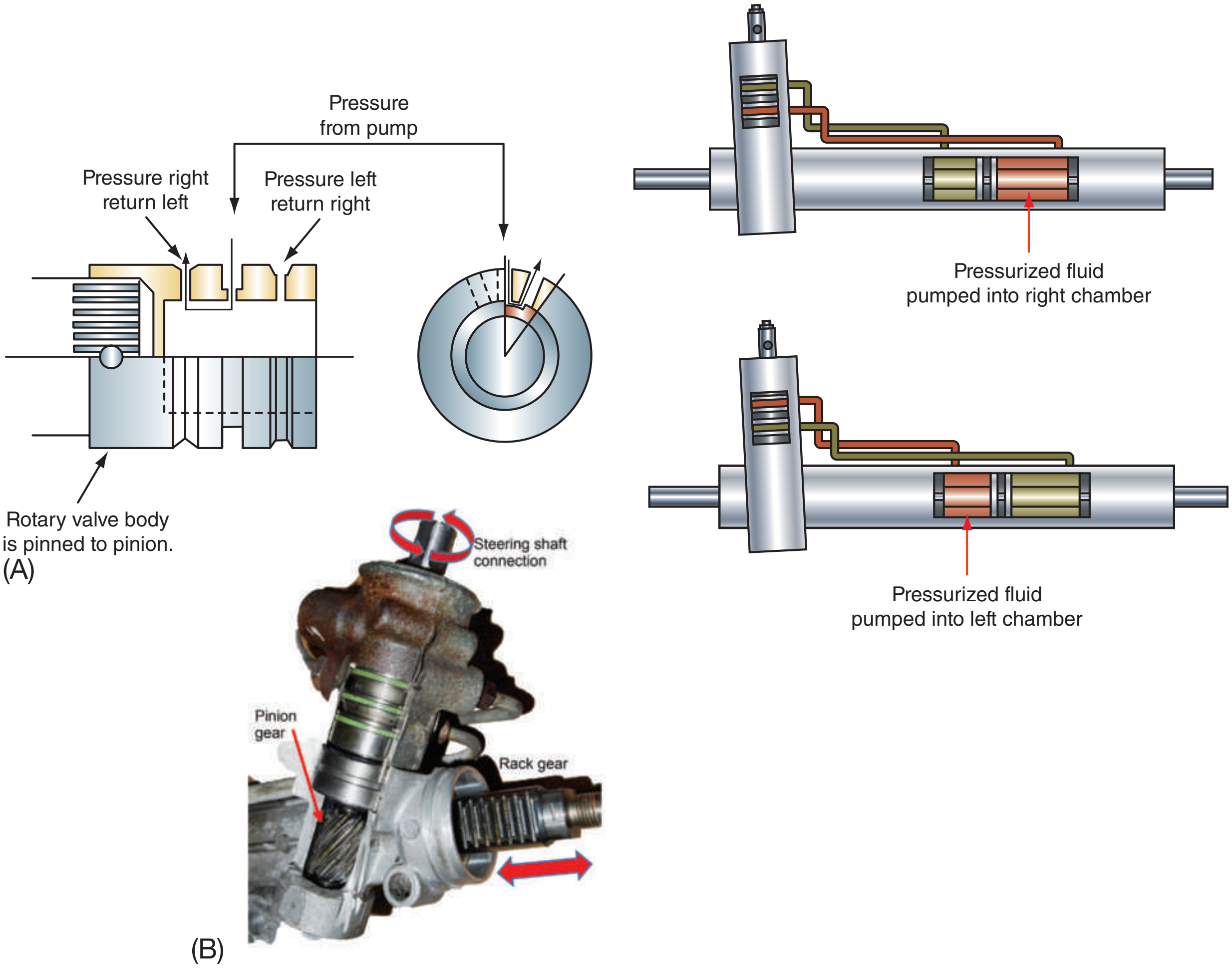


FIGURE 47–29 (A) A power-steering piston and cylinder for a rack and pinion steering gear. (B) The assembly that connects the steering wheel to the rack and pinion assembly.

Caution! Hoses must be carefully routed away from engine manifolds. Power-steering fluid is very flammable. If it comes in contact with hot engine parts, it could start an underhood fire.

By restricting fluid flow, it also maintains constant backpressure on the pump, which reduces pump noise. If the hose is of one diameter, the gearbox is performing the damping functions internally.

Because of working fluid temperature and adjacent engine temperatures, these hoses must be able to withstand temperatures up to 300 °F (150 °C). Due to various weather conditions, they must also tolerate subzero temperatures as well. Hose material is specially formulated to resist breakdown or deterioration due to oil or temperature conditions.

Electronically Controlled Power-Steering Systems

The object of power steering is to make steering easier at low speeds, especially while parking. However, higher steering efforts are desirable at higher speeds in order to provide improved down-the-road feel. The electronically controlled power-steering (EPS) systems **(Figure 47–31)** provide both of these benefits. The hydraulic boost of these systems is tapered off by electronic control as road speed increases. Thus, these systems require well under 1 pound (4.4 N) of steering effort at low road speeds and 3 pounds plus (13.2 N) of steering effort at higher road speeds to enable the driver to maintain control of the steering wheel for improved high-speed handling.

A rotary valve electronic power-steering system consists of the power-steering gearbox, power-steering oil pump, pressure hose, and the return hose. The amount of hydraulic fluid flow (pressure) used to boost steering is controlled by a solenoid valve that is identified as its PCV (pressure control valve).

SHOP TALK The PCV (pressure control valve) is not to be confused with the PCV (positive crankcase ventilation valve) used with emission controls systems.

The electronic power-steering system's PCV **(Figure 47–32)** is exposed to spring tension on the top and plunger force on the bottom. The plunger slips inside an electromagnet. By varying the electrical current to the electromagnet, the upward force exerted by the plunger can be varied as it works against the opposing spring. Current flow to the electromagnet is variable with vehicle road speed and, therefore, provides steering to match the vehicle's road speed.

General Motors' variable effort steering (VES) system relies on an input signal from the vehicle speed sensor to the VES controller to control the amount of power assist. The controller, in turn, supplies a pulse width modulated voltage to the actuator solenoid in the power-steering pump. The controller also provides a ground connection for the solenoid.

When the vehicle is operating at low speeds, the controller supplies a signal to cycle the solenoid faster so it allows high pump pressure. This provides for maximum power assist during cornering and parking. As the vehicle's speed increases, the solenoid cycles less and the pump provides a lower amount of assist. This gives the driver better road feel during high speeds.

MagnaSteer

In the mid-1990s, General Motors introduced magnetic speed variable assist, called MagnaSteer. These systems use a special rack and pinion gearbox that contains an electromagnet inside the spool valve. By varying current flow through the magnet's coil, assist can be increased or decreased. No current flow through the coil maintains a default amount of hydraulic assist.

Active Steering

Active steering improves vehicle stability by turning the wheels more or less sharply than commanded by the turn of the steering wheel during some situations. Through inputs and computer programming, this system can adjust the steering to respond quickly to the threat of skidding **(Figure 47–33)**. The system also allows for a variable steering ratio dependent on vehicle speed.

Current active steering systems are not true steer-by-wire systems. There is still a mechanical connection between the steering wheel and vehicle's wheels **(Figure 47–34)**. The systems have an overriding drive built into the steering column. This drive is controlled by an electric motor, which is

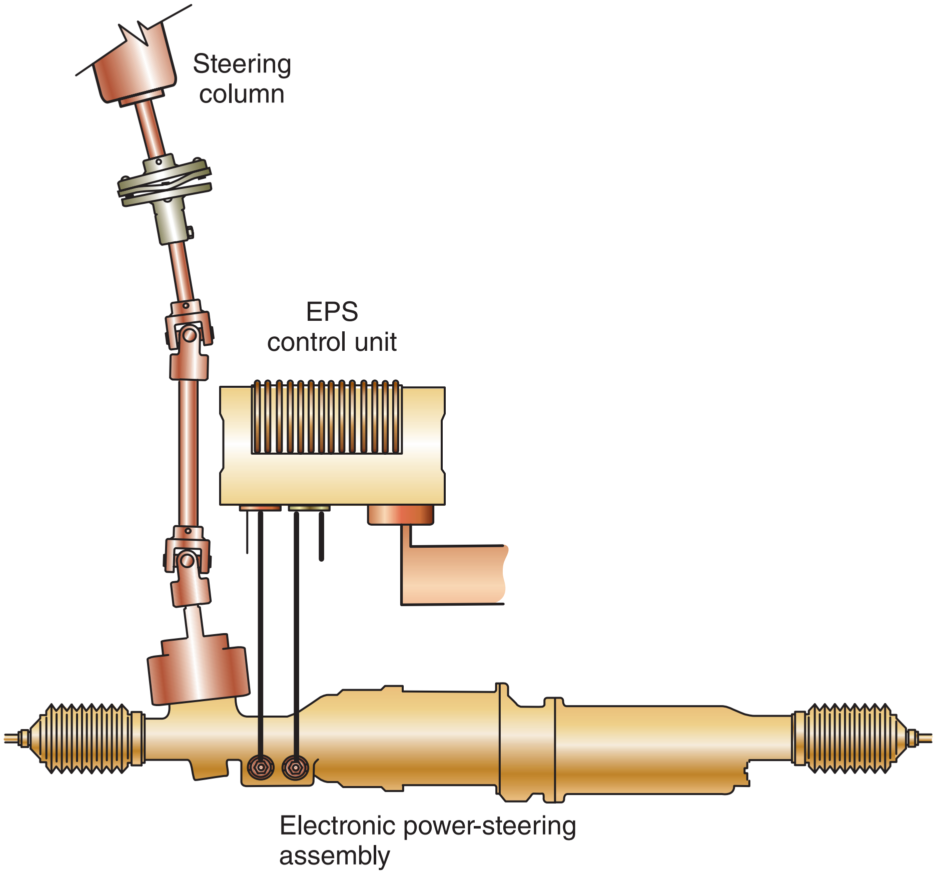


FIGURE 47-31 A variable-assist power-steering system.

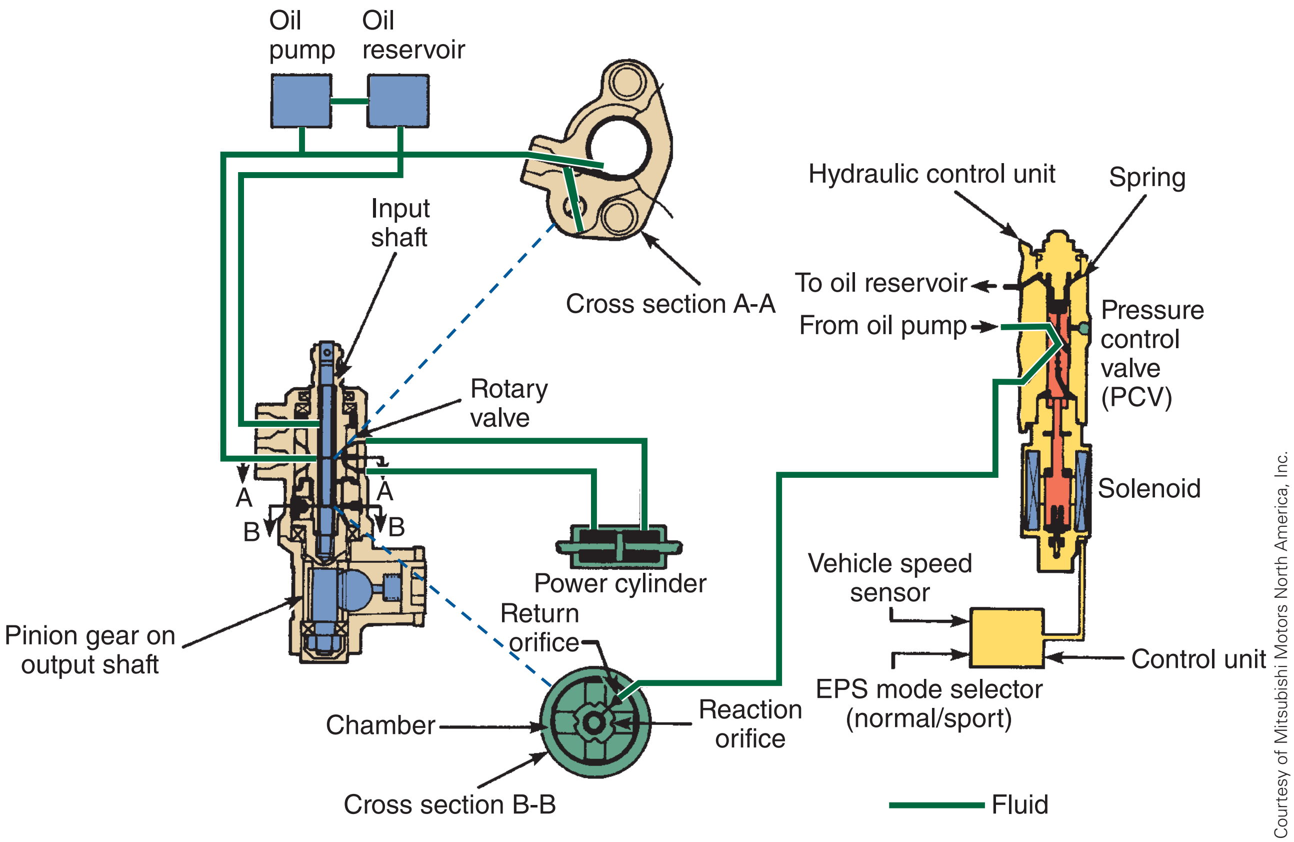


FIGURE 47-32 An outline of electronic power-steering components. The EPS PCV is exposed to spring tension and plunger force.

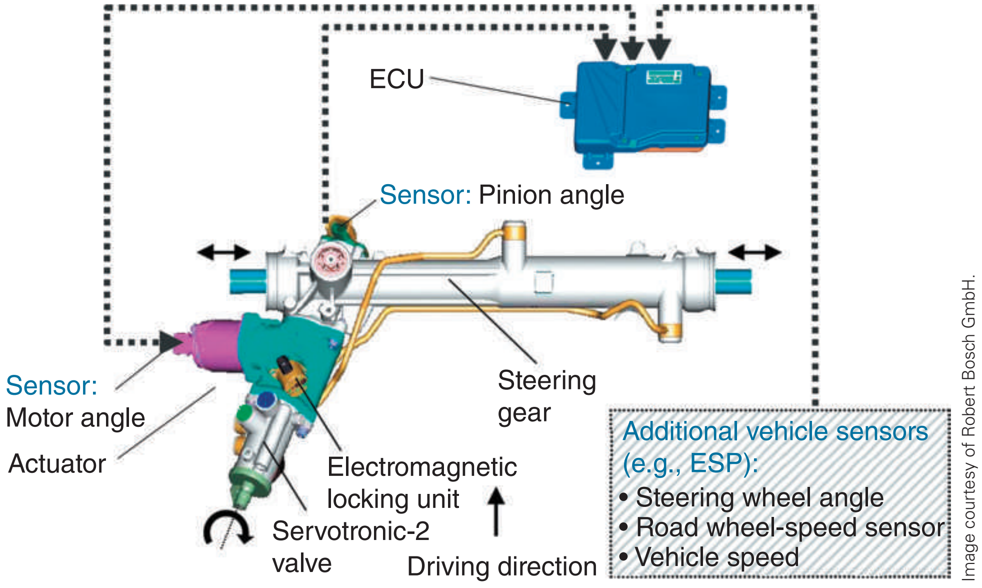


FIGURE 47–33 The main components and circuits of an active steering system.

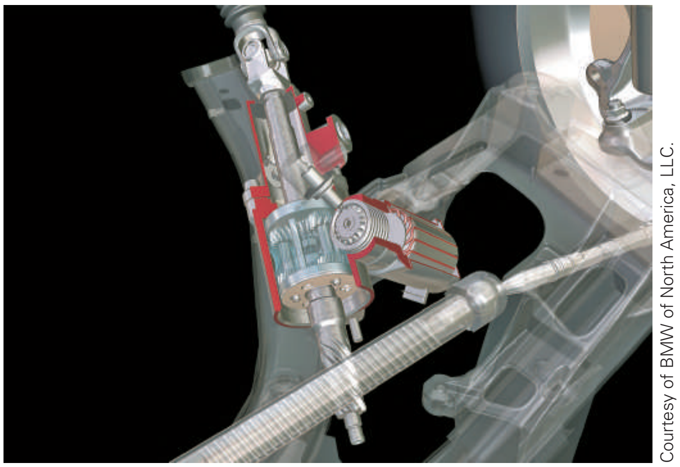


FIGURE 47–34 The planetary gearset and electric motor that turn the road wheels when the steering wheel is turned.

controlled by the system's computer. The computer determines whether the steering angle needs to be changed and by how much. If the system fails, the planetary gear unit will rotate directly with the steering wheel.

Electric/Electronic Rack and Pinion System

The electric/electronic rack and pinion unit replaces the hydraulic pump, hoses, and fluid associated with conventional power-steering systems with electronic controls and an electric motor. There are three basic types based on where the motor is located. One method is to place the motor concentric to the rack itself **(Figure 47–35)**. The design features a DC motor armature with a follow shaft to allow passage of the rack through it. The outboard housing and rack are designed so that the rotary motion of the armature can be transferred to linear movement of the rack through a ball nut with thrust bearings. The armature is mechanically connected to the ball nut through an internal/external spline arrangement.

Another method of driving the rack gear uses a belt-drive system **(Figure 47–36)**. In this design, the electric motor drives a toothed belt that drives the rack side-to-side with a ball nut type connection. The motor may also be used to directly drive the pinion shaft **(Figure 47–37)**.

The basis of system operation is its ability to change the rotational direction of the electric motor while being able to deliver the necessary amount of current to meet torque requirements at the same time. The system can deliver up to 75 amperes to the motor. The higher the current, the greater the force exerted on the rack. The direction of the turn is controlled by changing the polarity of the signal to the motor.

The field assembly houses permanent ceramic magnets while providing structural integrity for the gear system. In essence, the electronic/electric rack design allows for a direct power source to the rack and steering linkage. The system monitors steering wheel movement through a sensor mounted on the input shaft of the rack and pinion steering gear. After receiving directional and load information from the sensor, an electronic controller activates the motor to provide power assistance.

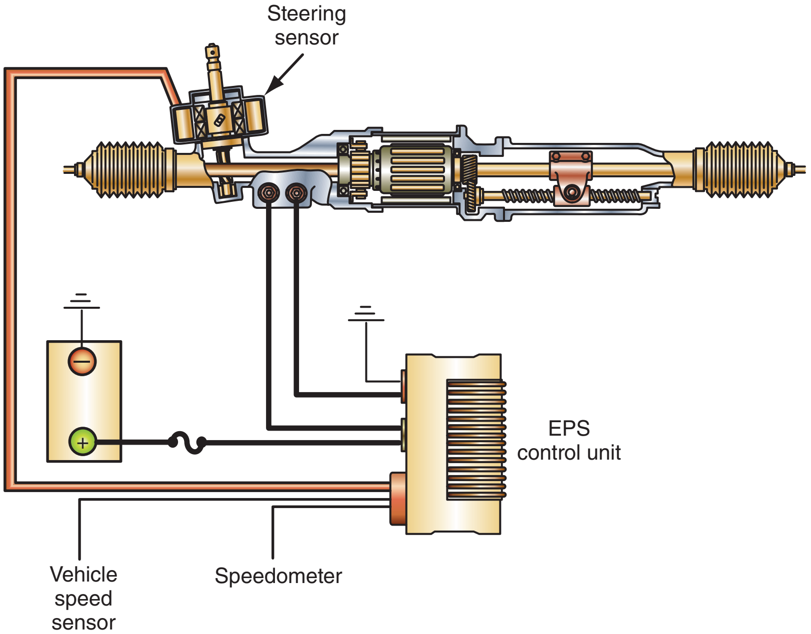


FIGURE 47–35 Electric assist applied with a ball nut to drive the rack gear.

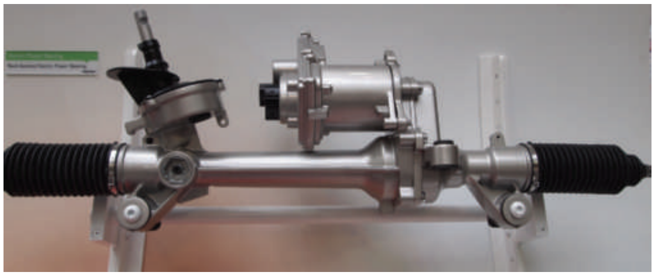


FIGURE 47–36 An external motor and drive belt design.

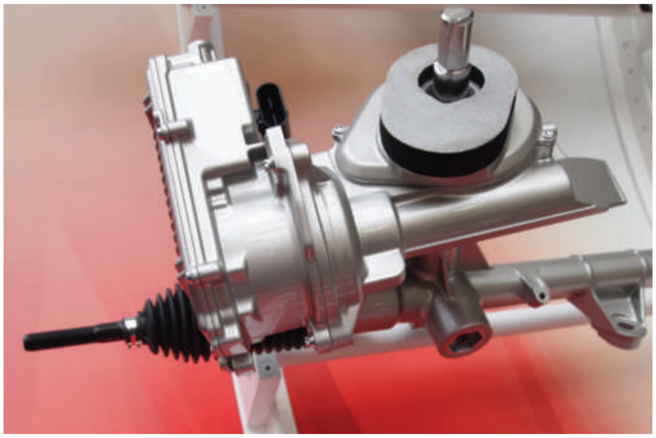


FIGURE 47–37 The motor is used to drive the pinion shaft.

These units are readily retrofitted to conventionally equipped vehicles. As for servicing, there are currently no replacement parts available; therefore, if the rack should become faulty, the entire unit should be replaced. Rebuild kits, with complete installation instructions, are available.

Unlike conventional power steering, electric/electronic units provide power assistance even when the engine stalls, since the power source is the battery rather than the engine-driven pump. The feel of the steering can also be adjusted to match the particular driving characteristics of cars and drivers, from high performance to luxury touring cars. It also eliminates hydraulic oil, which means no leaks.

Column Mounted Power Assist

Many vehicles use column mounted power assist systems. An electric motor is mounted to the steering column and uses a worm gear to directly drive the steering shaft **(Figure 47–38)**. Steering input is detected by one or more torque sensors. As the steering shaft turns, the sensors detect the change in movement. A torsion bar is used in the upper steering shaft. Turning the steering wheel causes movement in the torsion bar and upper torque sensor. The difference in the amount of movement between the two torque sensors is used to determine how to drive the lower steering shaft with the electric motor. The power steering control module (PSCM) uses input from the torque sensors and data from the network to control the torque applied to the steering shaft. Input from other sensors, such as vehicle speed, are used to determine the amount of assist that should be provided by the motor. A high-amperage motor, often a part of the steering module assembly, drives the steering shaft as needed.

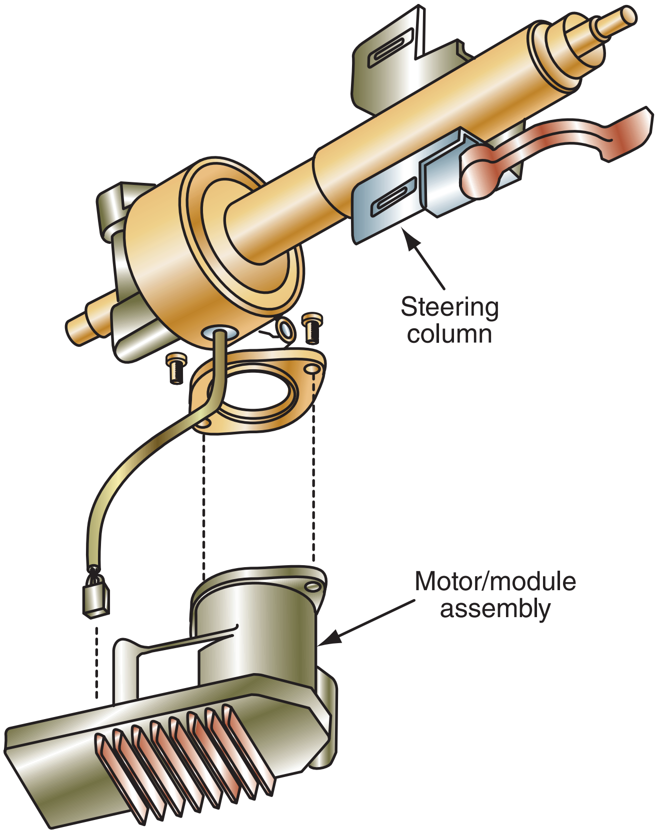


FIGURE 47–38 A column mounted power assist motor.

The electric power steering (EPS) is also incorporated into other systems, such as self-parking, lane monitoring, and lane-keeping assistance. If the vehicle is equipped, input from other systems and networks can be used to command EPS operation. Some newer vehicles will shake the steering wheel if the driver is drifting across the line markers while others will steer the vehicle back into the center of the lane as needed.

Steer-by-Wire System

Steer-by-wire systems **(Figure 47–39)** that completely eliminate the steering column are not yet used on any production vehicles today. However, the Infiniti Q50 has an option, called Direct Adaptive Steering (DAS), which is the next step toward full steer-by-wire. Available since the 2014 model year, the system still retains the mechanical link between the steering wheel and rack and pinon for safety, but the actual steering is handled electronically. In addition to providing variable amounts of assist based on driving speed and driving mode selection, DAS changes the steering ratio, allowing for quicker steering response at higher speeds.

Once implemented, these systems will not use a steering column or shaft to connect the steering wheel to the steering gear. The system is totally

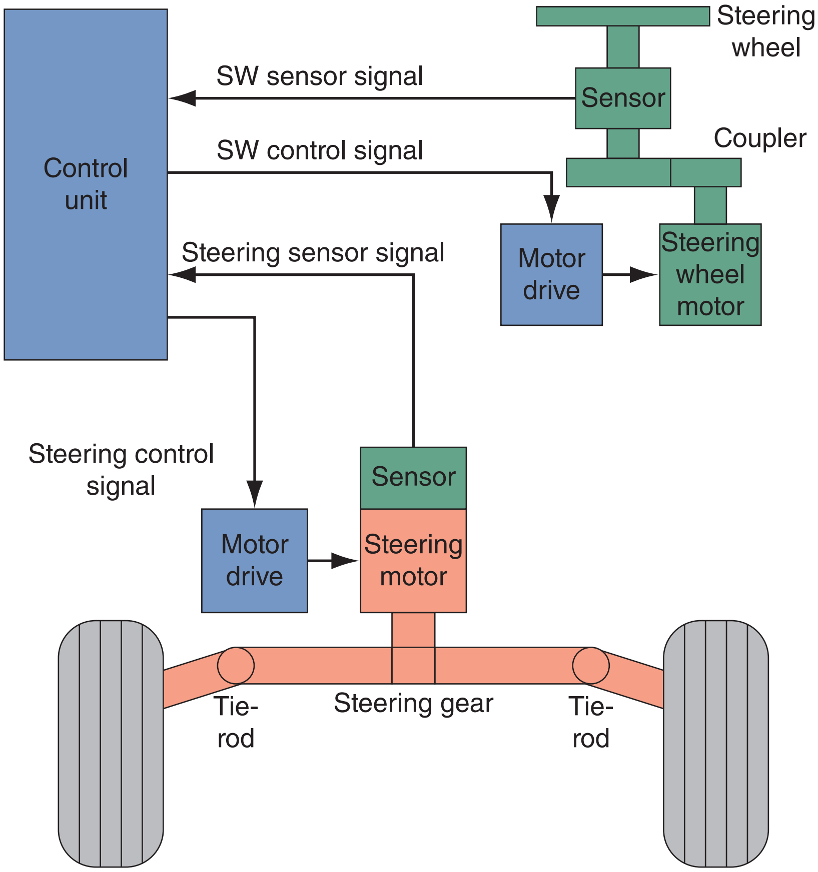


FIGURE 47–39 The basic layout for a steer-by-wire system.

electronic. The turning of the steering wheel is monitored by a sensor. The sensor sends an input signal to a controller. The controller, in turn, sends commands to an electric motor in the steering gear. The commands from the controller are also based on inputs from a variety of other inputs, such as vehicle speed.

A small feedback motor will be used for steering feel. This motor is controlled by a steering controller. This motor provides the correct steering feel for the current conditions. The driver needs this feel to maintain control of the vehicle.

Steer-by-wire systems allow total customization of steering performance and can provide a constantly variable steering ratio. The absence of a steering column opens up space in the vehicle's interior and engine compartment. The systems are also lighter than conventional steering systems.

Steering System Diagnosis

It is important to realize that many steering complaints are caused by problems in areas other than the steering system. A good diagnosis is one that finds the exact cause of the customer's complaint. Although customers may describe the problem in different ways, the most common complaints and their typical causes are discussed next.

Common Complaints

Excessive Steering-Wheel Play Excessive play in the steering wheel is apparent when there is too much steering-wheel movement before the wheels begin to turn. A small amount of play is normal.

This problem can be caused by the following:

- Loose, worn, or damaged steering linkages or tie-rod ends
- Worn ball joints
- Loose, worn, or damaged steering column U-joints
- Loose, worn, or damaged steering column bearings
- Damaged or worn steering gear
- Aerated fluid
- Loose steering gear bolts or faulty rack bushings
- Faulty strut bearing or plate

Feedback When the driver feels the surface of the road through the steering wheel it is called feedback.

This problem can be caused by the following:

- Loose, worn, or damaged steering linkages or tie-rod ends
- Loose, worn, or damaged steering column U-joints
- Loose or damaged steering gear mounting bolts
- Damaged or worn steering column bearings
- Loose suspension bushings, fasteners, or ball joints

A common complaint with electric power assist systems is the lack of feedback. This is due to the system dampening away the feel and feedback from the wheels and tires.

Hard Steering Obviously, a complaint of hard steering results when extra effort is needed to turn the steering wheel. This problem may be simply an absence of power assist. Internal leaks around the flow control valve seals in rack and pinion units is a common cause of hard steering, especially on cold starts. Once the fluid warms, the steering may improve.

This problem can be caused by the following:

- A faulty power-steering pump
- Damaged or faulty steering column bearings
- Seized steering column U-joints
- Steering gearset too tight or is binding
- Stuck flow control valve
- Inadequately inflated tires
- Restricted power-steering lines or hoses
- Blown EPS fuse(s)
- Faulty EPS motor

Nibble This feeling is similar to a shimmy. Nibble results from the interaction of the tires with the road's surface. The customer's complaint may describe the nibble problem as slight rotational oscillations of the steering wheel.

This problem can be caused by the following:

- Loose, worn, or damaged steering linkages or tie-rod ends
- Loose, worn, or damaged suspension parts

Pulling or Drifting A pull is a tugging sensation felt at the steering wheel. The driver must push the steering wheel in the opposite direction of the pull to keep the vehicle going straight. Drifting is a condition in which the vehicle slowly moves to one side of the road when the driver's hands are taken off the steering wheel.

SHOP TALK It must be noted that the steering gear does not cause the vehicle to pull to one side, nor does it cause road wheel shimmy.

These problems can be caused by the following:

- Improper frame or rear axle alignment
- Dragging brakes
- Worn or binding suspension components, especially springs
- Incorrect or uneven wheel alignment
- Unevenly loaded or overloaded vehicle
- Loose, worn, or damaged steering linkages or tie-rod ends
- Out of balance steering gear valve
- Torque steer
- Tire inflation or size differences
- Binding strut bearing
- Unlearned steering angle sensor calibration

Shimmy When the wheels shimmy, the driver will feel large, consistent, rotational oscillations at the steering wheel. These motions are caused by the lateral movement of the tires.

This problem can be caused by the following:

- Loose, worn, or damaged steering linkages or tie-rod ends
- Loose, worn, or damaged suspension parts
- Out-of-balance tires
- Excessive wheel runout
- Tire belt separation or different tread designs on same axle
- Loose wheel bearings

Sticking Steering or Poor Return Poor returnability and sticky steering describes the steering wheel's resistance to return to center after a turn.

This problem can be caused by the following:

- Binding steering column U-joints
- Loose, worn, or damaged steering linkages or tie-rod ends
- Steering gearset too tight or is binding
- Loose, damaged, or worn suspension parts
- Incorrect wheel alignment
- Binding steering column bearings
- Unlearned steering angle sensor calibration

Wandering When a vehicle wanders, the driver must constantly turn the steering wheel to the left and right to keep the vehicle going straight on a level road.

This problem can be caused by the following:

- Loose or worn suspension components
- Incorrect or uneven wheel alignment
- Unevenly loaded or overloaded vehicle
- Loose or damaged steering gear bolts
- Loose steering column U-joint bolts
- Loose, worn, or binding steering linkages or tie-rod ends
- Improper steering gear preload adjustment
- Leaking rack pistons

Diagnosis

As with the diagnosis of any problem, your diagnosis should begin with trying to duplicate the customer's complaint. For steering problems, this is done on a road test; make sure you drive carefully and cautiously, especially because the vehicle has a control problem. It is very important that during the road test the vehicle is driven under conditions similar to the owner's normal driving. Try to duplicate the conditions on which the customer's concern is based. Before going on the road test, do a thorough safety inspection of the vehicle, including the tires.

Once the road test has been completed and it has been determined that there is an abnormal condition, use the symptom to identify the possible trouble area. Then check the parts in that area.

Noise Diagnosis

Often customers complain of abnormal noises or vibrations coming from the steering system. Pay attention to these during the road test. There can be many causes for these; some are not the steering system. The cause of these noises is best identified by paying close attention to where the noise is coming from. Some noises may be caused by tires or interference between the steering wheel and the steering column covers. Others can result from a faulty power-steering pump or system. **Figure 47–40** features a list of common noises and the possible problem areas.

A handy tool for identifying the exact cause of a noise is called the Chassis Ear™ **(Figure 47–41).** This is a wireless electronic device that can identify the

Symptom	Possible Cause
Drive belt squeal or chirp when moving the steering wheel from stop to stop	Loose or worn drive belt
Noise during a cold start	Blockage in the power-steering fluid reservoir Air in the steering hydraulic system
Steering grunt, growl, or shudder when turning into or out of a turn at low speeds	Air in the steering hydraulic system Restricted power-steering hoses
Steering system clunk	Steering column U-joints Steering gear Worn rack bushings
Steering gear squeak	Incorrect fluid in system Steering gear rotary seal Steering column components Dry ball sockets
Power-steering hiss or whistle	Steering column shaft or binding or misaligned Damaged or worn steering gear input shaft and valve Power-steering pump low relief pressure Restricted power-steering lines
Power-steering pump moan when the steering wheel is rotated to the stop position	Low fluid Air in the hydraulic system Power-steering fluid reservoir or screen is blocked or damaged Power-steering pump brackets loose or misaligned Bad steering gear isolators
Power-steering pump whine noise	Aerated fluid Low fluid level Damaged power-steering pump
Rattle, chuckle, or knocking noise or roughness is felt in the steering wheel when the vehicle is driven over rough surfaces	Steering column shaft/coupling joints damaged or worn Loose, damaged, or worn tie-rod ends Steering gear insulators or mounting bolts loose or damaged Steering column shaft/coupling bolts are loose Steering column damaged or worn Loose suspension bushings, bolts, or ball joints
Steering column rattle	Loose bolts or attaching brackets Loose, worn or insufficiently lubricated column bearings Steering shaft insulators damaged or worn Steering column shaft/coupling compressed or extended
Steering column squeak, cracks, or grinds	Poorly lubricated steering shaft bushings Loose or misaligned steering column shrouds Steering wheel rubbing against steering column shrouds Upper or lower bearing sleeves out of position

FIGURE 47–40 Common causes of steering noises.

Courtesy of JS Products, Inc.

FIGURE 47–41 The ChassisEar™ tool is valuable for identifying the source of steering and suspension noises.

source of a noise during a road test. The unit relies on inductive pickups that clamp on or near the component you want to listen to. The device also has a control unit with adjustable volume and headphones. The value of this tool is that it simply is hard to identify the source of a noise while you are driving.

Visual Inspection

Begin your visual inspection of the steering system by inspecting the tires. Check for correct pressure, construction, size, wear, tread type, damage, and for defects that include ply separations, sidewall knots, concentricity problems, and force problems. Keep in mind that tire wear patterns are good indicators of steering and suspension problems **(Figure 47–42)**. Tire wear is also a great indicator for wheel alignment problems, which is covered in Chapter 48.

Continue your inspection by checking the drive belt for the power steering, if so equipped. Power-steering belt condition and tension are extremely important for satisfactory power-steering pump operation. A loose belt causes low pump pressure and hard steering. A loose, dry, or worn belt may cause squealing and chirping noises, especially during engine acceleration and cornering. The power-steering pump belt should be checked for tension, cracks, oil soaking, worn or glazed edges, tears, and splits. If any of these conditions are present, the belt should be replaced and adjusted properly.

GO TO Chapter 8 for procedures on checking, replacing, and adjusting belt tension.

Also check the fluid level and condition. The fluid is checked at the pump reservoir by observing the fluid level through the reservoir or with the dipstick attached to the reservoir cap. Before checking the fluid, allow the engine to run at idle for 2 or 3 minutes and cycle the steering wheel from lock to lock several times. This warms the fluid to its normal operating temperature and gives a more accurate reading.

Examine the condition of the fluid carefully. Check for evidence of contamination such as solid particles or water. If either of these conditions is present or the fluid has a burnt odor, the system should be flushed.

Also check the fluid for evidence of air trapped in the system. If the fluid looks foamy, it is likely that air is in the system. To verify this, run the engine until it reaches normal operating temperature. Then turn the steering wheel to the left and to the right several times without hitting the stops. If air is in the system, bubbles will appear in the fluid reservoir. Bleeding the system will remove the air.

With the ignition off, wipe off the outside of the power-steering pump, pressure hose, return hose, fluid cooler, and the steering gear **(Figure 47–43)**. Start the engine and turn the steering wheel several times from stop to stop. Check for leaks **(Figure 47–44)**. Fluid leakage will cause abnormal noises and may result in unequal and abnormal steering efforts. If there are no signs of leakage initially, repeat the test several times. While doing this, look at the hoses for signs of swelling. Always replace power-steering hoses with an exact replacement hose. Never attempt to patch or seal a leak in a hose or the hose's fittings.

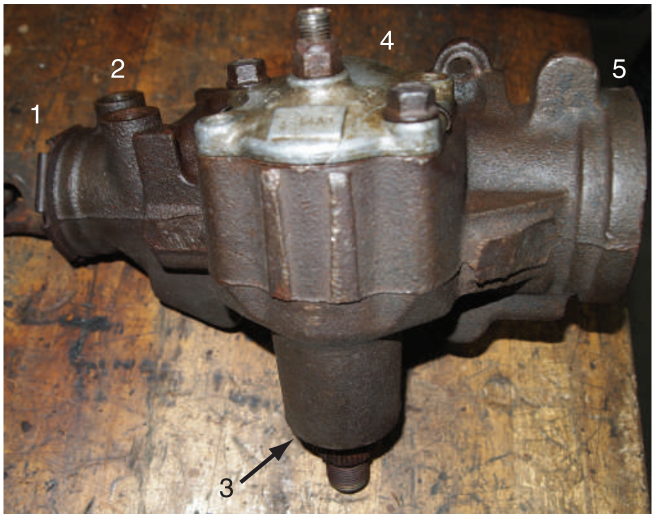
On all systems, carefully check all mechanical parts of the steering and suspension systems. Many suspension problems can affect the operation of the steering system. If any part is found to be defective it should be replaced.

Power-Steering Fluid

The power-steering fluid can be checked either hot or cold. Fluid level will vary with temperature, however, and a more accurate check is done when the engine is warm. The reservoir cap may have a dipstick **(Figure 47–45)**, which is typically marked HOT

Conditions	Rapid wear at shoulders	Rapid wear at center	Cracked treads	Wear on one edge	Feathered edge	Diagonal wipe rear tire FWD vehicles	Scalloped wear
Effect							
Causes	Underinflation or lack of rotation	Overinflation or lack of rotation	Underinflation or excessive speed	Excessive camber	Incorrect toe	Incorrect wheel toe	Lack of rotation of tires or worn or out-of-alignment suspension
Corrections	Adjust pressure to specifications when tires are cool. Rotate tires.			Adjust camber to specs	Adjust toe to specs	Perform rear wheel alignment	Rotate tires and inspect suspension

FIGURE 47–42 Tire wear patterns.



Legend:
1. Adjuster plug seal
2. Pressure line fittings
3. Pitman shaft seals
4. Side cover seals
5. Top cover seal

FIGURE 47–43 Points for fluid leaks at a steering gear.

and COLD on opposite sides of the dipstick. Make sure to check the level on the right side of the dipstick. If necessary, add fluid to correct the level. Some manufacturers require a specific fluid for the power-steering system. Always check the service information before installing fluid to the system. Using an incorrect fluid can cause damage to the system and a loss of assist.

Specific Checks

If preliminary checks did not reveal the cause of the customer's concern, detailed checks of the various subsystems and parts should be done.

Power-Steering Pressure Checks

Many steering problems are caused by incorrect pressures in the power-steering system. Most late-model vehicles have a power-steering pressure sensor that can be monitored with a scan tool. In others you must connect a power-steering pressure gauge to the system.

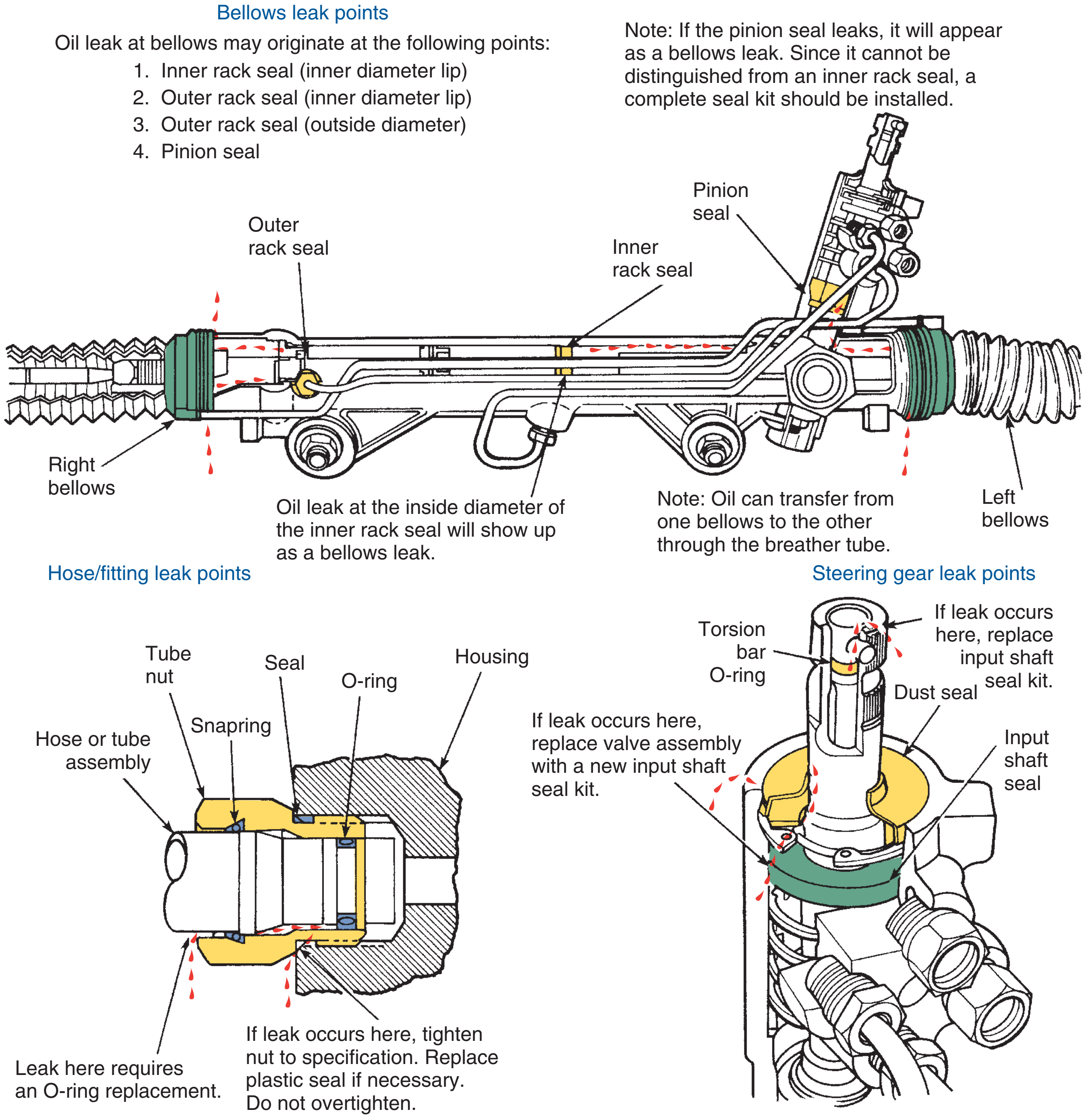


FIGURE 47–44 Possible leakage points on power-steering systems.

Older vehicles may use a pressure switch that only detects low or high pressure. Using a scan tool, the switch may show LOW or OFF under light power steering loads. When the wheels are turned and power steering load increases, the switch may show HIGH or ON. This signals the PCM to boost idle speed to prevent the engine from stalling under low-speed high-power steering demands.

Testing Systems with a Pressure Tester With the engine off, place a drain pan under the vehicle in order to catch any power-steering fluid. Disconnect the pressure hose at the pump. Install the pressure gauge between the pump and the steering gear and bleed the system.

Run the engine for about 2 minutes, and then stop the engine and add fluid to the power-steering pump if necessary. Restart the engine and allow it to idle. Turn the steering wheel and briefly hold it against the steering stops in order to release any trapped air from the system. Observe the pressure reading. The readings should be about 30 to 80 psi

FIGURE 47–45 Check the fluid level with the dipstick attached to the cap.

(200 to 550 kPa). If the pressure is low, the pump may be faulty. If the pressure is too high, the problem may be restricted hoses.

Continue testing by closing the shut-off valve on the gauge and observe the pressure reading **(Figure 47–46)**. When the valve is closed, the pressure should increase. If the pressure is too high, there may be a faulty flow control valve. If the pressure is too low, the pump may be bad. If the flow control valve is suspect, remove and inspect it. If there are any burrs or scratches on the valve, replace it. Do *not* attempt to clean it. Also, inspect the valve's bore. If there are any burrs or scratches, replace the power-steering pump.

After testing and verifying the repairs, remove the gauge, reconnect the lines, refill the system, bleed it, and refill it again.

Electric Power-Steering Systems

Many vehicles, including all hybrid and electric vehicles, have electric power steering. These systems do not have a power-steering pump and require no fluid services. Because these systems are electronically controlled, diagnosis is performed using a scan tool. There is a warning lamp on the dash that comes on when a problem is detected **(Figure 47–47)**. A DTC will also be set. In most cases, when the warning lamp is lit, there will be no power assist available. However, the system will allow for manual steering.

PROCEDURE

Follow these steps to check the pressure in a power-steering system using a scan tool:

STEP 1 Place a thermometer in the power-steering fluid reservoir.

STEP 2 Connect the scan tool.

STEP 3 Set the tool to monitor the power-steering pressure sensor PID.

STEP 4 Start the engine.

STEP 5 With the engine at idle, raise the power-steering fluid temperature to the specified amount by rotating the steering wheel fully to the left and right several times.

STEP 6 With the steering wheel in the straight-ahead position and the engine speed at idle record the pressure reading.

STEP 7 Compare the readings to specifications.

If the pressure reading is higher than specifications, check the power-steering lines and hoses for restrictions.

STEP 8 Turn the steering wheel to the left and right stops. Record the pressure readings at each stop. The pressure reading at both stops should be almost the same. If the pressure reaches the maximum pump pressure at one stop but not the other, install a new steering gear. If the pressure does not reach the maximum pump pressure at either side, install a new pump.

The system is constantly (from key on to key off) monitored by the control module. If a problem is detected, the EPS lamp may stay lit after the ignition is turned on, or it may come on while it is being driven.

Caution! Never hold the steering wheel against its stops for more than 3 to 5 seconds. Doing this can damage the pump.

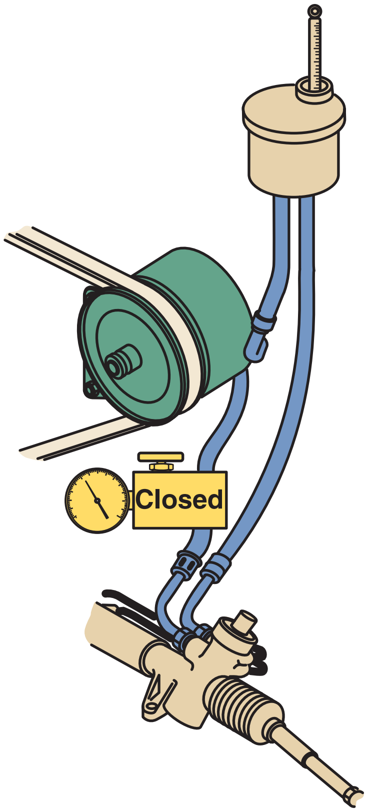


FIGURE 47–46 The final step when checking power-steering pump pressure is to close the tester's valve and observe the pressure in the system. Never keep the valve closed for more than 5 seconds.

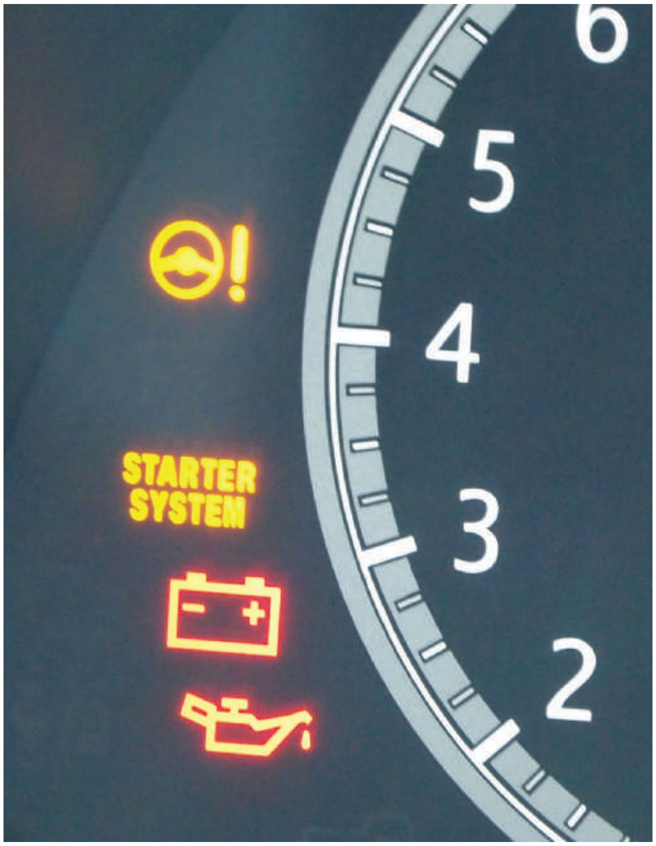


FIGURE 47–47 An electric power-steering fault light.

To identify the reason for the illumination of the lamp, interview the customer to find out when and where it first came on. Try to duplicate the situation during a road test and then retrieve any and all DTCs. If the problem cannot be duplicated, do a careful inspection of all associated wiring and connectors.

Steering problems in an EPS can be caused by the same things as a conventional steering system. However, power assist is provided by electronics, not hydraulics. Therefore, power-steering problems are related to the electronic/electrical components. If the driver complains about how hard it is to turn the steering wheel, the problem can be caused by power-steering motor, speed sensor, power-steering control unit, or electrical circuit problems. For turning effort concerns, inspect the vehicle for damage from hitting curbs or similar obstacles. An impact with a curb can transmit significant force back up the steering linkage and into the EPS motor. If you suspect a problem is with the mechanical components, remove the EPS fuse and perform a test drive. If the problem is still present, the issue is likely not in the EPS itself.

If the steering effort does not change with vehicle speed or is greater when turning left or right, suspect a faulty power-steering motor, speed sensor, or power-steering control unit. A defective power-steering motor may be evident by a high-pitched sound that occurs when the vehicle is stopped and the steering wheel is turned slowly.

On most models, if the power-steering motor gets too hot, the control module will decrease the current flow to it. This can cause increased steering effort. The systems do this to prevent permanent damage to the motor. As soon as the motor's temperature drops, normal current flow resumes. Therefore, a temporary loss of full assist may be normal.

Depending on the vehicle, an electric rack may be able to be serviced and repaired. Some belt-driven rack units can be disassembled and the drive motor and rack replaced separately. However, special tools may be required to reinstall and properly tension the drive belt. Other steering units, and most column-mounted systems are not able to be repaired and the entire unit is replaced.

Be sure to check TSBs and recalls as well. Several manufacturers have EPS bulletins and recalls for control modules, drive motors, and sensors. If the

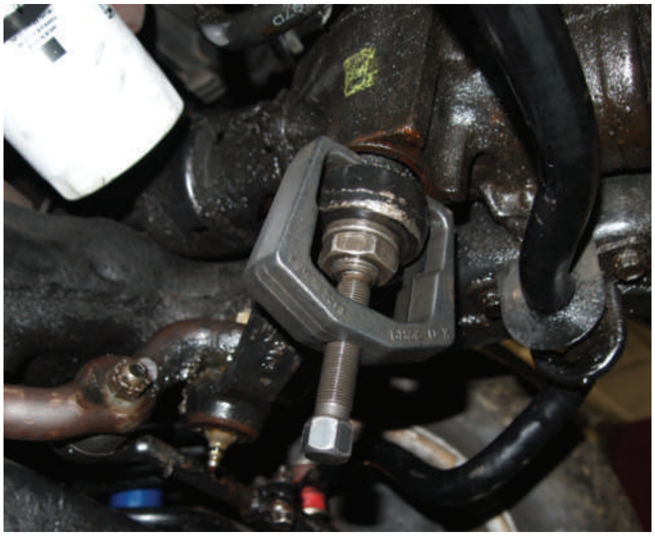


FIGURE 47–48 A Pitman arm puller.

vehicle is under recall, the repairs will be performed by the manufacturer at no charge.

Pitman Arm

Because of its function, the Pitman arm is the most heavily stressed point in the system. To inspect the Pitman arm, grasp it and vigorously shake it to detect any looseness. Check the socket to reveal any damage or looseness. Either condition must be corrected by replacing the worn part. Their removal normally requires the use of a special puller **(Figure 47–48)**.

Idler Arm

Idler arms normally wear more than Pitman arms, with wear usually showing up at the swivel point of the arm or assembly. Worn bushings or stud assemblies on idler arms permit excessive vertical movement in the idler arms.

A worn or damaged idler arm can cause steering instability, uneven tire wear, front-end shimmy, hard steering, excessive play in steering, or poor returnability. Because an idler arm is the weakest link in a parallelogram steering system, it wears more quickly than the rest of the system.

The procedure is simple for checking an idler arm for looseness or wear. The suspension should be normally loaded on the ground or on an alignment rack. When raised by a frame contact hoist, the vehicle's steering linkage is allowed to hang, and proper testing cannot be done. Check the idler arm ends for worn sockets or deteriorated bushings. Grasp the center link firmly with your hand at the idler arm end. Push up with approximately a 25-pound (110-N) load. Pull down with the same load. The allowable movement of the idler arm and support assembly in one direction is $^{1}/_{8}$-inch (3 mm), for a total acceptable movement of ¼ inch (6 mm). The load can be accurately measured by using a dial indicator or pull-spring scale located as near the center link end of the idler arm as possible. Keep in mind that the test forces should not exceed 25 pounds (110 N), as even a new idler arm might be forced to show movement due to steel flexing when excessive pressure is applied. It is also necessary that a scale or ruler be rested against the frame and used to determine the amount of movement. Observers tend to overestimate the actual movement when a scale is not used. The idler arm should always be replaced if it fails this test. Jerking the right front wheel and tire assembly back and forth (causing an up-and-down movement in the idler arm) is not an acceptable method of checking, as there is no control on the amount of force being applied.

Center Link

Worn or bent center links can cause front-end shimmy, vehicle pull to one side, or change in the toe setting, causing excessive tire wear. Center links with stud or bushing ends are likely to become worn from the effects of normal operation and should be inspected periodically. Links with open tapers usually need to be replaced only if they have been damaged in an accident or through excessive tolerance at the mounting position of the idler or Pitman arms.

When inspecting the center link, look closely to insure it has not been bent or damaged. Grasp the center link firmly and try moving it in all directions. Any movement, or sign of damage, is reason for replacement. Tapered openings seldom wear but should be checked for enlargement caused by a loose connection. If necessary, replace the center link.

Tie-Rod Assembly

Tie-rods are subject to wear and damage, particularly if the rubber or plastic dust boots covering the ball stud have been damaged or are missing. Contaminants such as dirt and moisture can enter and cause rapid part failure. A special bonded ball stud, in which no boot is used, is available for use on certain light-duty two-wheel-drive and four-wheel-drive trucks. An elastomer bushing bonded to the stud ball provides strong shock absorption and steering return in downsized vehicles. Worn tie-rod ends

result in incorrect toe-in settings, scalloped and scuffed tires, wheel shimmy, understeering, or front-end noise and tire squeal on turns.

Tie-rod end and center link inspections are similar. Grasp the tie-rod end firmly. Push vertically with the stud, and inspect for movement at the joint with the steering knuckle. Any movement or observation of damaged or missing parts, such as seals, is sufficient evidence that replacement is necessary.

Adjusting sleeves resemble a piece of internally threaded pipe. They have a slot or separation that runs either their entire length or just part way. Adjusting sleeves also have two crimping or squeezing clamps located at each end to lock the toe adjustment. Badly rusted, worn, or damaged adjusting sleeves should be replaced.

An additional check of the tie-rods can be made by rotating each tie-rod end to feel for roughness or binding, which could indicate that the socket has probably rusted internally. A special puller is often required to separate a tie-rod end from the steering knuckle **(Figure 47–49)**.

Steering Damper

The steering dampers found in some steering linkage designs are generally nonadjustable, nonrefillable, and not repairable. At each inspection interval, inspect the mountings and check the assembly for damage (such as being bent) and fluid leaks. A light film of fluid is evidence of fluid leakage. However, a light film of fluid is permissible on the body of the damper near the shaft seal. A dripping damper should be replaced. A bad steering damper may cause wheel shimmy even though the rest of the suspension and steering system is fine.

Courtesy of Federal-Mogul Corporation.

FIGURE 47–49 A tie-rod end separating tool.

Dry Park Check

An excellent overall check for worn or loose conventional steering components is the dry park check. With the full weight of the vehicle on the wheels, have an assistant rock the steering wheel back and forth. Start your inspection from one side to the other side. Note any looseness in tie-rod, center link, idler arm, or Pitman arm sockets **(Figure 47–50)**. If a second person is not available, reach up under the vehicle and grasp the flexible coupling on the steering shaft. Rock the linkage.

Turning Effort

If an owner's concern indicates excessive turning effort, a pull scale should be used to read the actual force required to turn the wheel **(Figure 47–51)**.

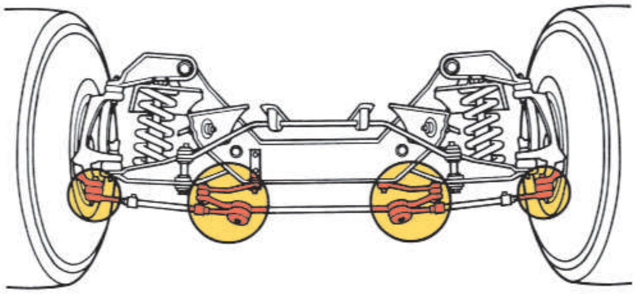


FIGURE 47–50 The circled areas indicate where a dry park check of steering linkage should be made.

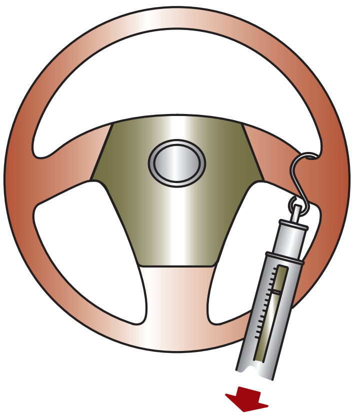


FIGURE 47–51 A pull scale is used to measure steering effort.

Compare the test results to the specifications in the service information. If the effort exceeds the maximum, carefully inspect the entire steering system before performing a pressure test.

Tie-Rod Articulation Effort

The effort required to move the tie-rod or its inner ball socket should be checked with a pull scale if excessive steering effort or looseness is noted during the road test. If the effort is not within the specified limits, the tie-rod must be replaced.

Rack and Pinion Steering

A rack and pinion system has no idler or Pitman arms and no center link. Instead, they are replaced by the rack gear. This reduces the number of wear points on rack and pinion systems to four—each of the tie-rod ends. Power rack and pinion assemblies should be carefully checked for leaks. Leaking rack end seals will allow fluid to accumulate in the bellows **(Figure 47–52)**. Leaks can also be caused by faulty pinion seals and fluid transfer lines. If leaks cause the pump to run out of fluid, the pump will be damaged.

PROCEDURE

Rack and Pinion Steering Inspection

STEP 1 Check all working components **(Figure 47–53)** of the systems. Inspect the flexible steering coupling or the universal joints for wear or looseness. If any play is found, recommend replacement. Universal joints can also seize or bind. They should be checked closely.

STEP 2 Grasp the pinion gear shaft at the flexible steering coupling and try to move it in and out of the gear. If there is movement, the pinion bearing preload might need adjustment. If there is no adjustment, internal components have to be replaced.

STEP 3 Carefully inspect the rack housing. In most cases, the rack and pinion steering assemblies are mounted in rubber bushings. As the vehicle gets older, these mounting bushings deteriorate from heat, age, and oil leakage from the engine. When this happens, the housing moves within its mounting and causes loose and erratic steering. Also, be alert for excessive movement of the rack housing. Stiffness in steering can be caused by a bent rack assembly, tight yoke bearing adjustment, loose power-steering belt, weak pump, internal leaks in the power-steering system, and damaged CV joints in front-wheel-drive vehicles.

STEP 4 Check the inner tie-rod socket assemblies located inside the bellows. The most foolproof way of checking these sockets is to loosen the inner bellows clamp and pull the bellows back, giving a clear view of the socket. During the dry park check, observe any looseness. The inner tie-rod socket can also be checked by squeezing the bellows boot until the inner socket can be felt. Push and pull on the tire. If looseness is found in the tie-rod, it should be replaced. On some vehicles the boot might be made of hard plastic. For this type of boot, lock the steering wheel and push and pull on the tire. Watch for in-and-out movement of the tie-rod. If movement is observed, replace the inner tie-rod.

One fact to keep in mind is that the condition of the bellows boot determines the life of the inner socket. The bellows boot protects the rack from contamination. If any cracks, splits, or leaks exist, the boot should be replaced. Also, be sure that clamps for the bellows are in their proper place and fastened tightly.

STEP 5 Inspect the outer tie-rod ends. In addition to the dry park check, grab each end and rotate to feel for any roughness that would indicate internal rusting. Be sure to check for bent or damaged forgings and studs, split or deteriorated seals, and damaged, out-of-round, or loose tapers. If any of these conditions exist, the parts should be replaced.

FIGURE 47–52 A leaking rack seal.

In order to solve customer complaints, a very thorough inspection of the entire system is needed. Everything, including ball joints, tires, outer tie-rods, bellows boots, inner tie-rods, rack-mounting bushings, mounting bolts, steering couplings, and gearbox adjustment must be checked. Rack and pinion steering inspection must be very thorough because of the system's sensitivity.

Steering System Servicing

When a steering system component is found to be faulty, it is replaced. Most often part replacement is quite straightforward but you should always refer to the service information before proceeding. Also check the TSBs for any updated parts or procedures. At times, diagnosis will indicate a need to adjust the steering gear or inspect and repair the steering column.

Steering Linkage

Eventually, steering linkage components wear and require replacement. Removing tie-rods and center links is straightforward. First, remove the nut securing the stud. This may require removing and discarding a cotter pin. Next, break the taper between the stud and component it is connected to. This is often done using a tie-rod puller or "pickle fork." However, do not use a pickle fork or hammer on aluminum parts. Use a ball joint separator so that the aluminum is not damaged. Once the part is removed, install the new component and torque the nut to specifications.

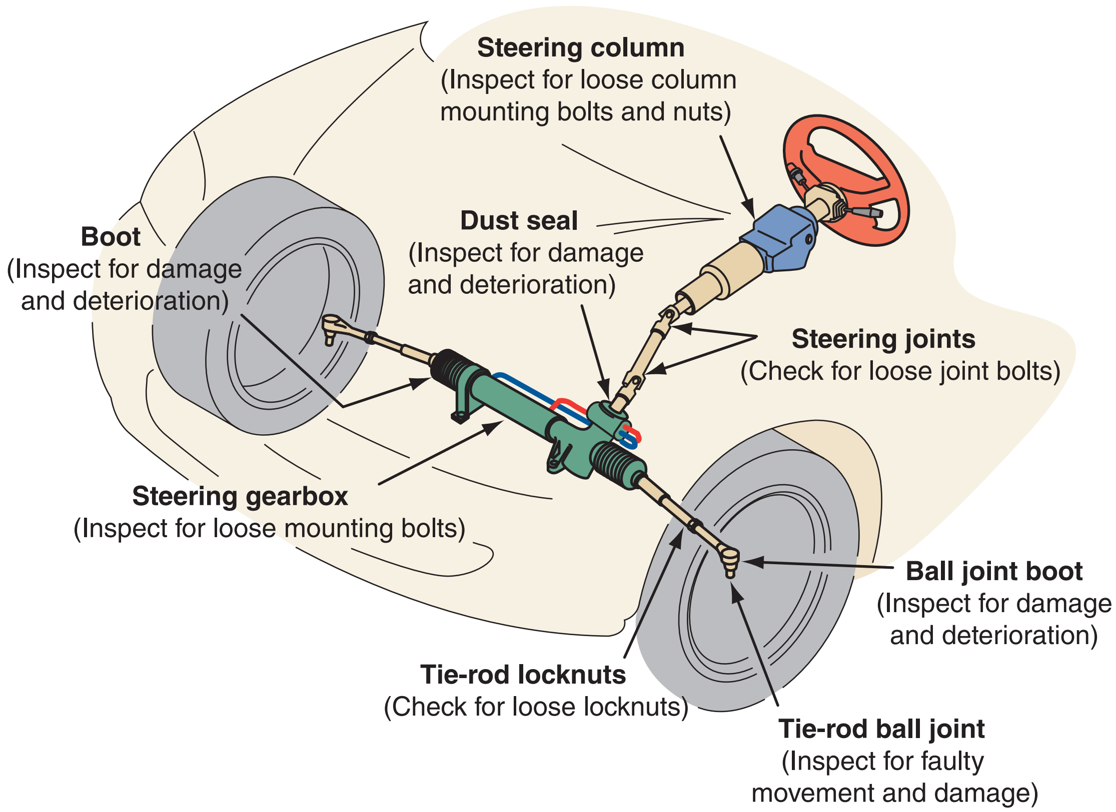


FIGURE 47–53 All steering parts should be carefully checked during diagnosis.

If a castle nut and cotter pin are used and the nut does not align with the hole in the stud, tighten the nut until it aligns, then install a new cotter pin. Bend one or both of the free ends to prevent the pin from working loose and falling out.

To replace an idler arm, remove it from the center link and then unbolt the arm from the frame. Install the new arm and torque the bolts and nuts to specifications. To replace a Pitman arm, first remove the retaining nut and washer. Next, install a Pitman arm puller over the arm and tighten the shaft against the Pitman shaft. Pitman arms tend to be tight so do not be surprised if it takes a bit of work to get it loose from the gearbox. Once off, install the new Pitman arm, washer, and nut. Tighten the nut to specifications.

Before assembling any steering linkage parts, thoroughly check all tapered holes for out-of-roundness and wear. Thoroughly clean all bores where the stud tapers set in. On new and reused parts, firmly install the tapered stud into its tapered hole. The stud must seat firmly without rocking. Only the threaded area should protrude from the hole. If the parts do not meet these requirements, the mating part is worn and must be replaced, or the correct parts are not being used. Always follow the manufacturer's stud and mounting bolt torque specifications when installing chassis parts.

Rack and Pinion Inner Tie-Rods

For end take-off rack and pinion units, removing the inner tie-rods begins by pulling the outer tie-rod ends from the steering knuckle. Measure and note the position of the tie-rod and jamb nut on the inner tie-rod. This will make setting the toe a little quicker if it is already close to where it was before the tie-rod was replaced. Loosen the jam nut securing the inner and out tie-rods tight and then unthread the outer tie-rod from the inner. Remove the jam nut and then the clamps holding the bellows to the inner tie-rod and the rack housing. Pull the bellows off the rack and inspect it for cracks or other damage.

Check the service information for tie-rod removal. Some tie-rods have set screws or staked washers that must be removed first. Also, some manufacturers require that the rack gear be held from moving when loosening the tie-rod. Photo Sequence 45 shows the typical procedure for replacing an inner tie-rod on a rack and pinion steering system.

Removing the inner tie-rod often requires a special tool, shown in Photo Sequence 45. The tool is placed over the tie-rod; make sure it fits snugly. Attach a ratchet to the tie-rod socket and remove the tie-rod. Tighten the inner tie-rod to specifications and reinstall any set screws or other retention devices as outlined in the service information. Tighten the outer tie-rod nut to specifications and install a new cotter pin. If the outer tie-rod uses a nylon friction nut to secure it to the steering knuckle, do not reuse the nut. Install a new nut and torque it to specs. Once the tie-rod is installed, the toe will need to be checked and adjusted.

Steering Gear Adjustments

Before any adjustments are made or servicing procedures performed to the steering gear, a careful check should be made of front-end alignment, shock absorbers, wheel balance, and tire pressure for possible steering system problems.

Before adjusting or servicing a manual steering gear, you may need to disconnect the battery ground cable. Raise the vehicle with the front wheels in the straight-ahead position. Remove the Pitman arm nut. Mark the relationship of the Pitman arm and shaft. Remove the Pitman arm with a Pitman arm puller. Loosen the steering gear adjuster plug lock nut and back the adjuster plug off one-quarter turn **(Figure 47–54)**. Remove the horn shroud or button cap. Turn the steering wheel gently in one direction until stopped by the gear; then turn back one-half turn. Measure and record bearing drag by applying a torque wrench with a socket on the steering wheel nut and rotating through a 90-degree arc. Check the service information for the correct amount of drag.

Once these steps are taken, the steering gear is ready for adjusting or servicing as per instructions in the vehicle's service information.

Rack and Pinion Service

When removing a rack and pinion steering gear, realize that the procedure for doing this will vary with the

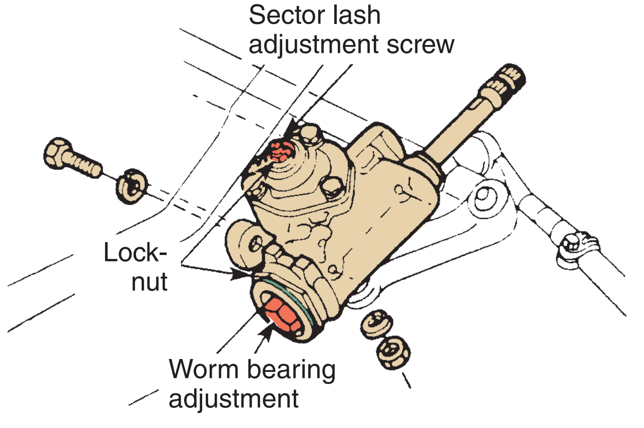


FIGURE 47–54 Typical steering gear adjustment points.

PHOTO SEQUENCE 45

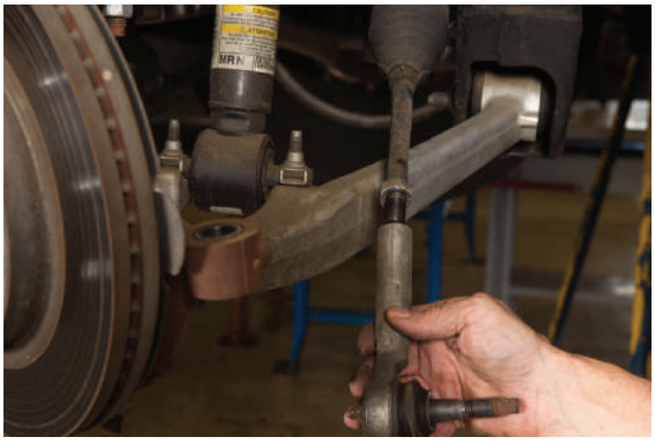
Replacing Inner Tie-Rod on a Rack and Pinion

P45-1 Remove the wheel and tire to gain access to the tie-rods. Thread the lug nuts back onto the wheel studs.

P45-2 Loosen the jam nut that locks the inner and outer tie-rods together.

P45-3 Next, remove the nut holding the outer tie-rod to the steering knuckle. Some vehicles use a cotter pin to retain the nut; discard the cotter pin since a new pin will be used during reassembly. If a nylon lock nut is used, a new nut will be needed.

P45-4 Using a tie-rod end remover, separate the tie-rod from the steering knuckle. Be careful not to damage the outer tie-rod end since it is not being replaced.



P45-5 Once the outer tie-rod is removed from the knuckle, thread the outer tie-rod and jam nut from the inner tie-rod.

P45-6 Next, remove the clamp from the small end of the bellows.

Replacing Inner Tie-Rod on a Rack and Pinion *(continued)*

P45-7 Remove the clamp securing the bellows to the rack and pinion housing. Once the clamp is removed, pull the bellows off of the inner tie-rod.

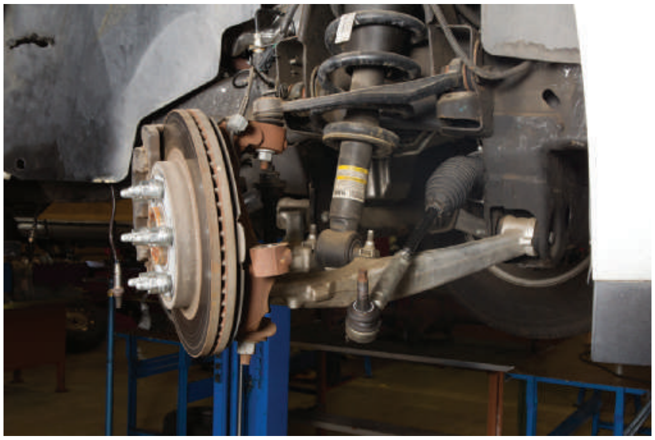
P45-8 With the bellows removed, the connection where the inner tie-rod threads onto the rack gear is visible.

P45-9 Depending on the vehicle, there are several different tools available for removing and installing the inner tie-rod.

P45-10 Use a ratchet and the inner tie-rod tool to remove the tie-rod. Refer to the service information to determine if the rack gear needs to be supported when removing the inner tie-rod.

P45-11 Compare the old and new tie-rods and make sure the replacement tie-rod is correct.

P45-12 Locate the inner tie-rod tightening spec and torque the tie-rod to the manufacturer's specification.



P45-13 Reinstall the bellows and secure it in place; use new clamps if necessary. Reinstall the jam nut and outer tie-rod end. Torque the outer tie-rod to specs and reinstall the wheel and tire. Be sure to check the wheel alignment since the toe is going to need adjustment.

model and make of the vehicle; always refer to the procedures outlined by the manufacturer. First, make sure the front wheels of the vehicle are in the straight-ahead position and the steering wheel is locked. A typical procedure includes removing the wheels and disconnecting the outer tie-rods from the steering knuckles. Next, remove hydraulic pressure and return lines at the rack. Do not remove the transfer lines unless they obstruct access to other items. Disconnect any electrical connectors from the rack. Locate the clamp that secures the steering shaft to the pinion shaft. The clamp is typically covered by a protective boot that may be secured to the body of the vehicle where the column passes through the fire wall. Remove the clamp bolt and slide the clamp off of the pinion shaft. Remove the rack mounting bolts and remove the rack. The rack may have to pass through the wheel opening in the body or in some cases, the cradle may have to be lowered or the engine and/or transaxle must be removed to remove the rack.

Typically a faulty rack is replaced and internal repairs are not made. However, if it is necessary to disassemble and inspect the assembly, the rack should be secured in a vise or the special tool recommended by the manufacturer. Once it is secured, all fluid transfer tubes can be removed, along with the tie-rod ends and boots. Check the boots for cracks or signs of leakage; replace them, if damaged.

Warning! **It is easy to damage the boots and the rack while disassembling the unit, so be careful and adhere to all of the manufacturer's recommendations.**

Make an index mark on the outer tie-rod end, jam nut, and tie-rod **(Figure 47–55)**. Remove the rack guide spring cap, compression spring, and rack guide subassembly. Then remove the O-ring from the rack guide spring cap and the dust cover. Now remove the control valve assembly and subassembly. In some cases the subassembly is removed by pressing it away from the main assembly. Once the subassembly is separated, remove the snaprings, seals, and spacers from it.

FIGURE 47–55 Before disassembling the steering gear, make an index mark on the outer tie-rod end, jam nut, and tie-rod.

The cylinder and "stoppers" in the rack are removed next, along with the steering rack bushing. When doing this, be careful not to drop the bushing or damage the inside of the steering gear housing.

Check the following:

- *Inner Tie-Rod Sockets.* If the inner tie-rod ends were found to be loose during the inspection or if they require too much effort to move, replace them.
- *Pinion and Bearing Assembly.* If the pinion bearing is loose on the shaft, replace the pinion and bearing assembly. A pinion shaft with worn or chipped teeth must be replaced. Inspect the pilot bearing contact area on the pinion shaft. Wear, pitting, or scoring in this area indicates that a new pinion shaft is required. If the pinion bearing is bad, replace the pinion shaft and bearing assembly.
- *Rack Bushing.* If the rack bushing is worn, bushing replacement is necessary.
- *Mounting Bushings.* If the mounting bushings are loose, replace the bushings. Always replace the bushings in pairs. If the bushings are in satisfactory condition, do not disturb them. Work rack bushings can cause noise and bump steer concerns.

SHOP TALK

Some manufacturers actually recommend different lengths for the torque wrench that is used to measure, test, and tighten things. This is a reason for always checking the manufacturer's recommendations before proceeding with a repair or service. For example, Toyota recommends using a torque wrench with a different fulcrum length for different applications. Torque wrenches with a fulcrum length of 9.84 inches (250 mm) or 11.81 inches (300 mm) are recommended to measure interference and tightening. Always check the service information for the correct procedures.

When installing new parts to the rack assembly or when reassembling the unit, all moving parts should be lubricated with power-steering fluid, molybdenum disulfide lithium-based grease, MP grease, or silicon grease. Also install new bellows, clamps, bushings, and seals. There are certain parts that need to be preloaded; again follow the manufacturer's recommendations. Reassembly is the reverse of the disassembly procedure. Installing a new or rebuilt rack and pinion steering gear follows the opposite procedure as when removing it. Make sure everything is tightened to the torque specified by the manufacturer with the wheels in a straightforward position. Also make sure to check the fluid level when finished and before the vehicle is driven. The vehicle will also need to have its wheels aligned.

Steering Columns

To perform service procedures on the steering column upper end components, it is not necessary to remove the column from the vehicle. The steering wheel, horn components, directional signal switch, ignition switch, and lock cylinder can be removed with the column remaining in the vehicle.

To determine if the energy-absorbing steering column components are functioning as designed, or if repairs are required, a close inspection should be made. An inspection is called for in all cases where damage is evident or whenever the vehicle is being repaired due to a front-end collision. If damage is evident, the affected parts must be replaced. Because of the differences in the steering column styles and various components, consult the service information for more explicit inspection and servicing procedures.

Warning! Set the parking brake before removing the steering column. Also, remove the battery cable from the negative terminal. Remember that special precautions must be observed before beginning disassembly and during assembly to ensure the correct fitting together of the steering column shaft and steering gear shaft connections.

SHOP TALK

On some 4WD vehicles, those with certain cross link steering linkages, the steering wheel must be removed and recentered once the front wheel toe has been set. Refer to the manufacturer's wheel alignment procedures.

Steering Wheels

At times, a customer may complain about an uncentered steering wheel. When the steering wheel is in its centered position, the front wheels should be pointing straight ahead. If the wheels are not in the straight-ahead position, this can be corrected by adjusting the toe of the vehicle. However, this adjustment should only be made if the steering wheel index mark is aligned with the steering column index marks. As a rule, indexing teeth or mating flats on the wheel hub and steering shaft prevent misindexing of these components. One way to verify an incorrectly positioned steering wheel is to turn it from stop to stop and count the number of turns it took. Then take that number and divide it by 2; the result represents the center or straight-ahead position. Now turn the steering wheel to a stop and then the number of turns that represents the center. Look at the front wheels; if they are not in the straight-ahead position, either the steering was installed wrong or the wheels need to have their toe adjusted.

At times the steering wheel must be removed, such as when servicing the multifunctional switch, horn, or the steering column covers. The steering wheel is very unlikely to cause a steering problem.

Warning! The center of the steering wheel contains the driver side air bag. Failure to disarm it can cause serious personal injury.

GO TO Chapter 48 for specific precautions that should be followed when working around or near an air bag.

PROCEDURE

The following is a typical procedure for removing and reinstalling a steering wheel:

To remove:

STEP 1 Place the front wheels facing straight ahead.

STEP 2 Disable the SRS.

STEP 3 Remove the steering pad and air bag.

STEP 4 Remove the steering wheel assembly set nut.

STEP 5 Put alignment marks on the steering wheel and the steering main shaft.

STEP 6 Disconnect the connectors from the spiral cable.

STEP 7 Using the correct puller, remove the steering wheel assembly **(Figure 47–56)**.

To install:

STEP 1 Slip the steering wheel over the main shaft.

STEP 2 Align the alignment marks on the steering wheel assembly and steering main shaft **(Figure 47–57)**.

STEP 3 Install the steering wheel assembly set nut. Torque the nut to specifications.

STEP 4 Connect the connectors to the clockspring (spiral cable) subassembly.

STEP 5 Connect the cable to the negative battery terminal.

STEP 6 Check the SRS warning light.

FIGURE 47-56 Use the correct puller to remove the steering wheel assembly.

Power-Steering System Servicing

Vehicles with power-steering systems have the same type of steering linkage as manual steering. The power-steering linkage is checked and serviced as previously described. Actually, the only difference is the servicing of the hydraulic components, such as the hoses, pump, and power-steering gear. One of the common procedures that is recommended by manufacturers as part of a preventive maintenance program is flushing the hydraulic system.

Flushing the System

The reason for flushing the system should be obvious. Hydraulic fluid becomes contaminated by moisture and dirt. Flushing removes the old fluid with its contaminants and new fluid is added to the system. It is also wise to flush the system after you have replaced or repaired a part in the system.

To flush the system, you should disable the engine's ignition. Then disconnect the power-steering return hose and plug the reservoir. Attach an extension hose between the power-steering return hose and an empty container. Raise the vehicle's front wheels off the ground. Fill the reservoir with the correct type of fluid.

Turn the steering wheel from stop to stop while cranking the engine until the fluid leaving the return hose is clean. Never crank the engine for more than 5 seconds at a time. Add fluid to the reservoir to make sure it does not empty. Once the fluid is clear, fill the reservoir to its full mark and lower the vehicle.

Warning! Never mix oil types. Any mixture or any unapproved oil can lead to seal deterioration and leaks.

Disconnect the extension hose from the power-steering return hose and reconnect the return hose to the reservoir. Check the fluid level again and add fluid as necessary. Now enable the ignition system. Start the engine and turn the steering wheel from stop to stop. If the power-steering system is noisy and bubbles are forming in the fluid, the system must be purged of air.

Flushing the system is also commonly performed with the engine running at idle speed. With the return hose placed in a suitable container, start the

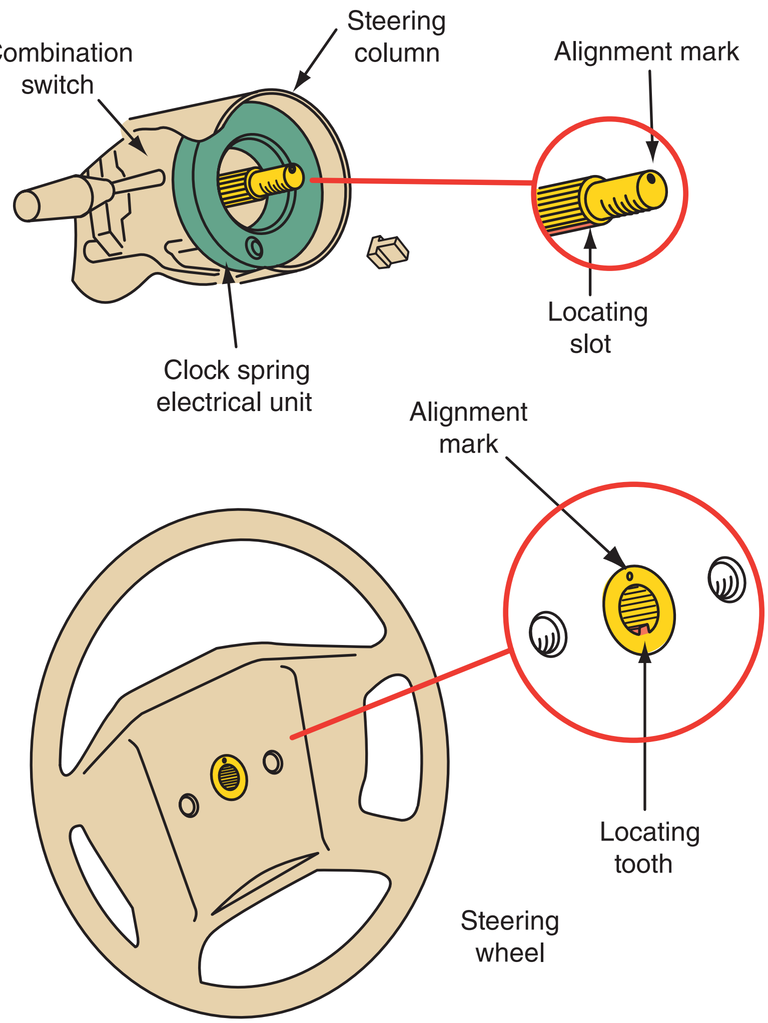


FIGURE 47–57 The steering wheel is splined to the steering column and must be aligned to the reference marks.

engine and turn the steering wheel lock to lock while adding new fluid. Once the fluid coming out of the return hose is new and clean, shut the engine off. Reconnect the return hose and refill the system. Start the engine and bleed any air from the system.

Bleeding the System

Often the procedure for bleeding the power-steering system is called "purging" the system, because it moves air that may be trapped in the fluid. Purging the system must be done after the replacement of any part of the power-steering hydraulic system or when there is a problem that indicates there may be aerated fluid, such as a whining noise.

The method for bleeding the system depends on the type of power steering the vehicle is equipped with. Follow the procedures given in the service information. If the system is not purged correctly or if air is allowed to remain in the system, the power-steering pump can fail prematurely. What follows is a typical procedure.

Electric Power-Steering Systems

When working on a vehicle with EPS, remember that the electric motor adds the assist. It must be positioned properly in order to provide assist equally to both sides. Therefore, it is important that the front wheels are in their straight-ahead position whenever any part of the steering linkage is removed or installed. If it is necessary to disconnect the steering column shaft from the steering gear, mark the alignment of the two before disconnecting it. When reattaching the shaft, make sure the marks are aligned.

Electric power assist systems use steering angle sensors or a torque sensor to help determine how much power assist to provide. A torsion bar links the input shaft from the steering column to the pinion in the steering gear. The torsion bar twists in response to the movement of the steering wheel. The torque sensor typically has two sensors or resolvers that detect the twist of the torsion bar. One sensor is on the input side of the shaft and another is on the output side. The difference in movement between the input and

PROCEDURE

Follow these steps to bleed a power-steering hydraulic system:

STEP 1 Remove the reservoir cap.

STEP 2 Tightly install the adapter of the vacuum pump to the reservoir opening.

STEP 3 Start the engine.

STEP 4 Connect the vacuum pump.

STEP 5 Apply 20 to 25 in. Hg (68 to 85 kPa) of vacuum. Note: If the vehicle has a hydro-boost system, depress the brake pedal two times.

STEP 6 Fully cycle the steering wheel from stop to stop ten times.

STEP 7 Turn off the engine.

STEP 8 Release the vacuum and remove the adapter from the reservoir.

STEP 9 Fill the reservoir with the correct fluid.

STEP 10 Tightly install the adapter of the vacuum pump to the reservoir opening.

STEP 11 Start the engine.

STEP 12 Apply 20 to 25 in. Hg (68 to 85 kPa) of vacuum. Note: If the vehicle has a hydro-boost system, depress the brake pedal two times.

STEP 13 Turn off the engine.

STEP 14 Release the vacuum and remove the adapter from the reservoir.

STEP 15 Fill the reservoir with the correct fluid.

STEP 16 Check the system for signs of leaks. Make repairs as necessary.

STEP 17 Install the reservoir cap.

output sensors is used to determine steering torque. Both steering angle and torque sensors must be recalibrated whenever the steering gear, steering wheel, steering column, or steering control module has been removed or replaced. Recalibration is also needed after setting the front wheel alignment or if there is a difference in steering effort when turning right or left. Follow the manufacturer's directions for calibrating this sensor. In general, there are three methods for sensor calibration:

- Self-calibrating—meaning the system will relearn on its own after turning the steering wheel from lock-to-lock.

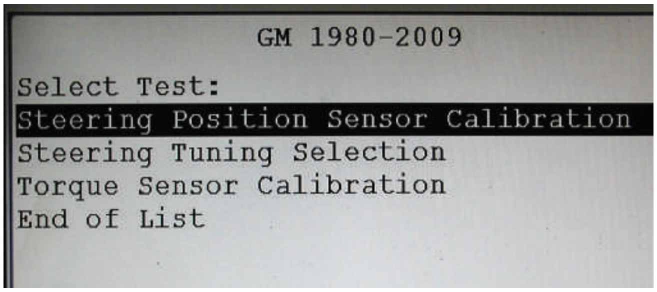


FIGURE 47–58 The electric power steering calibrations on a GM vehicle.

- Toyota/Lexus—using a jumper wire to short specific terminals together at the data link connector.
- Scan tool relearn—many vehicles using either a scan tool or the software with the alignment machine to perform a relearn **(Figure 47–58)**.

If the sensor is faulty, steering effort in both directions may increase or the steering wheel may not return properly.

Hoses and Lines

Hoses and lines should also be carefully inspected for leaks, dents, sharp bends, cracks, and swelling. Always replace the power-steering hoses with an exact replacement hose. Never attempt to patch or seal a leak in a hose or the hose's fittings. Lines and hoses must not rub against other components. This can wear a hole in the line or hose. Many high-pressure lines are made of high-pressure steel-braided hose with molded steel fittings on each end.

Power-Steering Pump

To replace a power-steering pump follow the manufacturer's service procedures. Begin by removing the drive belt. Next, determine if the pulley must be removed to remove the pump from its bracket. If so, remove the pulley using the appropriate puller. Remove the return hose and drain the power steering fluid into an oil pan, then remove the pressure hose. Next, unbolt the pump from the bracket and remove the pump. Compare the old pump to the replacement pump. Make sure the replacement pump has the same size fitting and mounting points. Install the new pump and torque the fasteners to specifications. Reconnect the hoses and reinstall the pulley and drive belt. Fill the system with the correct power steering fluid and bleed the air from the system. Start the engine, check for leaks, and ensure proper power steering operation.

Although power-steering pumps are not typically rebuilt by technicians, some parts are replaceable.

PROCEDURE

When power steering hose replacement is required, follow these steps:

STEP 1 With the engine stopped, remove the return hose at the power-steering gear, and allow the fluid to drain into a drain pan.

STEP 2 Loosen and remove all hose fittings from the pump and steering gear.

STEP 3 Remove all hose-to-chassis clips.

STEP 4 Remove the hoses from the chassis, and cap the pump and steering gear fittings.

STEP 5 If O-rings are used on the hose ends, install new O-rings. Some lines have gaskets. The old gasket must be pried out of the fitting before installing the new lines. Lubricate the O-rings with power-steering fluid.

STEP 6 Install the new hose by reversing the steps for removal. Make sure to tighten all fittings to the specified torque. Be sure all hose-to-chassis clips are in place. Do not position hoses where they rub on other components.

STEP 7 Fill the pump reservoir to the full mark with the manufacturer's recommended fluid. Bleed air from the power-steering system, then check the fluid level in the reservoir and add fluid as required.

The actual parts that can be replaced depend on the make of the pump. The common parts that can be replaced are discussed next.

Power-Steering Pump Pulley Replacement If the pulley wobbles while it is rotating, it is undoubtedly bent and should be replaced. Worn pulley grooves and/or cracks also indicate that the pulley should be replaced. A pulley that is loose on the pump's shaft must be replaced. Never hammer on the pump's drive shaft during pulley removal or installation. This will damage the internal parts of the pump.

If the pulley is pressed onto the pump's shaft, a special puller **(Figure 47–59A)** is required to remove it and a pulley installation tool is used to install the pulley **(Figure 47–59B)**. When replacing a pump, the replacement pump usually does not come with a pulley. You will need to remove the pulley from the old pump and reinstall it on the new pump.

To remove the pulley, install the puller over the lip of the pulley and tighten the puller bolt against the pump's driveshaft. Hold the body of the puller with a wrench and tighten the puller bolt. This will pull the pulley from the pump shaft. To reinstall, align the pulley onto the pump shaft and thread the installation bolt into the driveshaft. Tighten the bolt and hold it from turning with a wrench or socket. Using a wrench, tighten the nut against the pulley. This will push the pulley onto the driveshaft. Once the pulley is seated in place, spin the pulley to make sure it does not wobble. A bent pulley should be replaced since it will cause premature belt wear.

(A) Removal

(B) Installation

FIGURE 47–59 Removing and installing a press-fit pulley.

PROCEDURE

Remove and Replace the Pressure Relief Valve

Follow this procedure to service the pressure relief valve:

1. Wrap a shop towel around the land end of the flow control valve and clamp this end in a soft-jawed vise. Be very careful not to damage the valve lands.
2. Remove the hex-head ball seat. Clean the components in solvent. A worn or damaged pressure relief ball, spring, guide, or seat must be replaced.
3. Reinstall the new or cleaned components, and then install the ball seat.

If the power-steering pump pulley is retained with a nut, mount the pump in a vise. Always tighten the vise on one of the pump's mounting bolt surfaces. Do not tighten the vise with excessive force. Use a special holding tool to keep the pulley from turning, and loosen the nut with a box-end wrench. Remove the nut, pulley, and woodruff key. Inspect the pulley, shaft, and woodruff key for wear. Replace all worn components.

Remove and Replace the Flow Control Valve and End Cover To replace the flow control valve and end plate, remove the retaining ring with a slotted screwdriver and punch. Then remove the flow control valve, end cover, spring, and magnet. Check the flow control valve for burrs. Remove minor burrs with crocus cloth, and clean the flow control valve in solvent. Damaged or worn flow control valves must be replaced. Inspect the end cover sealing surface for damage. Also check the pump's drive shaft for corrosion and damage. Remove any corrosion with crocus cloth. Clean all parts and lubricate the end cover with power-steering fluid. Make sure to clean the magnet with a shop towel. To reassemble, install the flow control valve, end cover, retaining ring, and related components.

Four-Wheel Steering Systems

A few manufacturers have offered four-wheel steering systems in which the rear wheels also help to turn the car by electrical, hydraulic, or mechanical means. Although they certainly are not very common, you should be aware of how they work.

Production-built cars tend to understeer or, in a few instances, oversteer. Understeer is when the vehicle cannot follow a turn due to the front wheels losing traction. Trying to turn too fast on a slippery road and sliding through an intersection is an example of understeer. Oversteer occurs with the vehicle turns more than is needed, typically due to the back wheels losing traction and breaking loose. If a car could automatically compensate for an understeer/oversteer problem, the driver would enjoy nearly neutral steering under varying operating conditions. Four-wheel steering (4WS) is a serious effort on the part of automotive design engineers to provide near-neutral steering with the following advantages:

- The vehicle's cornering behavior becomes more stable and controllable at high speeds as well as on wet or slippery road surfaces **(Figure 47–60)**.
- The vehicle's response to steering input becomes quicker and more precise throughout the vehicle's entire speed range.
- The vehicle's straight-line stability at high speeds is improved. Negative effects of road irregularities and crosswinds on the vehicle's stability are minimized.
- Stability in lane changing at high speeds is improved. High-speed slalom-type operations become easier. The vehicle is less likely to go into a spin even in situations in which the driver must make a sudden and relatively large change of direction.
- By steering the rear wheels in the direction opposite the front wheels at low speeds, the vehicle's turning circle is greatly reduced. Therefore, vehicle maneuvering on narrow roads and during parking becomes easier.

To understand the advantages of four-wheel steering, it is wise to review the dynamics of typical steering maneuvers with a conventional front-steered

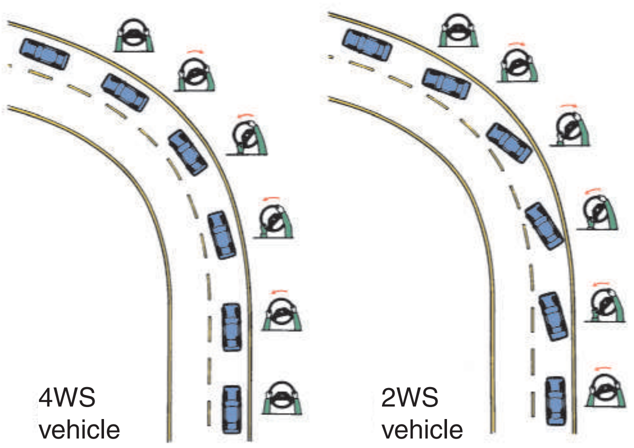


FIGURE 47–60 A comparison of 2WS and 4WS vehicle behavior during cornering.

vehicle. The tires are subject to the forces of grip, momentum, and steering input when making a movement other than straight-ahead driving. These forces compete with each other during steering maneuvers. With a front-steered vehicle, the rear end is always trying to catch up to the directional changes of the front wheels. This causes the vehicle to sway. As a normal part of operating a vehicle, the driver learns to adjust to these forces without thinking about them.

When turning, the driver is putting into motion a complex series of forces. Each of these must be balanced against the others. The tires are subjected to road grip and slip angle. Grip holds the car's wheels to the road, and momentum moves the car straight ahead. Steering input causes the front wheels to turn. The car momentarily resists the turning motion, causing a tire slip angle to form. Once the vehicle begins to respond to the steering input, cornering forces are generated. The vehicle sways as the rear wheels attempt to keep up with the cornering forces already generated by the front tires. This is referred to as rear-end lag because there is a time delay between steering input and vehicle reaction. When the front wheels are turned back to a straight-ahead position, the vehicle must again try to adjust by reversing the same forces developed by the turn. As the steering is turned, the vehicle body sways as the rear wheels again try to keep up with the cornering forces generated by the front wheels.

The idea behind four-wheel steering is that a vehicle requires less driver input for any steering maneuver if all four wheels are steering the vehicle. As with two-wheel-steer vehicles, tire grip holds the four wheels on the road. However, when the driver turns the wheel slightly, all four wheels react to the steering input, causing slip angles to form at all four wheels. The entire vehicle moves in one direction rather than the rear half attempting to catch up to the front. There is also less sway when the wheels are turned back to a straight-ahead position. The vehicle responds more quickly to steering input because rear wheel lag is eliminated.

Because each 4WS system is unique in its construction and repair needs, the vehicle's service information must be followed for proper diagnosis, repair, and alignment of a four-wheel system.

Mechanical 4WS

In a straight-mechanical type of 4WS, two steering gears are used—one for the front and the other for the rear wheels. A steel shaft connects the two steering gearboxes and terminates at an eccentric shaft that is fitted with an offset pin **(Figure 47–61)**. This pin engages a second offset pin that fits into a planetary gear.

The planetary gear meshes with the matching teeth of an internal gear that is secured in a fixed position to the gearbox housing. This means that the planetary gear can rotate but the internal gear cannot. The eccentric pin of the planetary gear fits into a hole in a slider for the steering gear.

A 120-degree turn of the steering wheel rotates the planetary gear to move the slider in the same direction that the front wheels are headed. Proportionately, the rear wheels turn about 1.5 to 120 degrees of the steering wheel. Further rotation of the steering wheel, past the 120-degree point, causes the rear wheels to start straightening out due to the double-crank action (two eccentric pins) and rotation of the planetary gear. Turning the steering wheel to a greater angle, about 230 degrees, finds the rear wheels in a neutral position regarding the front wheels. Further rotation of the steering wheel, at about 450 degrees, results in the rear wheels going counter phase with regard to the front

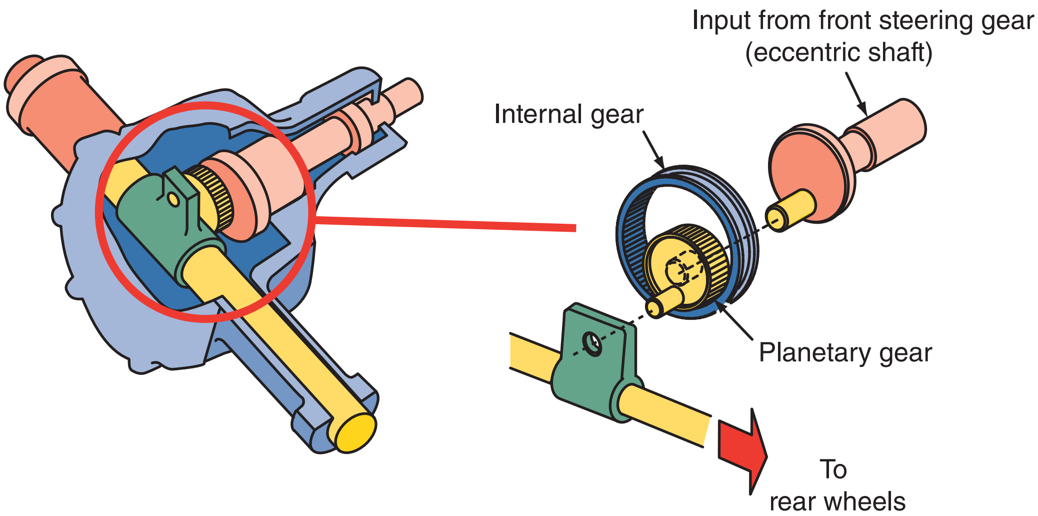


FIGURE 47–61 Inside a rear-steering gearbox is a simple planetary gear setup.

wheels. About 5.3 degrees maximum counterphase rear steering is possible.

Mechanical 4WS is steering angle sensitive. It is not sensitive to vehicle road speed.

Hydraulic 4WS

The hydraulically operated 4WS system shown in **Figure 47–62** is a simple design, both in components and operation. The rear wheels turn only in the same direction as the front wheels. They also turn no more than 1½ degrees. The system only activates at speeds above 30 mph (50 kph) and does not operate when the vehicle moves in reverse.

A two-way hydraulic cylinder mounted on the rear stub frame turns the wheels. Fluid for this cylinder is supplied by a rear steering pump that is driven by the differential. The pump only operates when the front wheels are turning. A tank in the engine compartment supplies the rear steering pump with fluid.

When the steering wheel is turned, the front steering pump sends fluid under pressure to the rotary valve in the front rack and pinion unit. This forces fluid into the front power cylinder, and the front wheels turn in the direction steered. The fluid pressure varies with the turning of the steering wheel. The faster and farther the steering wheel is turned, the greater the fluid pressure.

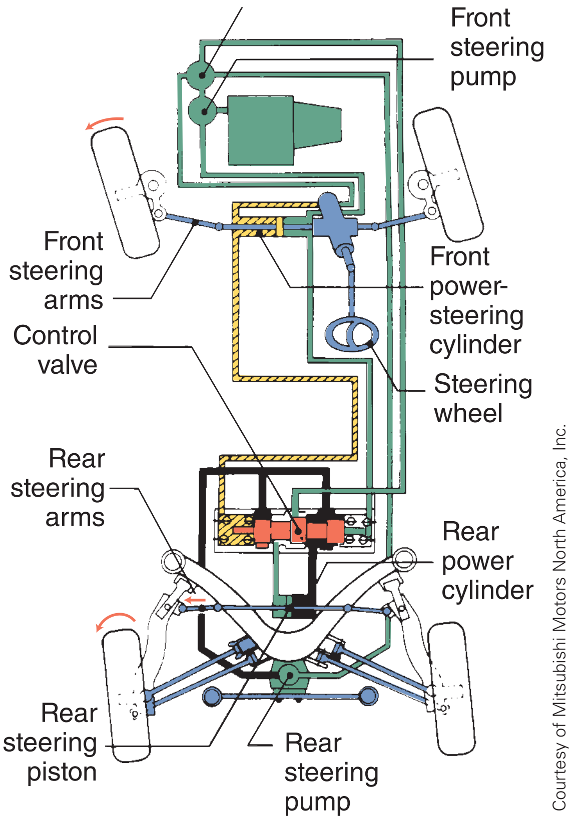


FIGURE 47–62 A simple hydraulic 4WS system.

The fluid is also fed under the same pressure to the control valve, where it opens a spool valve in the control valve housing. As the spool valve moves, it allows fluid from the rear steering pump to move through and operate the rear power cylinder. The higher the pressure on the spool, the farther it moves. The farther it moves, the more fluid it allows through to move the rear wheels. As mentioned earlier, this system limits rear wheel movement to 1½ degrees in either the left or right direction.

Electrohydraulic 4WS

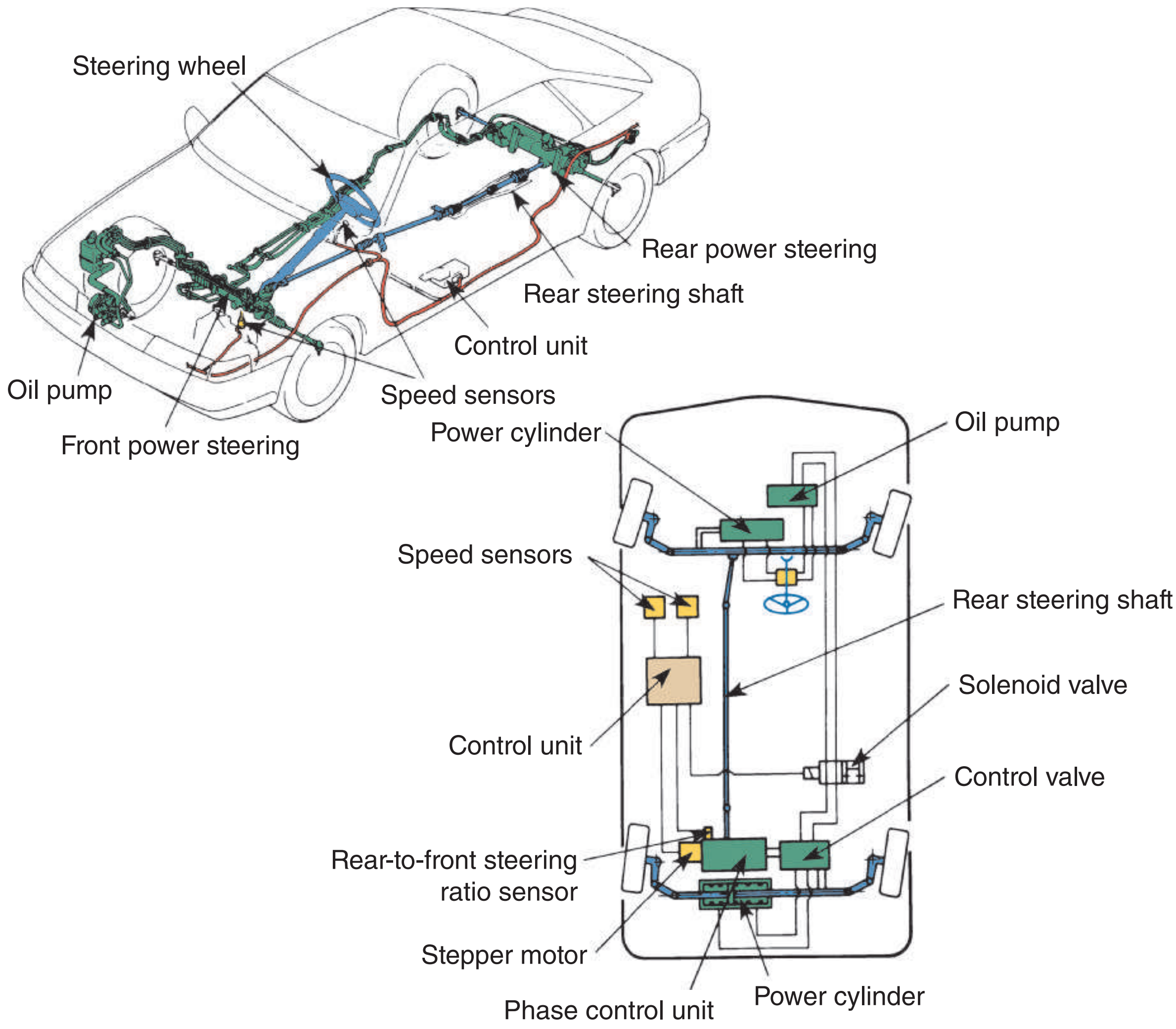
Several 4WS systems combine computer electronic controls with hydraulics to make the system sensitive to both steering angle and road speeds. In this design, a speed sensor and steering wheel angle sensor feed information to the electronic control unit (ECU). By processing the information received, the ECU commands the hydraulic system to steer the rear wheels. At low road speed, the rear wheels of this system are not considered a dynamic factor in the steering process.

At moderate road speeds, the rear wheels are steered momentarily counterphase, through neutral, then in phase with the front wheels. At high road speeds, the rear wheels turn only in phase with the front wheels. The ECU must know not only road speed, but also how much and how quickly the steering wheel is turned. These three factors—road speed, amount of steering wheel turn, and the quickness of the steering wheel turn—are interpreted by the ECU to maintain continuous and desired steering angle of the rear wheels.

Another electrohydraulic 4WS system is shown in **Figure 47–63**. The basic working elements of the design are the control unit, a stepper motor, a swing arm, a set of beveled gears, a control rod, and a control valve with an output rod. Two electronic sensors tell the ECU how fast the car is going.

The yoke is a major mechanical component of this electrohydraulic design. The position of the control yoke varies with vehicle road speed. For example, at speeds below 33 mph (53 km/h), the yoke is in its downward position, which results in the rear wheels steering in the counterphase (opposite front wheels) direction. As road speeds approach and exceed 22 mph (35 km/h), the control yoke swings up through a neutral (horizontal) position to an up position. In the neutral position, the rear wheels steer in phase with the front wheels.

The stepper motor moves the control yoke. A swing arm is attached to the control yoke. The position of the yoke determines the arc of the swing rod. The arc of the swing arm is transmitted through a control arm that passes through a large bevel gear. Stepper motor action eventually causes a push-or-pull



Courtesy of Mazda North American Operations.

FIGURE 47–63 An electronically and hydraulically controlled 4WS system using a stepper motor and control yoke.

movement of its output shaft to steer the rear wheels up to a maximum of 5 degrees in either direction.

The electronically controlled 4WS system regulates the angle and direction of the rear wheels in response to speed and driver's steering. This speed-sensing system optimizes the vehicle's dynamic characteristics at any speed, thereby producing enhanced stability and, within certain parameters, agility.

The actual 4WS system consists of a rack and pinion front steering that is hydraulically powered by a main twin-tandem pump. The system also has a rear-steering mechanism, hydraulically powered by the main pump. The rear-steering shaft extends from the rack bar of the front-steering assembly to the rear-steering-phase control unit.

The rear steering is comprised of the input end of the rear-steering shaft, vehicle speed sensors, and steering-phase control unit (deciding direction and degree), a power cylinder, and an output rod. A centering lock spring is incorporated that locks the rear system in a neutral (straight-ahead) position in the event of hydraulic failure. Additionally, a solenoid valve that disengages the hydraulic boost (thereby activating the centering lock spring in case of an electrical failure) is included.

All 4WS systems have fail-safe measures. For example, with the electrohydraulic setup, the system automatically counteracts possible causes of failure, both electronic and hydraulic, and converts the entire steering system to a conventional two-wheel steering type. Specifically, if a hydraulic defect should reduce pressure level (by a movement malfunction or a broken driving belt), the rear-wheel-steering mechanism is automatically locked in a neutral position, activating a low-level warning light.

An electrical failure would be detected by a self-diagnostic circuit integrated in the four-wheel-steering control unit. The control unit stimulates a solenoid valve, which neutralizes hydraulic pressure, thereby alternating the system to two-wheel steering. The failure would be indicated by the system's warning light in the main instrument display.

On any 4WS system, there must be near-perfect compliance between the position of the steering wheel,

the position of the front wheels, and the position of the rear wheels. It is usually recommended that the car be driven about 20 feet (6 meters) in a dead-straight line. Then, the position of the front/rear wheels is checked with respect to steering wheel position. The base reference point is a strip of masking tape on the steering wheel hub and the steering column. When the wheel is positioned dead center, draw a line down the tape. Run the car a short distance straight ahead to see if the reference line holds. If not, corrections are needed, such as repositioning the steering wheel.

Even severe imbalance of a rear wheel on a speed-sensitive 4WS system can cause problems and make basic troubleshooting a bit frustrating.

Quadrasteer

Quadrasteer was a 4WS system that was an option on GM's full-size pickup and model 2500 Suburbans during the model years 2002 through 2005. This system improved low-speed maneuverability, high-speed stability, and trailering capabilities for full-size pickups, vans, and SUVs. The system combined normal front-wheel steering with an electrically powered and electronically controlled rear-wheel steering system. The system was primarily controlled by vehicle speed sensors and a central control module **(Figure 47–64)**.

At low speeds, the rear wheels turned in the opposite direction as the front wheels **(Figure 47–65)**.

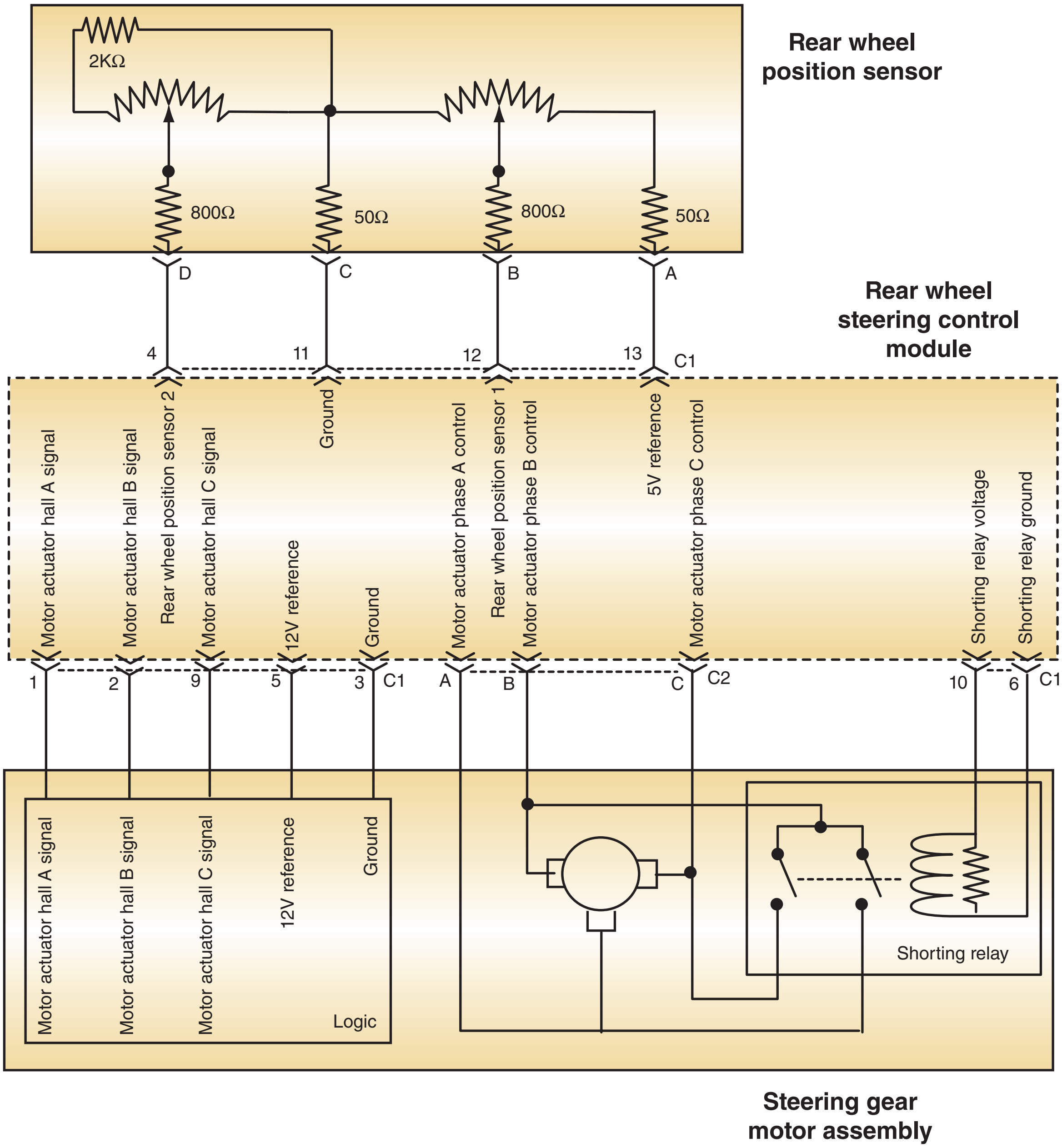


FIGURE 47–64 The components controlling the four-wheel steering system.

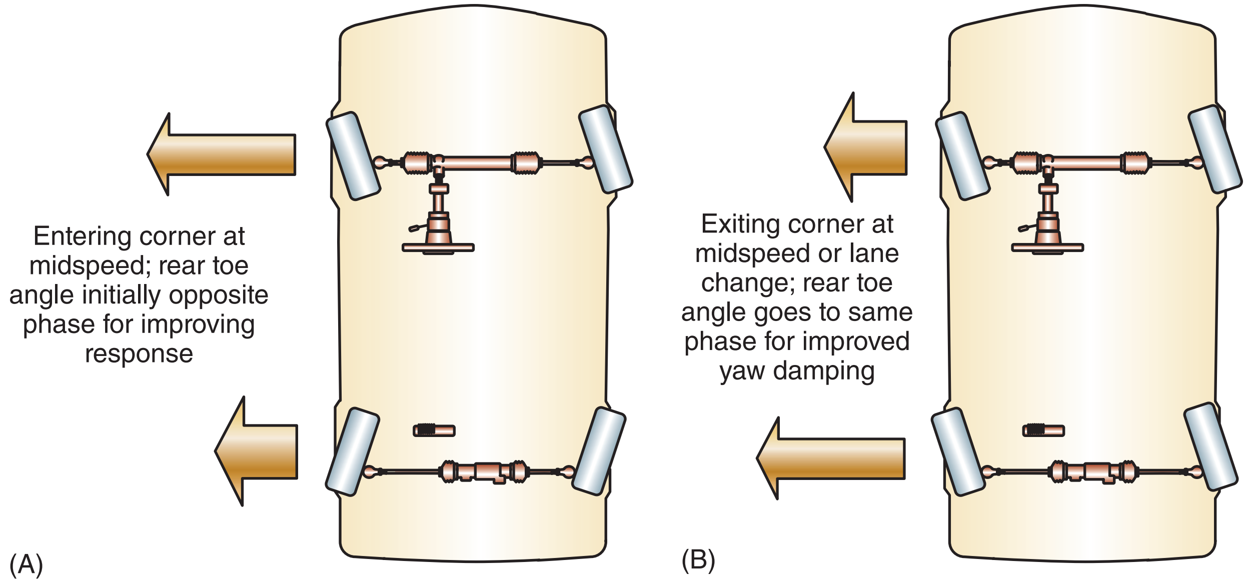


FIGURE 47–65 The different operational modes of a Quadrasteer system. Counter-steering at low speeds (A) and in-phase or following steering at higher speeds (B).

At moderate speeds, the rear wheels remained straight. At high speeds, the rear wheels turned in the same direction as the front wheels. If the system failed, the truck defaulted to normal two-wheel steering.

Acura Precision All-Wheel Steer

The Acura Precision All-Wheel Steer (P-AWS) system introduced in 2015 was their first system capable of independently adjusting the toe angle of the rear wheels. The system relies on two electric actuators, one for each rear wheel **(Figure 47–66)**. The actuators can change rear tire angle up to 1.8 degrees. During low speed operation, the wheels are reverse- or counterphase, pointing in the opposite direction of the front tires to improve turning radius. At higher speeds, the rear wheels turn with the front wheels to allow quick lane changes. During high-speed cornering, the rear wheels reverse-phase to help the car through the turn. Under high-speed braking, both rear wheels toe-in to increase braking stability.

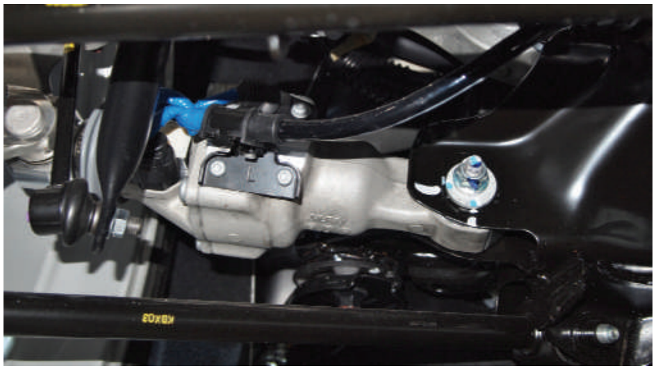


FIGURE 47–66 Acura's 4WS system uses two electric actuators, one for each rear wheel.

Active Rear Axle Steering

ZF Friedrichshafen AG, also known as the ZF Group, has developed a 4WS system that is used by a few European manufacturers, such as Porsche, Audi, BMW, Mercedes-AMG, and Lamborghini. Porsche models, for example, use two different variations of this rear axle steering system. Basically the system relies on an electric motor that is controlled by a control module. The module receives inputs from a variety of sensors that monitor the current operating conditions, including the direction of the front wheels and vehicle speed. This is why it is called an active system. These are pure "by-wire" systems, there is no mechanical connection between the steering wheel and the motors.

One variation of the system relies on two small electromechanical actuators that change the rear wheel's toe angle. This system is used on the rear-engine RWD 911. With this dual-actuator system, each wheel is individually steered by a separate

actuator **(Figure 47–67)**. The motors inside the actuator assembly move each wheel slightly to the right or the left. The motors drive a belt that in turn drives a gear, which moves a tie rod attached to each wheel's spindle.

The other system, called a central actuator system is used in Porsche's Panamera. This system has one motor installed in the center of the rear axle which simultaneously turns both wheels by moving a tie rod attached to each wheel's spindle. The ultimate goal of this system is the same as the dual actuator system and most other 4WS systems.

FIGURE 47–67 A rear toe actuator for 4WS.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2007	**Make:** Chevy	**Model:** Cobalt	**Mileage:** 130,753	**RO:** 19357
Concern:	Customer states car darts to right or left after hitting a bump.			
The technician performs a test drive and notes several noises and that the car does bump steer. Back at the shop, he performs a visual inspection and a dry park check.				
Cause:	Found one broken sway bar link, a worn (loose) inner tie-rod and worn and rotted rack bushings. The worn tie-rod and rack bushings are allowing the rack to move and causing the bump steer.			
Correction:	Replace the rack bushings and inner tie-rod. Set wheel alignment to specifications. During test drive, bump steer did not occur.			

KEY TERMS

Bump steer
Center link
Idler arm
Pitman arm
Rack and pinion
Tie-rod

SUMMARY

- The components of a manual-steering system include the steering linkage, steering gear, and the steering column and wheel.
- The term *steering linkage* is applied to the system of pivots and connecting parts placed between the steering gear and the steering arms that are attached to the front wheels, controlling the direction of vehicle travel. The steering linkage transfers the motion of the steering gear output shaft to the steering arms, turning the wheels to maneuver the vehicle.
- Basic components of a parallelogram steering linkage system include the Pitman arm, idler arm, links, tie-rods, and, in some designs, a steering damper.
- The worm and roller steering components are basically the same as found in the parallelogram system.
- In rack and pinion steering linkage, steering input is received from a pinion gear attached to the steering column. This gear moves a toothed rack that is attached to the tie-rods that move the wheels.
- There are three types of manual steering gears in use today: recirculating ball, worm and roller, and rack and pinion.
- The steering wheel and column produce the necessary force to turn the steering gear.
- The power-steering unit is designed to reduce the amount of effort required to turn the steering wheel. It also reduces driver fatigue on long drives and makes it easier to steer the vehicle at slow road speeds, particularly during parking.
- There are several power-steering systems in use on passenger cars and light-duty trucks. The

most common ones are the integral, linkage, hydro-boost, and power-assisted rack and pinion systems.

- The major components of a conventional power-steering system are the steering linkage, power-steering pump, flow control and pressure relief valves, reservoir, spool valves and power pistons, hydraulic hose lines, and gearbox or assist assembly on the linkage.
- Electronic rack and pinion systems replace the hydraulic pump, hoses, and fluid associated with conventional power-steering systems with electronic controls and an electric motor located concentric to the rack itself.
- Four-wheel steering (4WS) advantages include cornering capability, steering response, straight-line stability, lane changing, and low-speed maneuverability.

REVIEW QUESTIONS

Short Answer

1. Describe how a rack and pinion steering, a parallelogram steering, and a worm and roller system operate.
2. A power-steering hose transmits fluid under pressure from the ___ to the ___ ___ ___.
3. Describe the operation of a power assisted recirculating ball gearbox.
4. Define the term *gearbox ratio*.
5. What are the benefits of four-wheel steering systems?
6. List the four main components in a parallelogram steering linkage and explain the purpose of each component.
7. What is the purpose of the spool valve in the power assisted rack and pinion?

Multiple Choice

1. In a rack and pinion steering system, what protects the rack from contamination?
   a. The inner tie-rod socket
   b. The outer tie-rod socket
   c. Grommets
   d. The bellows boot
2. The main job of the idler arm is to ___.
   a. support the left side of the center link
   b. support the right side of the center link
   c. support the Pitman arm
   d. keep both ends of the steering system level
3. Which of the following is *true* of electric power steering systems?
   a. The power assist motor can be integrated with the rack gear.
   b. The assist motor may be located in the steering column.
   c. The assist motor may drive the pinon gear.
   d. All of the above.
4. Rack and pinion steering ___.
   a. is lighter in weight and has fewer components than parallelogram steering
   b. does not provide as much feel for the road as parallelogram steering
   c. does not use tie-rods in the same fashion as parallelogram steering
   d. all of the above
5. If an electrical defect occurs in the electronic power-steering (EPS) system, ___.
   a. the system continues to operate normally, but the EPS warning light is illuminated
   b. the system continues to operate with a slightly reduced power-steering assist
   c. manual steering remains but there will not be any power assist
   d. the EPS control unit locks the armature in the steering gear to prevent armature and screw shaft damage
6. Wandering or poor straight-ahead tracking may be caused by all of the following *except* ___.
   a. worn or loose rack mounting bushings
   b. rack piston seal leaks
   c. off-center steering gear
   d. loose or worn tie-rod ends
7. A rack and pinion steering gear ___.
   a. has tie-rods that connect the rack directly to the steering arms
   b. is a gear in which the rack needs an idler arm to change the direction of the steering arms
   c. has inner tie-rod ends that are pressed onto the rack
   d. has more friction points compared to a parallelogram steering linkage
8. Which is the *least likely* cause of hard steering?
   a. Worn rack spool valve seals
   b. Insufficient drive belt tension
   c. Kinked power-steering pressure line
   d. Loose steering column U-joint

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that play in the steering gear is the probable cause of a shimmy. Technician B says that it could be loose steering linkage. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Technician A says that adjusting the steering gear too tightly can cause hard steering. Technician B says that adjusting the steering gear too tightly can cause poor returnability. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. An owner's concern indicates excessive play in the steering wheel: Technician A checks the steering shaft U-joints. Technician B performs a dry park check of the linkage. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. While discussing steering problems: Technician A says that a "jerky" steering wheel and a "clunking" noise could indicate worn steering column U-joints. Technician B says that lack of assist and a "growling" noise in a fluid-filled steering pump could indicate a hose or pump internal restriction. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. While discussing the fail-safe function: Technician A says that the 4WS indicator light is illuminated during the fail-safe function. Technician B says that the rear wheels continue to steer normally when the 4WS control unit enters the fail-safe mode. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. Technician A says that electronically controlled power-steering systems allow for power assistance even when an engine stalls. Technician B says that an electronic rack and pinion system provides power assistance even when the engine stalls. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. A vehicle has continual excessive steering effort, but there is no noise and the fluid level in the reservoir is correct: Technician A says that the cause of the problem could be a stuck flow control valve. Technician B says that the cause of the problem fluid bypassing around the rack and pinion flow control valve. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. While diagnosing a complaint of excessive play in the steering on a vehicle with power steering: Technician A says that the problem could be caused by air in the system. Technician B says that the problem could be caused by a worn steering shaft U-joint. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. While diagnosing the problems that can be caused by worn tie-rod ends: Technician A says that they can cause scalloped and scuffed tires. Technician B says that they can cause the vehicle to pull to one side. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. While diagnosing the cause of wheel shimmy: Technician A says that this problem can be caused by loose wheel bearings. Technician B says that this can be caused by binding steering column U-joints. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 48

RESTRAINT SYSTEMS: THEORY, DIAGNOSIS, AND SERVICE

OBJECTIVES

- Explain the difference between active and passive restraint systems.
- Know how to service and repair passive belt systems.
- Describe the function and operation of air bags.
- Identify the major parts of a typical air bag system.
- Safely disable and inspect an air bag assembly.
- Know how to diagnose and service an air bag system.
- Diagnose faults with restraint systems.

Safety is foremost in the minds of automobile manufacturers. According to a survey by the Insurance Institute for Highway Safety, occupant protection has emerged as a leading factor in determining which car people will buy. According to the institute, 68 percent of the households surveyed ranked the "degree to which the car protects people" as a very important purchase-decision factor.

Many safety features are now available as standard equipment or as options. Some of these standard features include side impact barriers, crumple zones in the body, seat belts, antilock brakes, traction control, stability control, and air bags **(Figure 48–1)**. There are many safety items that have been around for many years, such as laminated and tempered glass.

Common restraint systems—seat belts and air bags—are covered in this chapter. It is important for a technician to understand how

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2005	**Make:** Chrysler	**Model:** Sebring	**Mileage:** 153,471	**RO:** 19507
Concern:	Customer states air bag warning light stays on.			

Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.

FIGURE 48–1 A driver's air bag.

these systems work and how to diagnose and service them.

An **active restraint system** is one that a vehicle's occupant must make a manual effort to use **(Figure 48–2)**. For example, in most vehicles the passenger must fasten the seat belts for crash protection. A passive restraint system operates automatically **(Figure 48–3)**. No action is required of the occupant to make it functional.

Passive safety equipment includes the safety belt system, the air bags, the rigid occupant cell, and the crumple zones at the front of the vehicle. The rear and sides of the body are among the most important safety features of today's cars and are designed to dissipate most of the impact energy for the protection of vehicle occupants.

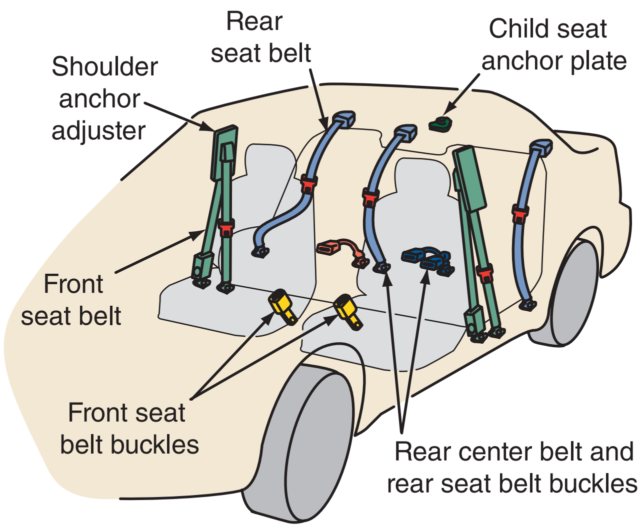


FIGURE 48–2 An active restraint system.

Seat Belts

A passive seat belt system uses electric motors to automatically move shoulder belts across the driver and front seat passenger. The upper end of the belt is attached to a carrier that moves in a track at the top of the doorframe. The other end is secured to an inertia lock retractor mounted to the center console. When the door is opened, the outer end of the shoulder belt moves forward to allow for easy entry or exit. When the doors are closed and the ignition is turned on, the belts move rearward and secure the occupants. The active lap belt is manually fastened and should be worn with the passive belt.

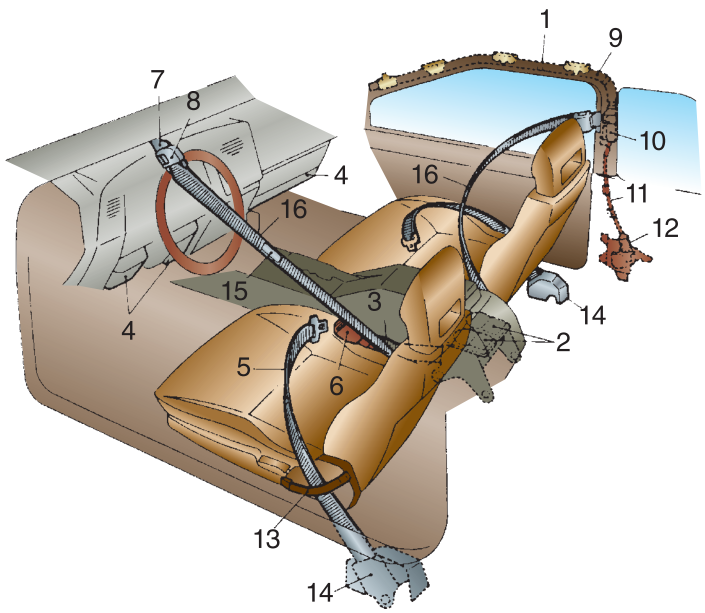
Most vehicles have two active belts. One is a lap belt that goes across the occupant's lap; the other is a shoulder belt that goes across the shoulder and chest. The two belts join together at a single point where they are inserted into a buckle anchored to the vehicle's floor.

If a seat belt will not buckle, use a flashlight and look inside the buckle. Often something is inside the buckle that can be safely removed. It does not take much to hamper the operation of the buckle. In most cases, the buckle should be replaced if something is lodged inside.

Seat Belt Retractors

When unbuckled, seat belts are stowed away by the seat belt retractors **(Figure 48–4)**. The retractors may also work as pretensioners to take up the belt's slack during an accident to limit the forward movement of the occupant's body. Inertia lock retractors **(Figure 48–5)** prevent the belt from coming out of the retractor when there is a sudden pull on the belt. Some vehicles have electric or pyrotechnic-type pretensioners. Both of these are designed to quickly tighten the belt at the start of a crash.

Pyrotechnic pretensioners are the most common **(Figure 48–6)**. When the pretensioner receives a signal from the control module, the pretensioner is ignited. There is a small explosion in the pretensioner that reverses its action. This puts a firm hold on the passenger. Many of these systems also



1 Rail and motor assembly
2 Emergency locking retractor assembly
3 Belt guide
4 Knee panel
5 Outer bell assembly (manual tap belt)
6 Inner belt assembly (manual lap belt)
7 Shoulder anchor
6 Emergency release buckle
9 Rail
10 Locking device
11 Tube
12 Motor
13 Belt holder
14 Emergency locking retractor assembly (manual lap belt)
15 Caution label
16 Shoulder belt

FIGURE 48-3 A passive restraint system.

FIGURE 48-4 A seat belt retractor.

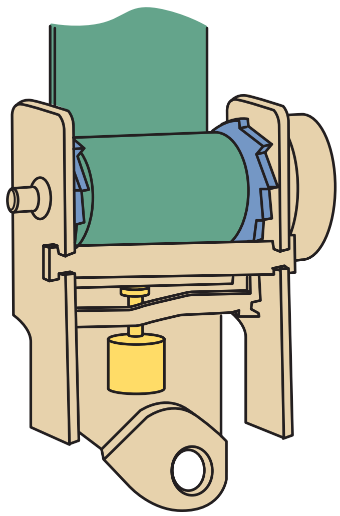


FIGURE 48-5 An inertia lock seat belt retractor.

have a mechanism that releases the pressure on the seat belt after it has been tightened by the pretensioner. When the pressure between the passenger's chest and the seat belt exceeds a particular point, the pressure on the seat belt is relaxed to prevent injury.

On some vehicles, the action of the pretensioners varies with the weight of the person in the seat and the amount of force on the seat belt as that person is moving forward during an impact. Some vehicles are equipped with two-stage belt force limiters.

FIGURE 48–6 A buckle-mounted pretensioner.

Warning Lights

All modern seat belt systems have a warning lamp and a buzzer or chime that is turned on when the vehicle is started to remind the occupants to buckle up. When the ignition is turned on, a signal is sent to the warning lamp **(Figure 48–7)**. If the seat belt is fastened, a signal is sent from the buckle switch to the indicator controller and the lamp turns off. If the belt is not buckled, the indicator and buzzer will alert the driver in intervals. There is a sensor in the front passenger seat that detects when someone is in the seat. This information is sent to the control module and the indicator lamp will blink until the seat belt is fastened.

Seat Belt Service

Inspecting seat belt systems should follow a systematic approach. Always take as much time as necessary to do your inspection. Remember that seat belts are designed to protect people.

Webbing Inspection

Pay special attention to where the webbing contacts maximum stress points, such as the buckle, D-ring,

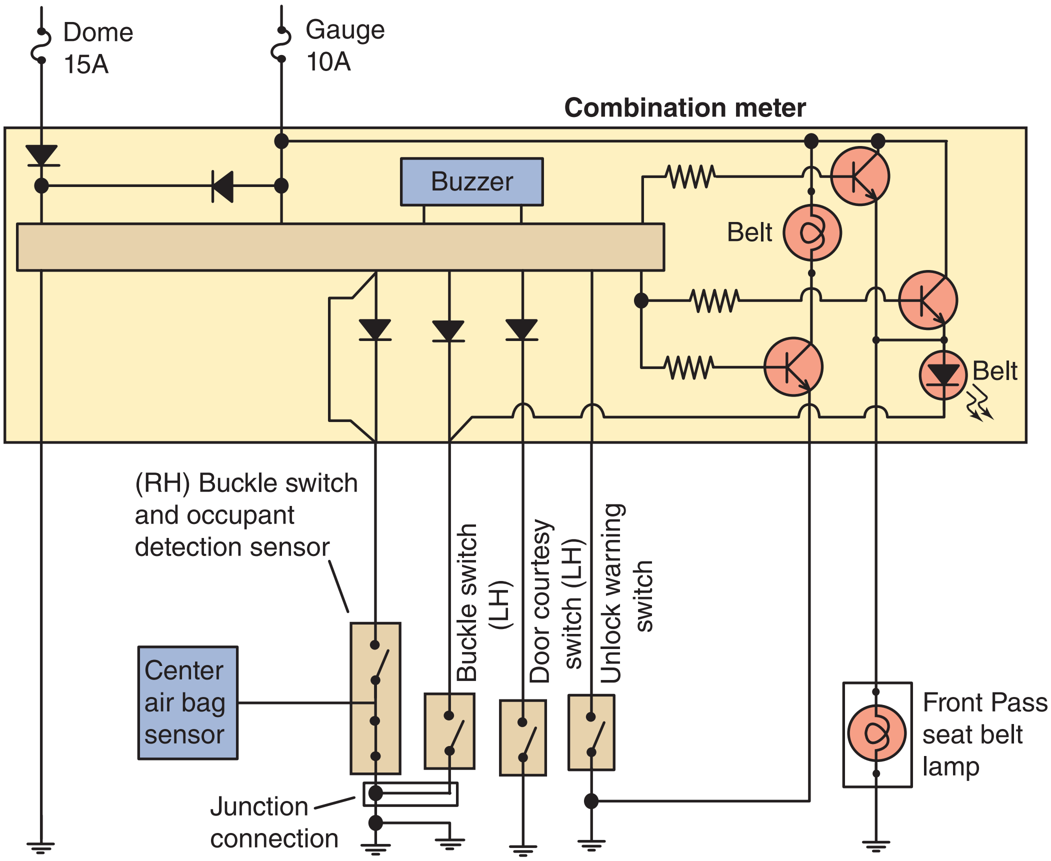


FIGURE 48–7 A wiring diagram for the seat belt warning and key reminder indicators.

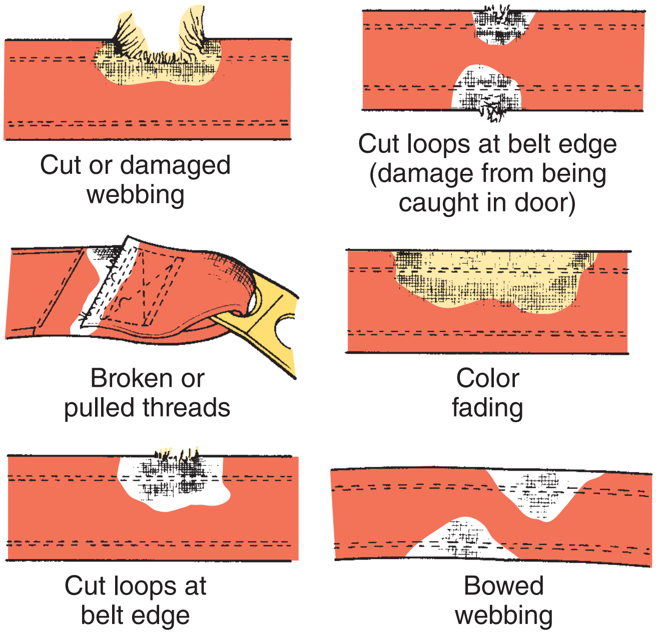


FIGURE 48–8 Examples of webbing defects.

and retractor. Collision forces center on these locations and can weaken the belt. Signs of damage at these points require belt replacement. Check for twisted webbing due to improper alignment when connecting the buckle. Fully extend the webbing from the retractor. Inspect the webbing and replace it with a new assembly if the following conditions are noted **(Figure 48–8)**: cut or damaged webbing, broken or pulled threads, cut loops at the belt edge, color fading as a result of exposure to sun or chemical agents, or bowed webbing.

If the webbing cannot be pulled out of the retractor or will not retract to the stowed position, check for the following conditions and clean or correct as necessary: webbing soiled with gum, syrup, grease, or other material; twisted webbing; or the retractor or loop on the B-pillar out of position.

Buckle Inspection

To determine if the buckle works or if the buckle housing has been damaged, insert the seat belt into the buckle until a click is heard. Pull back on the webbing quickly to ensure that the buckle is latched properly. Replace the seat belt assembly if the buckle does not latch. Depress the button on the buckle to release the belt. The belt should release with a pressure of approximately 2 pounds. Replace the seat belt assembly if the buckle cover is cracked, the push button is loose, or the pressure required to release the button is too high.

Retractor Inspection

Retractors for lap belts should lock automatically once the belt is fully out. Either webbing-sensitive or vehicle-sensitive seat belt retractors are used with passive seat belt systems. Webbing-sensitive retractors can be tested by grasping the seat belt and jerking it. The retractor should lock up; if it does not, replace the seat belt retractor.

Vehicle-sensitive belt retractors will not lock up using the same procedure. To test these belts, a braking test is required. Perform this test in a safe place. A helper is required to check the retractors on the passenger side and in the back if the vehicle is equipped with rear lap/shoulder belts.

Test each belt by driving the car at 5 to 8 mph and quickly applying the brakes. If a belt does not lock up, replace the seat belt assembly. During this test, it is important for the driver and helper to brace themselves in the event the retractor does not lock up.

Most retractors are not interchangeable. That is, an R marked on the retractor tab indicates that it is for the right side only, and an L should be used on the left side only.

Anchor Inspection

Carefully inspect the anchor areas and attaching bolts for the retractors. A buildup of dirt in the anchors can cause the seat belts to retract slowly. Wipe the inside of the loops with a clean cloth dampened in isopropyl alcohol. Loose bolts should be replaced and the new bolts tightened to specifications. Look for cracks and distortion in the metal at the anchor points. If there is damage to the metal in the mounting area, proper repairs, such as welding in reinforcement metal, must be completed before reattaching the anchor. Be sure to restore corrosion protection to the area. When spraying anticorrosion materials, make sure they do not enter the retractor. This can keep it from operating properly. Finally, look for dirt and corrosion around the anchor area.

Pretensioners should be replaced if a collision caused the air bags to deploy. They are explosive devices and good for one-time use.

SHOP TALK Never bleach or dye the belt webbing. Clean it with a mild soap solution and water.

Caution! Never measure the resistance of a seat belt pretensioner. The voltage from the meter may accidentally ignite the pretensioner. This can result in serious personal injury.

Drive Track Assembly

Passive systems have a drive motor usually located at the base of the track assembly behind the rear seat side trim panel. The motor pulls the tape that positions the belt. If the motor is faulty, replace it. To service a motorized seat belt system, follow the instructions given in the service information.

Rear Seat Restraint System

Rear seat belts are inspected in the same way as the front. However, some vehicles have a center seat belt. These belts do not have a retractor. Check the webbing, anchors, and the adjustable locking slide for the belt. Fasten the tongue to the buckle and adjust by pulling the webbing end at a right angle to the connector and buckle. Release the webbing and pull upward on the connector and buckle. If the slide lock does not hold, remove and replace that seat belt assembly.

Warning Light and Sound Systems

When the ignition is turned to the on or run position, the Fasten Seat Belt light should come on. There should also be a buzzer or chime. If these warning light and sound systems do not come on, check for a blown fuse or circuit breaker. If that checks out fine, and there is sound but no light, check for a damaged or burned-out bulb. If the bulb lights but there is no sound, check for damaged or loose wiring, switches, or buzzer (voice module).

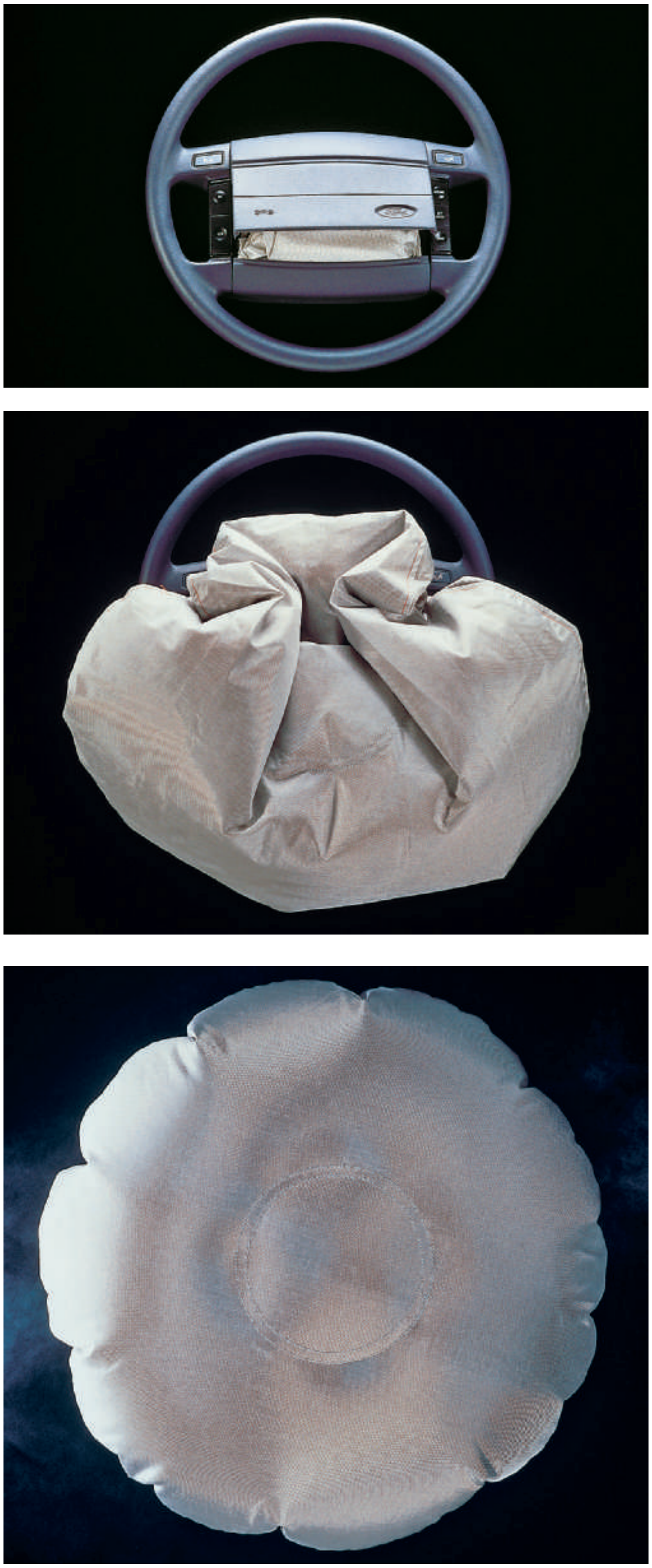
Service Guidelines

Some guidelines for servicing lap and shoulder belts follow:

- Replace the seat belt with a new assembly if there is any abnormality.
- Never disassemble any part of the seat belt system.
- Never attempt repairs on lap or shoulder belt retractors or retractor covers. Replace them if necessary.
- Tighten all anchor bolts to specifications.

Air Bags

An air bag is much like a nylon balloon that quickly inflates to stop the forward movement of the occupant's upper body during a collision. Air bags are designed to be used *with* seat belts, not replace them. If there is a collision, an air bag takes less than 1 second to protect the driver and/or passengers **(Figure 48–9)**. Consider this sequence:



Courtesy of TRW, Incorporated.

FIGURE 48–9 Various stages of air bag inflation.

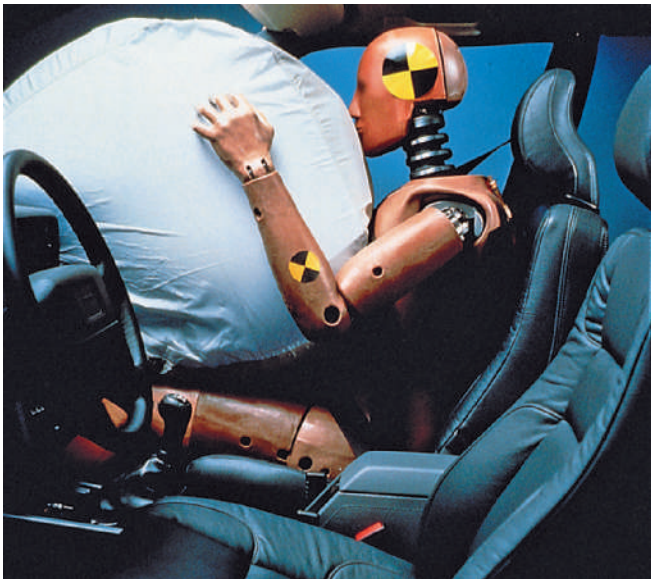
- Time zero—Impact begins and the air bag system is doing nothing.
- Twenty milliseconds later—The sensors are sending an impact signal to the air bag module and the air bag begins to inflate.

- Three milliseconds later (total time from impact is now 23 milliseconds)—The air bag is inflated and is up against the occupant's chest. The occupant's body has not yet begun to move as a result of the impact.
- Seventeen milliseconds later (total time from impact is now 40 milliseconds)—The air bag is almost fully deployed and the occupant's body begins to move forward because of the impact.
- Thirty milliseconds later (total time from impact is just 70 milliseconds)—The air bag begins to absorb the forward movement of the occupant and the air bag begins to deflate through its vents. Once the air bag deflates, its job is over.

The systems and parts used to deploy an air bag vary with the year and manufacturer of the vehicle, as well as the locations of the air bags. An air bag is inflated or deployed by rapid expansion (explosion) of a gas. The gas is fired by an igniter commonly called a **squib**.

Different manufacturers also call their air bag systems by different names, such as **supplemental inflatable restraint (SIR)** and **supplemental restraint system (SRS)**. All late-model vehicles have a driver-side and a passenger-side air bag **(Figure 48–10)**. Most late-model vehicles have side impact, knee, and curtain air bags as well.

Passenger-side air bag modules are located in the vehicle's dash. These air bags are very similar in design and operation to those on the driver's side. However, many manufacturers use a different set of sensors. The actual capacity of gas required to inflate the passenger-side air bag is much greater because the bag must span the extra distance between the occupant and the dashboard. The steering wheel and column make up this difference on the driver's side.



Courtesy of Volvo Cars of North America.

FIGURE 48–10 A passenger air bag.

A driver-side and passenger-side air bag system may include a knee diverter, also called a knee bolster. This unit is designed to help restrain the lower parts of the bodies of the driver and front passenger and prevent the driver from sliding under the air bag during a collision. It is located underneath the steering column and behind the steering column trim. In 2015, Ford introduced a new passenger knee airbag design. This new airbag has an inflatable, molded plastic bladder that is wedged between the inner and outer glove compartment door panels. When a collision occurs, the bladder inflates to fill the space between the dash and the passenger's lower legs. This action reduces the movement of the passenger's pelvic area and back, thereby reducing the load on the pelvis area.

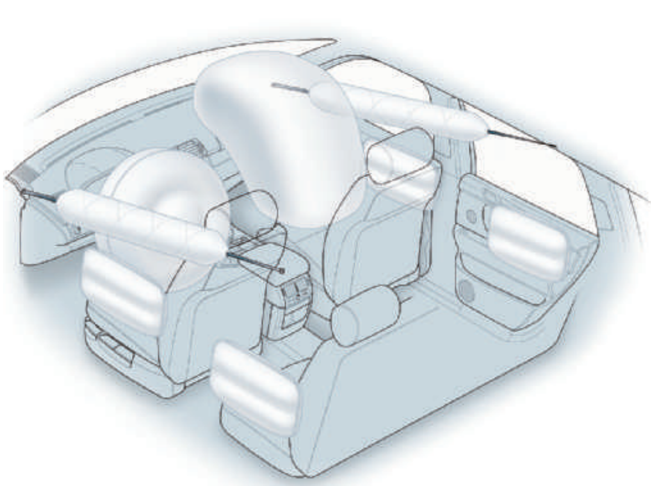
Some vehicles have front and rear seat cushion air bags that inflate the front of the seat cushion to restrain the occupant's lower hip. This helps dampen the impact energy that acts on the occupant's upper body, including the head and chest.

Because of the concern for babies and small children, pickups and other two-seat vehicles either do not have a passenger-side SIR or have a switch that prevents it from deploying. The switch is typically operated with a key to activate or deactivate the SIR. On some vehicles, the passenger air bag is turned on and off through the driver information center. An indicator light in the instrument panel shows the current status of the passenger-side SIR.

Side Air Bags

On many vehicles the occupants may be further protected by side air bags and/or side curtain air bags **(Figure 48–11)**. The rear passengers may be protected by air bags in the rear of the front seat backs, side air bags, and/or the side curtain air bags.

Side air bags can take on many different shapes and are deployed from various locations. Side curtains



Courtesy of BMW of North America, Inc.

FIGURE 48–11 This vehicle has a total of eight air bags.

FIGURE 48–12 A side curtain protecting the passengers inside this vehicle.

Courtesy of BMW of North America, Inc.

FIGURE 48–14 A side impact head air bag.

(Figure 48–12) blanket the entire side of the car. Side air bags **(Figure 48–13)** are available for the front and rear doors on some cars. These air bags are deployed from the interior trim on the door or from the outside of the seat. Curtain air bags are located inside the headliner and extend from the driver's and front passenger's front pillars to the rear pillars behind the rear seat. Each air bag is a one-piece unit.

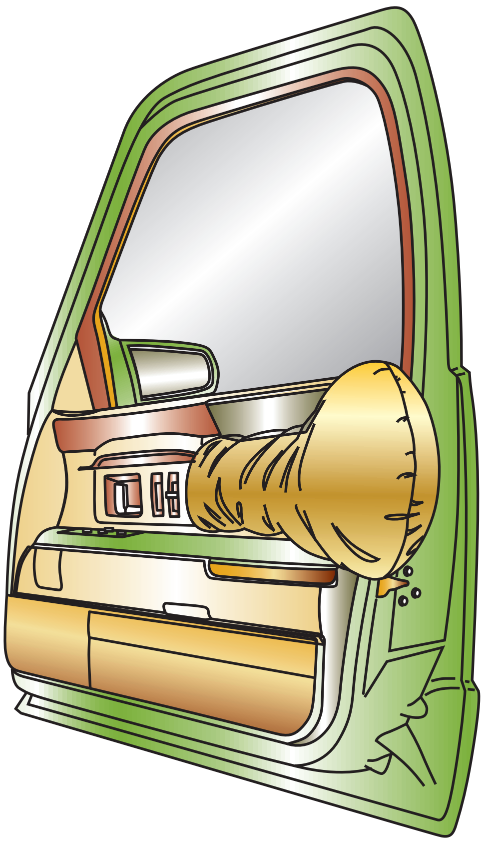


FIGURE 48–13 A side air bag.

Side head protection systems inflate a long, narrow air bag that extends from the windshield area to the back of the front seat **(Figure 48–14)**.

When a side impact air bag is deployed: the front side, rear side, and curtain shield air bags are deployed at the same time. Door-mounted side air bags must begin deploying in 5 to 6 milliseconds. This requirement is based on the fact that only a few inches separate the occupant from the other vehicle during a side impact. Seat-back-mounted side air bags do not need to operate at these great speeds. The head air bag is designed to stay inflated for about 5 seconds to offer protection against a second or third impact.

Current air bag systems work in conjunction with the seat belt pretensioners and retractors. When the air bag circuit is turned on, so is the pretensioner circuit. These actions limit the movement of the occupants.

Inflatable Seat Belts

An inflatable seat belt can control the movement of a passenger's head and neck during a crash. This inflatable belt spreads the crash forces over more of the body than a standard belt. The shoulder strap contains a folded, cylindrical air bag that is deployed during a collision **(Figure 48–15)**. These belts are found in the rear seats of a few SUVs and some cars. They are designed to protect the fragile bones of passengers, especially older adults and children, who are very vulnerable to chest, head, and neck injuries.

Front Center Air Bags

In 2013, General Motors introduced a front center airbag on some models. This tubular airbag deploys

FIGURE 48–15 An inflatable shoulder harness, which controls a person's forward movement when the seat belt tightens during a collision.

from the right side of the driver's seat and fills the void between the front seats near the center of the vehicle. This airbag is designed to offer some restraint during passenger-side crashes when the driver is alone, it also acts as an energy-absorbing cushion between driver and front passenger in both driver- and passenger-side crashes.

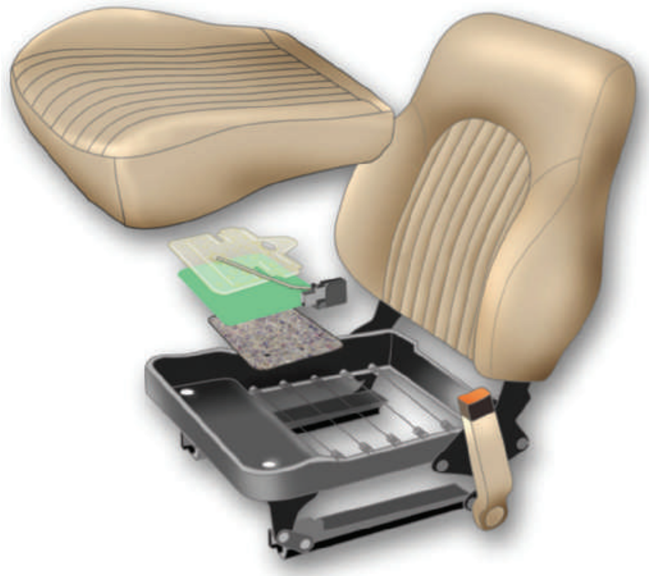
Second-Generation Air Bags

Newer vehicles are equipped with second-generation air bags that inflate with less force than earlier air bags. The air bags are depowered by reducing the peak inflation pressure and/or the force and speed at which an air bag inflates. These systems reduce the number of injuries caused by the air bag itself. Depending on the specific model vehicle, air bag size, and seat belt system, a second-generation air bag inflates with an average of 20 percent to 35 percent less energy.

Adaptive SRS Systems

All 2006 and newer vehicles must have a system that allows for air bag suppression when infants, children, or small adults are in the front passenger seat. This system uses a load sensor, seat belt tension sensor, and an electronic control unit **(Figure 48–16)**. The load sensor measures the weight on the seat and classifies the occupant as an adult or child and provides the classification to the air bag controller, which enables or suppresses passenger air bag deployment. A belt tension sensor identifies cinched child seats.

Newer vehicles have "**smart**" or **adaptive air bags**. Many of these systems have two possible stages of air bag deployment. The force of the expanding air bag is controlled to match the severity of the impact and/or by the size and weight of the seat's occupant **(Figure 48–17)**. Other things considered are seat-track position and seat belt use. All of these factors require different deployment rates.



Courtesy of Delphi Corporation.

FIGURE 48–16 An occupant detection system with a seat belt tension sensor.

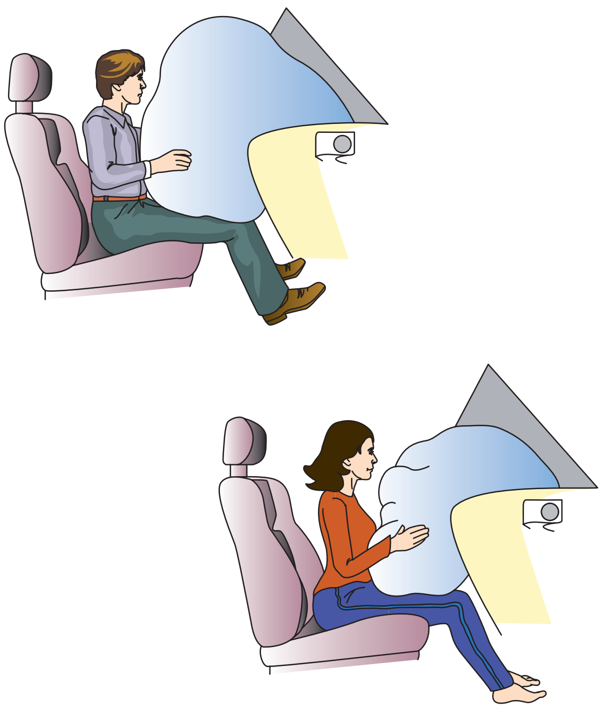


FIGURE 48–17 (Top) Full strength air bag deployment because of the weight of the occupant. (Bottom) Reduced air bag deployment because of the weight of the occupant.

Two-stage air bags have one air bag, two containers of gas, and two squibs. When low-pressure deployment is desired, only one squib is fired. Depending on the system, the second stage may fire just after the first, providing a longer inflation time with less force. A severe collision can fire both igniters simultaneously. The air bag sensor assembly calculates the extent of impact, seat position, and status of the seat belts and controls the inflation times for the two chambers.

Mechanical Air Bag Systems

Mechanical air bag systems are found in some vehicles (early Toyotas, Volvos, and Jaguars). These systems are totally independent systems and do not rely on electricity or electronics to deploy. They have a mechanical trigger that ignites the propellant to deploy the air bag. The trigger is an impact sensor with a firing pin. During an impact, the firing pin moves and ignites a primer that ignites sodium azide pellets inside a gas generator. The gases released by the burning pellets inflate the air bag. This type of system is often used to equip a vehicle with air bags when it was not originally fitted with them.

Mechanical air bag systems can be used at any location in the vehicle. The number of gas generators used in each type of air bag depends on the size of the air bag. For example, a side impact air bag may have two generators and a side curtain can have as many as eight generators.

Electrical System Components

The electrical circuit of an air bag system includes impact sensors and an electronic control module. The electrical system conducts a system self-check to let the driver know that it is functioning properly, records DTCs for technician use, detects an impact, and sends a signal to deploy the air bags.

A vehicle can contain many different air bag modules **(Figure 48–18)**. The driver-side, passenger-side, side, and curtain air bag modules each has an inflator (igniter), air bag, and an ignition unit (cracker, igniter charger, gas). When the sensors send a signal to the module, current flows into the inflator and activates the ignition material to deploy the air bag.

To prevent accidental deployment, most systems require that at least two sensor switches be closed before an air bag is deployed **(Figure 48–19)**. The number of sensors used in a system depends on the design of the system. Normally, sensors are located in the engine and passenger compartments.

Sensors

Typically, ignition of the air bag only occurs when an outside (impact or crash) sensor and an inside (safing or arming) sensor are closed. Once the two sensors are closed, the electrical circuit to the igniter is complete.

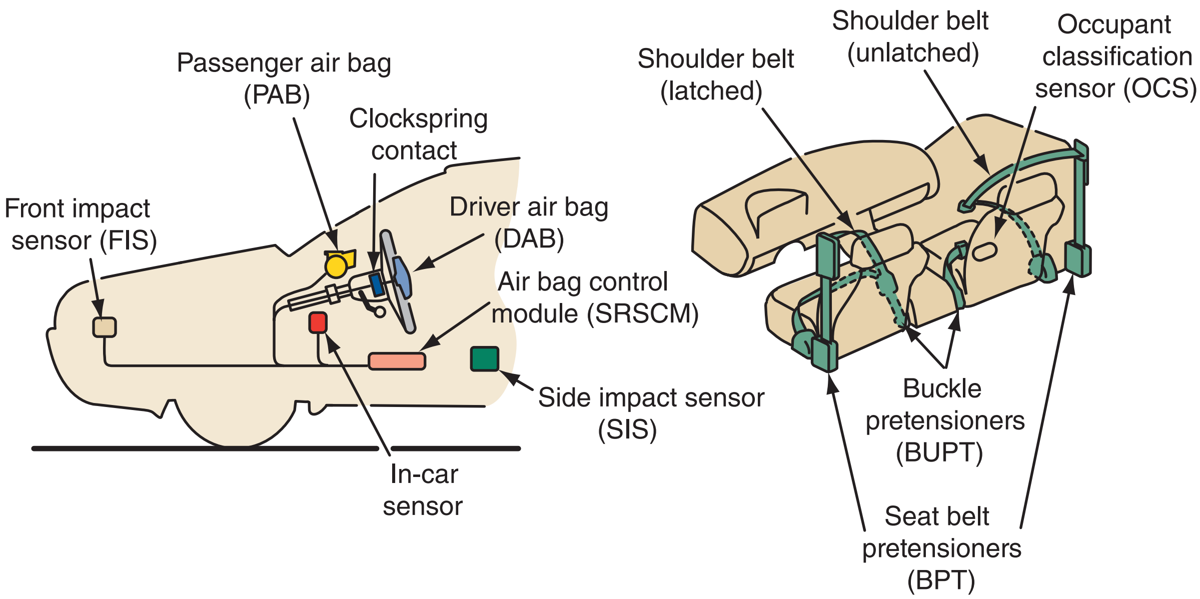


FIGURE 48–18 Location of common SRS components.

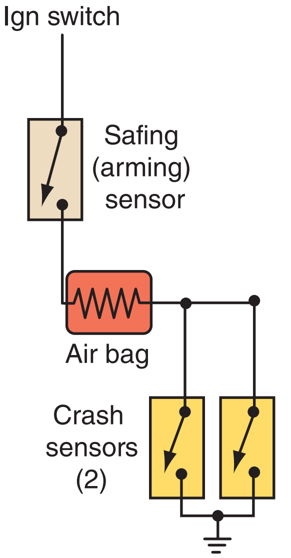


FIGURE 48–19 A simple air bag circuit with sensors.

Impact—Safing Sensors There are three basic types of safing sensors:

Roller-Type. These have a roller located on a ramp **(Figure 48–20)**. One terminal of the sensor is connected to the ramp. The other terminal is connected to a spring contact extending through an opening in the ramp but not touching the ramp. Small springs hold the roller against a stop. During a heavy impact, the roller moves up the ramp and strikes the spring contact. This completes the circuit between the ramp and the spring, and the air bag deploys.

Mass-Type. This sensor has a normally open set of gold-plated switch contacts and ball. The ball is the sensing mass and is held in place by a magnet **(Figure 48–21)**. When there is sufficient force, the ball breaks loose and makes contact with the electrical contacts to complete the circuit. Other similar systems rely on a mass-type sensor that has a pivoted weight connected to a movable contact that completes the circuit when moved.

Accelerometer. This is a piezoelectric element that is distorted during a collision **(Figure 48–22)**. It generates an analog voltage that reflects the strength of the deceleration forces.

Seat Position Sensor The seat position sensor is mounted on the inner rail of the front seats **(Figure 48–23)**. The sensor is basically a magnet and a Hall-effect switch. The sensor is used to detect when the seat is in the forward position. When the seat is in a rearward position, the rail is close to the seat position

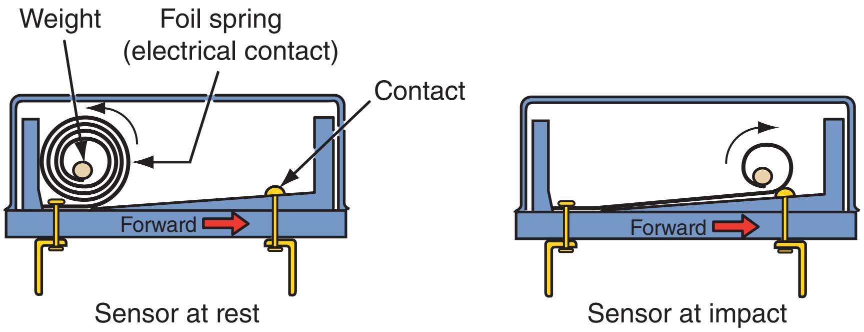


FIGURE 48–20 A roller-type air bag sensor.

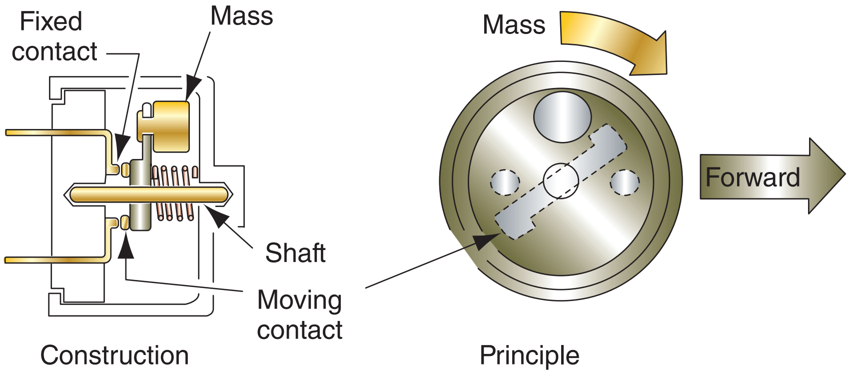


FIGURE 48–21 A mass-type sensor with a pivoted weight connected to a movable contact.

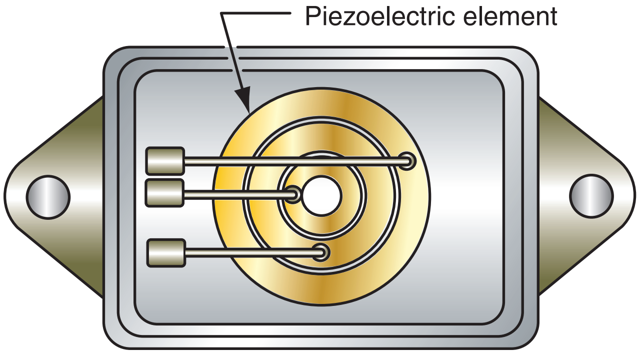


FIGURE 48–22 An accelerometer air bag sensor.

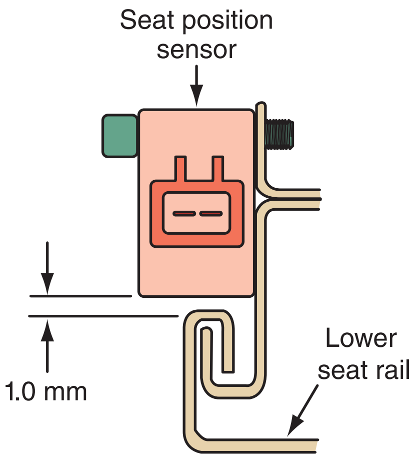


FIGURE 48–23 The seat position sensor has a specified gap between the sensor and the lower seat rail.

sensor. When it is in the forward position, the distance between the rail and the sensor becomes larger. The position of the rail in relation to the Hall-effect switch determines the signal the sensor sends to the air bag sensor assembly. When the seat is close to the steering wheel, the air bag deploys with less pressure.

Seat Belt Buckle Switch The seat belt buckle switch detects whether or not the seat belt is fastened. It also is a Hall-effect switch and magnet. The magnetic field changes as the seat belt is fastened and unfastened. The SRS system adjusts the force of the air bags according to this input.

Occupant Classification Sensor

To determine the force of the front and side passenger air bags, the weight of the occupant is measured. If there is no occupant, the air bags will not deploy during a collision. Most passenger occupant classification sensors use a bladder placed beneath the seat cushion. The bladder is connected to a pressure sensor that sends a signal to the control unit for the air bags. The bladder is a silicone-filled gel mat. When there is weight on the seat cushion, pressure is applied to the silicone in the mat. The pressure sensor measures that pressure and converts it to voltage signals **(Figure 48–24)**.

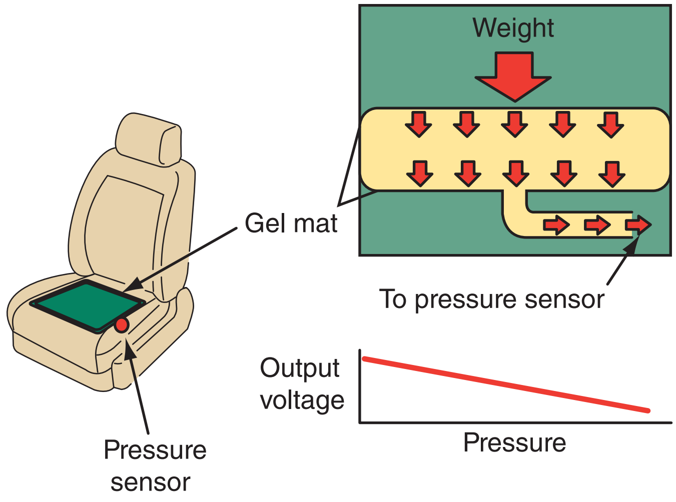


FIGURE 48–24 A gel mat-type occupant classification sensor.

Other occupant classification sensors are made up of two sheets of electrodes separated by a spacer. Weight on the seat causes the electrodes to contact each other through a hole in the spacer. The weight on the seat determines the contact area of the sheets. The amount of conductance between the sheets is used to determine weight.

The occupant classification sensor, seat belt tension sensor, and seat belt buckle switch send signals to the control unit. The control unit then determines if the seat is occupied, and if the seat is occupied by an adult, a child, or a child in a booster seat. The latter is detected by the seat belt tension sensor. When a child seat is sitting on the seat cushion, seat belt tension pulls the child seat down, adding pressure to the seat cushion. This pressure, plus the weight of the child and the child seat, is sensed by the weight detection sensor.

Diagnostic Monitor Assembly The air bag sensing diagnostic monitor (ASDM) constantly monitors the readiness of the SIR electrical system. If the module determines there is a fault, it will illuminate the warning lamp. Depending on the fault, the SIR system may be disarmed until the fault is corrected.

The diagnostic module also supplies back-up power to the air bag module in the event that the battery or cables are damaged during the accident. The stored charge can last up to 30 minutes after the battery has been disconnected.

Warning! The back-up power supply must be depleted before any air bag service is performed. To deplete this back-up power, refer to the service information. This may require removing fuses or disconnecting the battery and waiting for at least 30 minutes.

Wiring Harness

For identification and safety purposes, the electrical harnesses of the SIR system typically have yellow connectors. Each connector has a special function and is designed specifically for the SRS. To increase their reliability, all SRS connectors have durable gold-plated terminals and are placed in specific locations. The connectors also have a shorting bar, called an activation prevention mechanism, that prevents accidental deployment while being serviced.

Single-stage air bags have one inflator and one pair of wires that connect to the air bag module. Two-stage air bags have two inflators and two pairs of wires connected to the air bag module.

Clockspring The **clockspring** allows for electrical contact to the air bag module at all times. Since the air bag module sits in the center of the steering wheel, the clockspring is designed to provide voltage to the module regardless of steering wheel position. The clockspring is located between the steering wheel and the steering column **(Figure 48–25)**.

The clockspring's electrical connector contains a long conductive ribbon. The wires from the air bag's electrical system are connected from the underside of the clockspring to the conductive ribbon. The other end of the ribbon is connected to the air bag module. When the steering wheel is turned, the ribbon coils and uncoils without breaking the electrical connection.

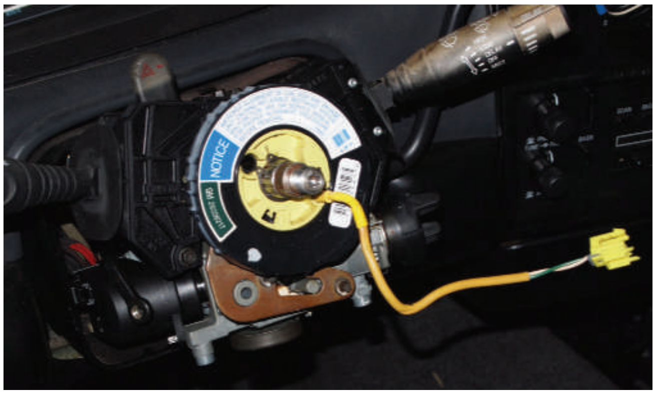


FIGURE 48–25 A clockspring.

SIR or Air Bag Readiness Light This light lets the driver know the air bag system is ready to do its job. The warning lamp is operated by the diagnostic module. The readiness lamp lights briefly when the driver turns the ignition key from off to run. The lamp should go out once the engine is running. A malfunction in the air bag system causes the light to stay on continuously or to flash. Some systems have a tone generator that sounds if there is a problem in the system or if the readiness light is not functioning.

Vehicles with side impact air bags have a light that informs the driver if the side impact bags are turned off **(Figure 48–26)**. This is common when objects, such as boxes or packages are placed on the passenger seat. The occupant detection system determines the weight is not a person and turns off the side impact airbags.

Air Bag Module

The air bag module is the air bag and inflator assembly packaged into a single unit or module. The module is located in the steering wheel for the driver and in the dash panel for the front-seat passenger **(Figure 48–27)**. The various types of side protection

FIGURE 48–26 An example of a side impact air bag indicator light.

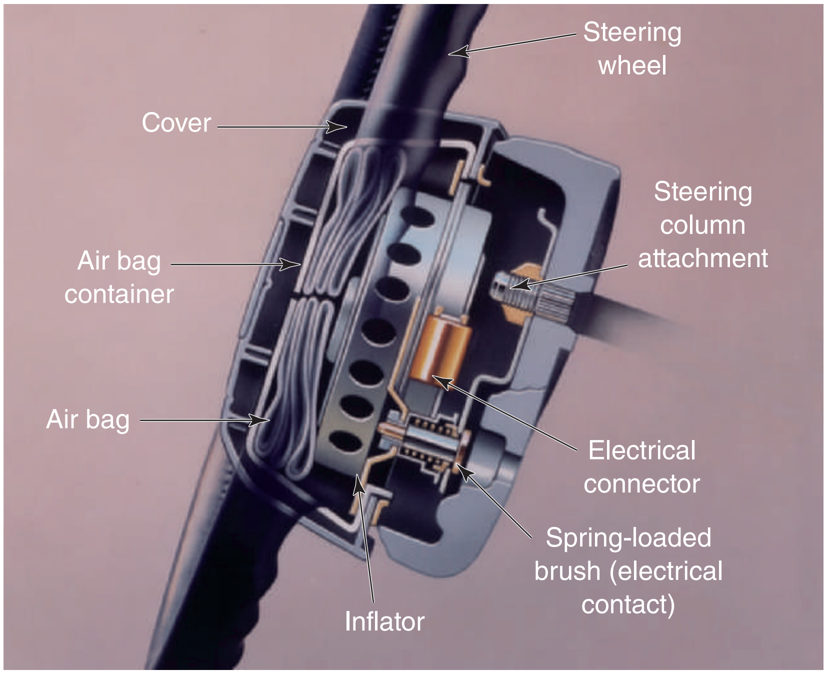


FIGURE 48–27 A cutaway view of an air bag module.

air bags have the module located at the point where the bag is deployed.

The inflation of the air bag is typically accomplished through an explosive release of nitrogen gas. The igniter **(Figure 48–28)** is an integral part of the inflator assembly. It starts a chemical reaction to inflate the air bag. At the center of the igniter assembly is the squib, which contains **zeronic potassium perchlorate (ZPP)**. When voltage is supplied through the squib, an electrical arc is formed between two pins. The spark ignites the gas generator and causes a rapid expansion of the gas, which deploys, or inflates, the air bag.

The inflation assembly is composed of a gas generator (called a generant) containing sodium azide and copper oxide or potassium nitrate propellant. The ZPP ignites the propellant charge. During ignition, large quantities of hot, expanding nitrogen gas are produced very quickly and quickly inflate the air bag. As the nitrogen moves into the air bag, it is filtered to remove sodium hydroxide dust formed during the chemical reaction.

Caution! **Wear gloves and eye protection when handling a deployed air bag module. Sodium hydroxide residue may remain on the bag and cause a skin irritation.**

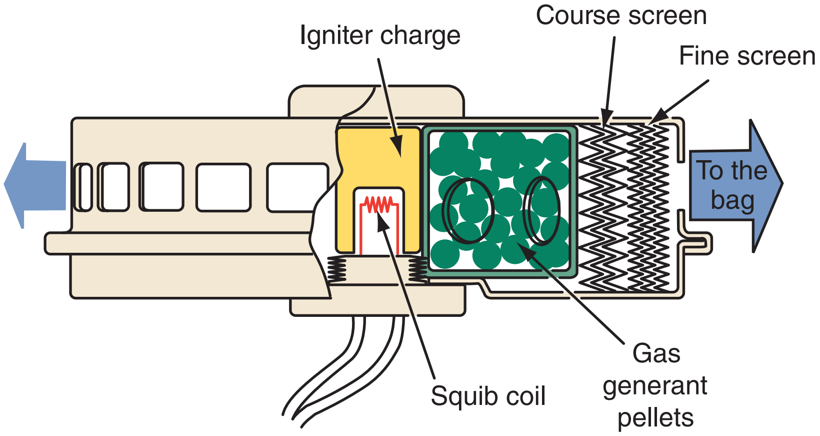


FIGURE 48–28 The action of an air bag module releasing nitrogen gas to an air bag.

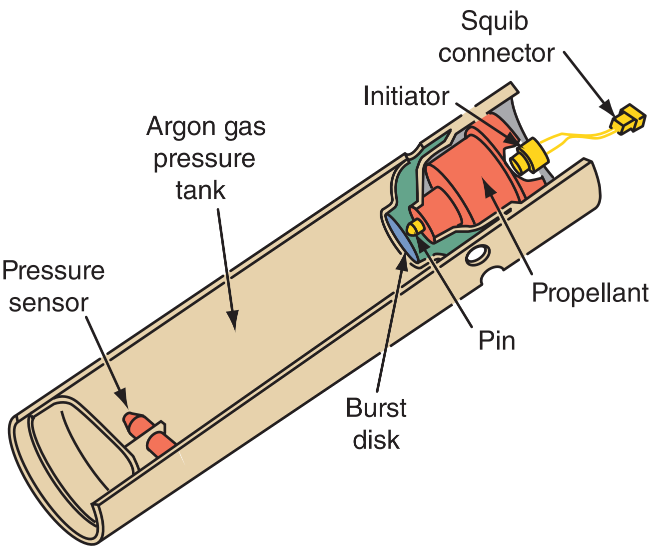


FIGURE 48–29 An inflator module that uses argon gas.

Not all air bags use nitrogen gas to inflate the bag; some use a solid propellant and compressed argon gas **(Figure 48–29)**. Argon has a stable structure, cools more quickly, and is inert as well as nontoxic. Argon is commonly used for passenger-side and side protection air bags.

A mounting plate and retainer ring attach the air bag assembly to the inflator. They also keep the entire air bag module connected to the steering wheel.

The bag itself is made of a thin, nylon fabric that is folded into the steering wheel, dash, seat, or door. The powdery substance released from the air bag when it is deployed is regular cornstarch or talcum powder. These powders are used by the air bag manufacturers to keep air bags lubricated and pliable while they are in storage. The entire module must be replaced as one unit when repair of the air bag system is required.

Diagnosis

Before diagnosing the system, perform a system check by observing the air bag warning light and comparing your findings with those described in the service information for the vehicle. To check the status of the air bag system, make sure the ignition has been off for at least 2 seconds. Then turn the ignition on. The SRS warning lamp should turn on and remain on for about 6 seconds. During this time, the system is performing a preliminary check of the system, including the pretensioners.

If the system detects a problem, the SRS warning light will remain on. If the lamp flashes or turns off and then turns on again, low source voltage may be indicated. A system problem is also indicated when the lamp does not come on when the ignition is initially turned on.

If any of these conditions are present, the system needs to be checked. Begin diagnosis by connecting a scan tool and attempting to communicate with the air bag system. On some older systems, the air bag light displays flash codes by blinking the fault light once a diagnostic connected is shorted. Testing should also include a thorough visual inspection of system components when diagnosing a system that is disarmed because of a fault. Damage from a collision or mishandling during a nonrelated repair can set up a fault area, which will disarm the air bag system.

The passenger air bag indicator should also be observed. Its display is an indication of the condition of the passenger weight sensor as well as the air bag's modules. Always refer to the service information to interpret the indicators. Normal displays will vary with what is detected in the passenger seat. If a problem is detected, the SRS warning lamp will be lit, as will the passenger air bag "OFF" indicator.

If the action of the warning lamp indicates a problem, the system should be checked for DTCs. If there is a problem in the passenger side, check the DTCs in the air bag system first. Then check the occupant classification system.

Retrieving Trouble Codes

If the system detects a problem in the SRS system, the malfunction data will be stored in memory and the warning indicator will be lit. Normally two types of faults are stored. Active DTCs will turn the air bag warning lamp on, whereas stored codes are intermittent problems and probably will not turn on the warning lamp.

SRS problems are difficult to verify; therefore, DTCs are extremely important for troubleshooting the system. Most systems have two- and five-digit DTCs. The two-digit codes are flash codes displayed with the SRS warning indicator. The five-digit codes are displayed on a scan tool. It is important to note that when the negative battery cable is disconnected, the system's memory is erased. Therefore, DTCs should be retrieved before disconnecting the battery.

Flash Codes On vehicles that display codes with the warning light or on the digital instrument panel, make sure you follow the procedure prescribed by the manufacturer to retrieve the codes. Normally a jumper wire is connected across two terminals in the DLC with the ignition switch on. Make sure the wire

is connected correctly and does not contact other pins in the connector. Once the jumper is in place, observe the action of the SRS warning lamp. Count the blinks and refer to the manufacturer's code table to interpret the code. If there is more than one stored DTC, the second code will flash shortly after the first code is displayed. In most cases, the codes will be erased when the ignition is turned off.

Scan Tool DTC Retrieval To retrieve codes, connect the scan tool **(Figure 48–30)** to the DLC and turn the ignition on. Follow the instructions for the scan tool to retrieve air bag information. Record all stored and active codes. Diagnose the cause of the codes in order, from the lowest number to the highest. Stored codes can be erased with the scan tool but active codes will only be erased when the problem is corrected.

Once the codes are retrieved, refer to the manufacturer's information to identify the steps for isolating and correcting the problem.

Courtesy of SPX Service Solutions.

FIGURE 48-30 An OBD-II scan tool that checks the air bag, antilock brake, and engine control systems.

> **Caution!** Testing individual parts of the system must be done with care. Not following the correct procedure or using the wrong tools can cause an air bag to deploy. This is not only dangerous but it is also very expensive. Never attempt to check the resistance of an air bag module.

Courtesy of SPX Service Solutions.

FIGURE 48-31 An air bag simulator is used as a substitute for the actual air bag during testing.

Air Bag Simulator To safely test SRS components, the use of an air bag simulator **(Figure 48–31)** is recommended. This simulator is installed in place of the air bag. The simulator can be adjusted to provide the normal electrical load of the air bag, thereby allowing accurate testing of the circuits without the fear of accidental air bag deployment.

Servicing the Air Bag System

Whenever working on or around air bag systems, it is important to follow all safety warnings **(Figure 48–32)**. Examples of these warnings follow:

1. When performing any work on the inside of a vehicle, make sure you are aware of the location of all air bags and exercise caution when working in those areas.
2. Wear safety glasses when servicing the air bag system.
3. Wait at least 5 minutes after disabling the system before beginning any service on or around the air bag system. The reserve energy module stores enough power to deploy the air bag after battery voltage is lost.

FIGURE 48-32 One example of an air bag warning label.

4. Always follow service procedures exactly as given by the manufacturer. Failure to do this can cause the SRS to deploy. Also, if the system is not serviced properly, it may not work when it needs to.
5. Never disassemble or attempt to repair any parts in order to reuse them; always replace them with new ones.
6. Handle all air bag sensors with care. Do not strike or jar a sensor in such a manner that deployment may occur.
7. When carrying a live air bag module, face the trim and bag away from your body.
8. Do not carry the module by its wires or connector.
9. When placing a live module on a bench, face the trim and air bag up.
10. Deployed air bags may have a powdery residue on them. Sodium hydroxide is produced by the deployment reaction and is converted to sodium carbonate when it comes into contact with atmospheric moisture. It is unlikely that sodium hydroxide will still be present. However, wear safety glasses and gloves when handling a deployed air bag. Wash your hands immediately after handling the bag.
11. A live air bag module must be deployed before disposal. Because the deployment of an air bag is through an explosive process, improper disposal may result in injury and fines. A deployed air bag should be disposed of according to EPA and manufacturer procedures.
12. Do not use a battery- or AC-powered voltmeter, ohmmeter, or any other type of test equipment not specified in the service information to test the air bag module. Never use a testlight to probe for voltage.
13. After work on the SRS is completed, perform the SRS warning light check.

Disarming Mechanical Systems

Because mechanical air bag systems are not tied to the electrical system, they cannot be deactivated by disconnecting the battery. The parts responsible for triggering the air bags and seat belt pretensioners are marked with “Danger Zone” in red. In some cases, the air bags cannot be deactivated and care must be taken not to jar the vehicle or close a door with an obstacle between the door and seat. To disarm other systems, certain cables need to be disconnected or cut. For example, on Volvos with side air bags, it is a black ribbed cable located between the bottom and back cushions of the seat. Always check the service information before working on or near these systems.

Service Guidelines

An air bag module is serviced as a complete assembly. Technicians repairing these systems are also advised to service crash sensors, mercury switches, and any other related components in assembly

Caution! A two-stage air bag may appear to be fully deployed when only its first stage has deployed. Care must be taken to make sure that two-stage air bag has been fully deployed before handling them. Always assume that any deployed two-stage air bag has an active stage two. Improper handling or servicing can activate the inflator module and cause personal injury. Always follow the manufacturer’s recommended handling procedures.

groupings. A damaged crash sensor must be replaced. It is a good idea to replace the entire set if a failure or degradation of any single sensor is found. Typically, when an air bag or bags have deployed, the control module and sensors must be replaced in addition to the air bags. This is because permanent codes or latch codes are stored in the air bag control module. These codes cannot be erased and only a new module will reactivate the system. The new control module will likely need to be programmed with a scan tool once installed.

Photo Sequence 46 covers a typical procedure for replacing an air bag module.

The steering column clockspring should be maintained in its correct index position at all times. Failure to do so can cause damage to the enclosure, wiring, or module. Any of these situations can cause the air bag system to default into a nonoperative mode. The clockspring should be replaced any time it has been removed.

Before returning the vehicle to the customer after service, make sure the sensors are firmly fastened to their mounting fixtures, with their arrows facing forward. Be certain all the fuses are correctly rated and replaced. Make sure a final check is made for codes using the approved scan tool. Carefully recheck the wire and harness routing before releasing the car.

Other Protection Systems

To make vehicles safe and to protect the occupants inside the vehicle, manufacturers include many different systems and options. What follows is a quick look at a few of these. By no means is this discussion conclusive; there are many things about how a vehicle is made that influence the protection and safety it offers. Basically, cars that offer good protection are those that are constructed to maintain integrity when impacted on. This construction includes side door beams, crumple zones, and reinforced areas of the frame.

Crumple zones are areas of the body that will bend or break away to protect the passengers inside the vehicle. These crumple zones absorb or take on the impact while keeping the passenger compartment undisturbed.

Headrests

Nearly two-thirds of all injuries from collisions are soft-tissue related, commonly referred to as whiplash. Good head restraints and proper adjustment help prevent these injuries. A properly adjusted headrest stops the head and neck from extending backward on impact. Nine out of ten people do not adjust the headrest for their height and comfort. A headrest should be positioned at least to the top of their ear and less than 4 inches (10 cm) from the back of their head.

New systems that automatically adjust the headrest have been developed. These headrest systems move the headrest up and forward when the vehicle is hit from behind. If the vehicle was in a collision, the action of the headrest should be checked. This is done by measuring the amount the headrest can be moved **(Figure 48–33)**.

Event Data Recorder (EDR)

Newer air bag systems have an event data recorder (EDR) that records data from a crash or a near crash. The recorder is normally inside the air bag control module assembly. It records air bag system diagnostic data, air bag deployment data, seat belt status, engine speed, throttle and brake pedal data, position of the transmission selector, and position of the driver's seat.

Precollision System

A precollision system predicts possible collisions with an obstacle, based on information it receives from various sensors. The system uses a millimeter wave radar sensor to predict a possible collision and retracts the seat belts before the collision. The inputs also are used to control the brake system. Millimeter wave radar uses an extremely high frequency with an extremely short wavelength. Millimeter wave radar does a good job at recognizing obstacles.

The precollision system removes the slack in the front seat belts and warns the driver of an impending collision. The sensor only detects metal objects and

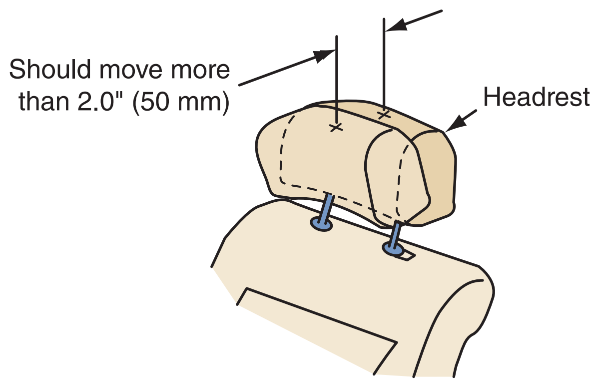
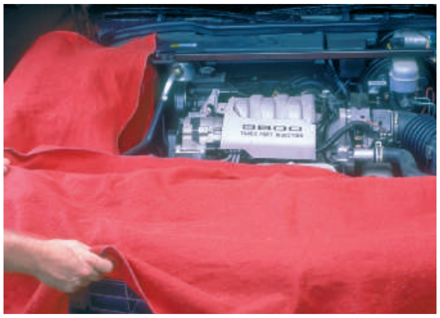


FIGURE 48–33 Checking an active headrest.

PHOTO SEQUENCE 46

Removing an Air Bag Module

P46-1 Tools required to remove the air bag module: safety glasses, seat covers, screwdriver set, Torx driver set, battery terminal pullers, battery pliers, assorted wrenches, ratchet and socket set, and service information.



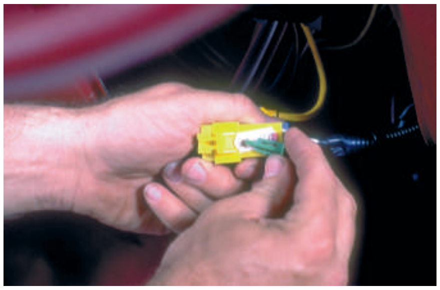
P46-2 Place the seat and fender covers on the vehicle.

P46-3 Place the front wheels in the straight ahead position and turn the ignition switch to the LOCK position.

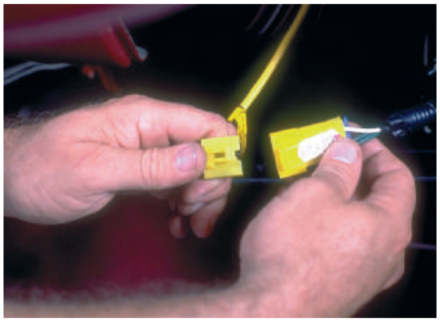
P46-4 Disconnect the negative battery cable.

P46-5 Tape the cable terminal to prevent accidental connection with the battery post. Note: A piece of rubber hose can be substituted for the tape.

P46-6 Remove the SIR fuse from the fuse box. Wait 30 minutes to allow the reserve energy to dissipate.

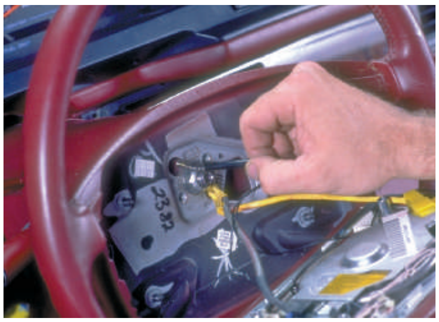


P46-7 Remove the connector position assurance (CPA) from the yellow electrical connector at the base of the steering column.

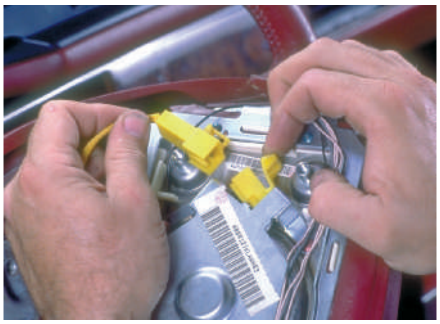


P46-8 Disconnect the yellow two-way electrical connector.

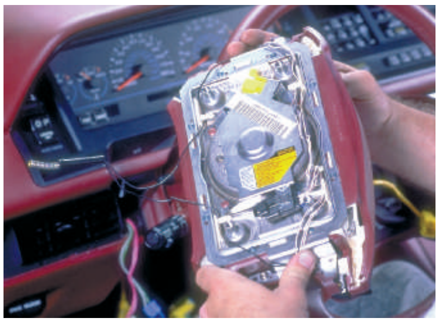
P46-9 Remove the four bolts that secure the module from the rear of the steering wheel.



P46-10 Rotate the horn lead ¼ turn and disconnect.



P46-11 Disconnect the electrical connectors.



P46-12 Remove the module.

will not respond to people, bicycles, trees, and animals. It also will not respond if the seat belts are not buckled.

Rollover Protection

Some convertibles have a built-in roll bar to protect the passengers in case of a rollover. These units are permanent structures of the vehicle. Others have automatic systems that provide for this. They deploy a roll bar from behind the headrests when the vehicle experiences extreme tilting, when the wheels lose contact with the ground, or during a serious accident **(Figure 48–34)**.

Vehicles with rollover protection use sensors to monitor the speed of the rollover and inflate the air bags accordingly. During a rollover, the air bags stay inflated for a longer than normal time to keep the occupants safe until the vehicle comes to a rest. These systems also take the slack out of the seat belts, shut off the fuel pump, and disconnect the battery when a rollover is sensed.

Hybrid vehicles also have a rollover protection feature. This system isolates the high-voltage circuits whenever the air bags are deployed.

Chrysler LLC.

FIGURE 48–34 This roll bar pops out when the system anticipates a potential rollover.

Four-Point Seat Belts

Although not in use at this time, Ford Motor Company and other companies are studying the use of four-point seat belts. This belt system has two shoulder straps integrated into the frame of the seat. The shoulder straps and the two lap belts buckle together at the center of the passenger's waist. The design allows the forces from a crash to be evenly distributed across the body.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2005	**Make:** Chrysler	**Model:** Sebring	**Mileage:** 153,471	**RO:** 19507
Concern:	Customer states air bag warning light stays on.			
The technician confirms that SRS light remains on after the engine starts. Next, she connects a scan tool and retrieves a DTC for the driver's side air bag circuit open. She removes the driver's air bag module and inspects the module and wiring. Not seeing any problem with the air bag wiring, she checks the clockspring.				
Cause:	Found clockspring open.			
Correction:	Replaced clockspring. Cleared DTC, system operating normally.			

KEY TERMS

Active restraint system
Adaptive air bags
Clockspring
Smart air bags
Squib
Supplemental inflatable restraint (SIR)
Supplemental restraint system (SRS)
Zeronic potassium perchlorate (ZPP)

SUMMARY

- All new vehicles built or sold in the United States must have one or both types of passive restraints: seat belts or air bags.
- Restraint systems are either active or passive.
- When servicing seat belts, inspect the webbing, buckles, retractors, and anchorage.
- An air bag is inflated or deployed by rapid expansion of a gas fired by igniter or squib.

- Smart air bags have two possible stages of deployment in an attempt to match the severity of the impact and/or the size and weight of the seat's occupant.
- The electrical circuit of an air bag system includes impact sensors and an electronic control module.
- The air bag module is the air bag and inflator assembly packaged into a single unit.
- A system check of an air bag system consists of observing the air bag warning light.
- The control module will store trouble codes that can be retrieved by either a scan tool or flash codes.
- Before doing any work on an air bag system, disable the system.
- Care must be taken when removing a live (not deployed) air bag. Be sure the bag and trim cover are pointed away from you.

REVIEW QUESTIONS

Short Answer

1. What is the difference between a passive and an active restraint system?
2. What is a crumble zone and how is it used for occupant protection?
3. List at least five service precautions that must be adhered to when working on or near air bag systems.
4. Describe the two basic types of passenger weight detection sensors used in most vehicles.
5. Describe the three types of safing sensors.

True or False

1. *True or False?* The powdery substance released from the air bag when it is deployed is sodium hydroxide, which can cause skin irritation.
2. *True or False?* The air bag diagnostic monitor supplies back-up power to the air bag module in the event that the battery or cables are damaged during the accident.
3. *True or False?* Second-generation air bags may contain two explosive charges.
4. *True or False?* When servicing the steering wheel or column, disconnect and remove the clockspring to make sure it is in good shape before reusing it.

Multiple Choice

1. Which of the following statements about the SRS warning lamp is *not* true?
   a. When the ignition is first turned on, the indicator should turn on and remain on for approximately 6 seconds.
   b. If the system seems to be able to work correctly, the lamp will stay lit as the engine runs.
   c. If the lamp flashes or turns off and then turns on again, low source voltage may be indicated.
   d. A system problem is indicated when the lamp does not turn on when the ignition is initially turned on.
2. What type of seat belt operates automatically with no action required by the vehicle's occupant?
   a. Passive restraint
   b. Retractor
   c. Active restraint
   d. Anchorage
3. Which of the following is false?
   a. The air bag igniter assembly is a spark plug-type device with two pins that current must jump across.
   b. The air bag igniter assembly creates a spark that ignites a canister of gas generating zerconic potassium perchlorate.
   c. The air bag igniter assembly is housed in the module assembly.
   d. None of the above.
4. Which of these statements about air bag sensors is *not* true?
   a. Roller-type sensors rely on a roller held in place with a magnet. The circuit is closed when the roller moves and strikes the spring contact.
   b. Mass-type sensors rely on a ball and a magnet. The circuit is complete when the ball makes contacts with the electrical contacts in the sensor.
   c. An accelerometer contains a piezoelectric element that generates an analog voltage in relation to the severity of the deceleration forces.
   d. An accelerometer also senses the direction of an impact force.

5. Which of the following statements about two-stage air bags is *not* true?
   a. When low-pressure air bag deployment is desired, only one squib is fired.
   b. When the vehicle is in a severe collision and the occupant needs maximum protection, the squib related to the larger container of gas fires.
   c. For rapid deployment, both squibs fire at the same time.
   d. To phase in full deployment, one squib is fired, then a few milliseconds later the other is.
6. Which of the following statements about seat belt retractors is *not* true?
   a. They stow away the seat belts when they are not being used.
   b. They allow freedom of movement for the occupant of the seat.
   c. They can tighten up and pull the occupant back during a crash.
   d. On some vehicles, they work in concert with the air bag system.

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that compressed argon gas is often used to deploy passenger-side and side impact air bags. Technician B says that compressed argon gas is used to deploy some driver's side air bags. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Technician A says that seat belt webbing should be replaced if it is bowed. Technician B says that webbing does not need to be replaced if the color has merely faded due to exposure to the sun. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. Technician A says that the module assembly will disarm the air bag system if certain faults occur. Technician B says the passenger side air bag may be turned off if there is not enough weight on the passenger seat. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. While testing seat belt retractors: Technician A grasps a vehicle-sensitive-type belt and jerks it. Technician B grasps a webbing-sensitive-type belt and jerks it. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. Technician A checks the clockspring electrical connections for signs of damage when replacing a deployed air bag module. Technician B backprobes an air bag system with a multimeter to determine if the system is in good working order. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. Technician A removes the positive battery cable before servicing any component in the air bag system. Technician B wears safety glasses and protective gloves when handling inflated air bags. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. Technician A says that ignition of the air bag only occurs when an outside sensor and an inside sensor are closed. Technician B says that the safing sensor determines if the collision is severe enough to inflate the air bag. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

8. When replacing an air bag module: Technician A says that the steering column clockspring should be maintained in its correct index position at all times. Technician B says that failure to keep the clockspring straight ahead or in the neutral position relative to the steering wheel can cause damage to the enclosure, wiring, or module. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. While diagnosing a seat belt that will not buckle: Technician A looks inside the buckle and disassembles it and removes any obstructions that may prevent it from latching onto the belt latch. Technician B replaces the buckle if an obstruction cannot be easily removed from the buckle. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. While diagnosing the cause of a constant SRS warning light: Technician A follows the service procedures and connects a jumper wire across designated pins in the DLC then records the flashed codes. Technician B connects a scan tool to the DLC and records the displayed codes. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

CHAPTER 49

WHEEL ALIGNMENT

OBJECTIVES

- Explain the benefits of accurate wheel alignment.
- Explain the importance of correct wheel alignment angles.
- Describe the different functions of camber and caster with regard to the vehicle's suspension.
- Identify the purposes of steering axis inclination.
- Explain why toe is the most critical tire wear factor of all the alignment angles.
- Identify the purposes of turning radius or toe-out in turns.
- Explain the conditions known as tracking and thrust angle.
- Perform a pre-alignment inspection.
- Describe how alignment angles can be changed on a vehicle.
- Understand the importance of rear-wheel alignment.
- Identify and understand steering sensor calibration requirements.

Wheel Alignment

A vehicle's wheels, tires, suspension system, and steering system are all designed to work together to provide safe, stable, and reliable handling. The goal of these systems working together is proper wheel alignment **(Figure 49–1)**. During an alignment, the angles of the suspension and wheels are measured and adjusted. The procedure places the tires to maximize performance, ride quality, and tire life. These angles are adjusted by changing the position of various steering and suspension parts. The desired angles are those set by the vehicle's manufacturer.

Correct wheel alignment allows the wheels to roll without scuffing, dragging, or slipping on different types of road surfaces. Proper alignment of both the front and rear wheels ensures greater safety, easier steering, longer tire life, reduction in fuel consumption, and less strain on the steering and suspension systems.

The alignment of the wheels should be checked whenever new tires or steering and suspension parts are installed. Also, the wheels should be aligned whenever the tires are wearing abnormally. A vehicle's wheels become out-of-alignment due to worn

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2010	**Make:** Honda	**Model:** Civic	**Mileage:** 102,301	**RO:** 19384
Concern:	Customer requested wheel alignment, steering wheel off-center.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

Courtesy of Hunter Engineering Company.

FIGURE 49-1 Technicians who specialize in wheel alignment are always in demand.

suspension parts, a change in ride height, or driving hard into a pothole or curb. All of these can affect the angle of the wheels.

A wheel alignment restores the geometry of the suspension to the angles that were determined to properly locate the vehicle's weight on the tires and to facilitate steering.

Types of Wheel Alignment

For many years and until the 1980s, two-wheel alignments were performed. This is because most vehicles were RWD and had live rear axles that did not allow for four-wheel alignment. Today, since suspension and steering systems are more complex, four-wheel alignments are performed. This is true even if only the alignment of the front-wheels can be adjusted.

Four-wheel alignment measures the angles at the four wheels. On some vehicles, adjustments are made only to the front wheels. This is primarily due to the fact that there is no way to make adjustments to the rear wheels. However, by adjusting the front wheels so they are rotating in the same direction as the rear wheels, the vehicle will tend to move straight. Many vehicles have provisions for adjusting the rear wheels. When this is the case, the rear wheels are adjusted first and then the fronts are aligned to the vehicle's centerline.

Road Crown

Most roads are not designed to be flat. They are paved to slope at a slight angle. This allows water to flow off the road's surface rather than allowing it to accumulate. The angle is called **road crown** and can cause a vehicle to tend to pull toward the right of the road. To compensate for this, different angles may be set at each side of the vehicle.

Alignment Geometry

The proper alignment of a suspension/steering system centers on the accuracy of the following angles.

Caster

Caster is the angle of the steering axis of a wheel from the vertical, as viewed from the side of the vehicle. The forward or rearward tilt from the vertical line **(Figure 49–2)** is caster. Caster is most often the first angle adjusted during an alignment. Tilting the axis forward is negative caster. Tilting backward is positive caster. An example of positive caster is on bicycles and motorcycles. The steering and front forks create positive caster that is easily seen **(Figure 49–3A)**. Sometimes, caster can easily be seen in the suspension system, such as on the Ford Explorer **(Figure 49–3B)**.

Caster is designed to provide steering stability. The caster angle for each wheel on an axle should be equal or very close to equal. Caster can be used to compensate for road crown by setting the right wheel caster slightly more positive than the left. Excessively unequal caster angles cause the vehicle to pull toward the side with less caster. Too much negative caster can cause the vehicle to have sensitive steering at high speeds. The vehicle might wander as a result of negative caster. Caster is not considered to be a tire wearing angle. However, high amounts of caster, as built into some sports cars, affects camber angles as the wheels are turned. A vehicle with high caster settings may experience increased shoulder wear on the tires, especially if driven primarily in the city.

Caster is affected by worn or loose ball joints, strut rods, and control arm bushings. Caster adjustments

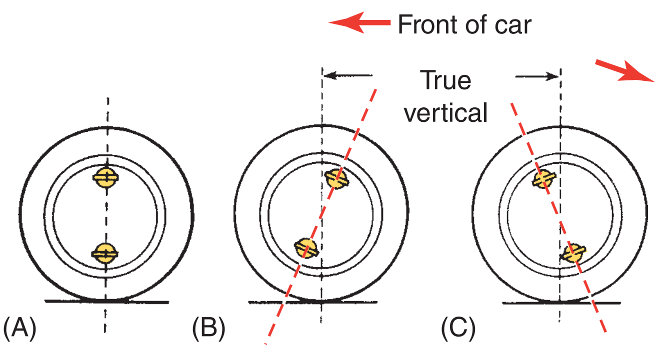


FIGURE 49-2 Three types of caster: (A) zero, (B) positive, and (C) negative.

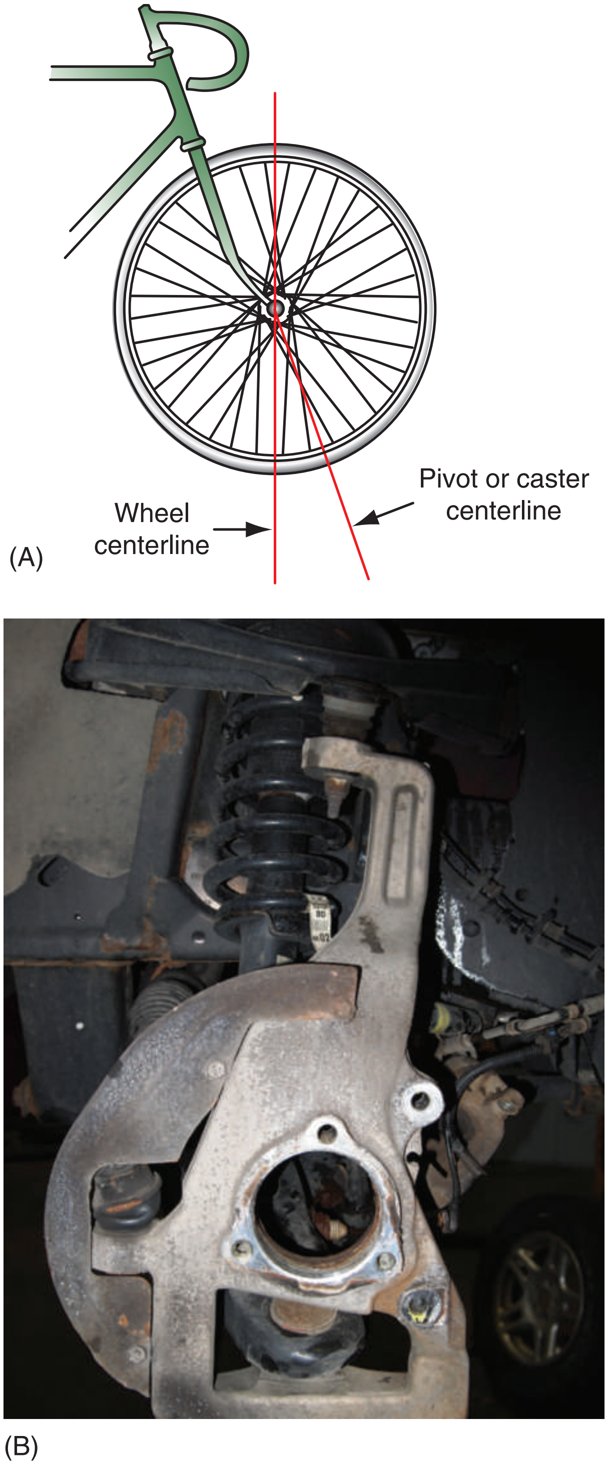


FIGURE 49–3 Caster illustrated as used on a bicycle (A) and as seen built into the front suspension (B).

are not possible on some strut suspension systems without an aftermarket service kit. Often if these vehicles have a caster problem, something is worn or bent and those parts must be replaced or repaired. Where adjustment points are provided, they can be made at the top or bottom mount of the strut assembly.

Camber

Camber is the angle represented by the tilt of either the front or rear wheels inward or outward from the vertical as viewed from the front of the car **(Figure 49–4)**. Camber is designed into the vehicle to compensate for road crown, passenger weight, and vehicle weight. Camber is usually set equally for each wheel. Equal camber means each wheel is tilted outward or inward the same amount. Unequal camber causes the vehicle to pull toward the side that is more positive. Excessive camber causes tire wear.

Camber angle changes, due to the travel of the suspension system, are controlled by the suspension's pivots. Camber is affected by weak or broken springs and worn or loose ball joints, control arm bushings, and wheel bearings. Anything that changes riding height also affects camber.

Camber is adjustable at the control arms on most vehicles. Some vehicles with a strut suspension include a camber adjustment at the spindle assembly. Camber adjustments are also provided on some strut suspension systems at the top mounting of the strut. Very little adjustment of camber (or caster) is required on strut suspensions if the tower and lower control arm locations are correct. If serious camber error has occurred and the suspension mounting positions have not been damaged, it is an indication of bent suspension parts. Damaged parts should be replaced.

Toe

Toe is the distance comparison between the leading edge and trailing edge of the front tires. If the leading edge distance is less, then there is positive toe or toe-in. If it is greater, there is negative toe or toe-out **(Figure 49–5)**. Actually, toe is critical as a tire-wearing angle. Wheels that do not track straight ahead have to drag as they travel forward. Excessive toe measurements (in or out) cause a sawtooth

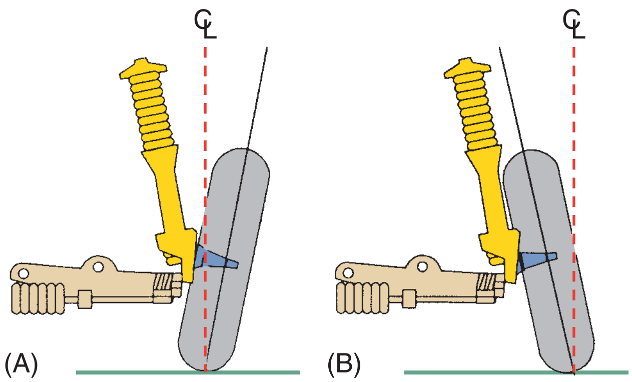


FIGURE 49–4 (A) Positive and (B) negative camber.

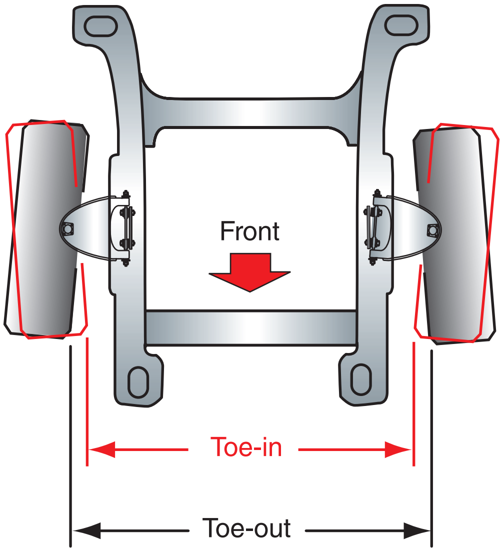


FIGURE 49–5 (Red) Toe-in. (Black) Toe-out.

edge on the tread surface from dragging the tire sideways. Excessive toe-in will cause tire wear on the outside edge of the tire. Toe-out causes wear on the inside edge.

Toe adjustments are made at the tie-rod. They must be set equally on both sides of the car. If the toe settings are not equal, the car may tend to pull due to the steering wheel being off-center. An off-center steering wheel and steering pull should be corrected by making the toe adjustments equal on both sides of the car with the steering wheel centered.

Toe is affected by worn steering linkage components, worn springs, ball joints, or anything that changes camber. Toe changes caused by loose or worn parts often causes bump steer. Bump steer occurs when the vehicle darts left or right after hitting a bump in the road. The change in suspension and/or steering geometry changes the toe, causing the wheels to move left or right.

Toe will change with vehicle speed. As the vehicle moves, friction forces the tires to move straight ahead or have zero toe. However, aerodynamic forces on the vehicle cause a change in its riding height. This will also change the toe as well as camber. Therefore, most toe specifications anticipate these changes and are set to provide zero toe at highway speeds.

Thrust Line

All vehicles are built around a geometric centerline that runs through the center of the chassis from the back to the front. The **thrust line** is the direction the rear axle would travel if unaffected by the front wheels. This condition is also called **tracking**. Correct tracking results from having all suspension parts in their correct location, in good condition, and aligned so that the rear wheels follow directly behind the front wheels while moving in a straight line **(Figure 49–6)**. For this to occur, the axles and wheels must be parallel with one another and the centerlines through the axles and spindles must be at 90-degree angles to the vehicle's centerline. Simply stated, all four wheels should form a perfect rectangle.

A main consideration in any alignment is to make sure the vehicle runs straight down the road, with the rear tires tracking directly behind the front tires when the steering wheel is in the straight-ahead position. The geometric centerline of the vehicle should parallel the road direction. This is the case when rear toe is parallel to the vehicle's geometric centerline in the straight-ahead position. If rear toe does not parallel the vehicle centerline, a thrust direction to the left or right is created **(Figure 49–7)**. This difference of rear toe from the geometric centerline is called the **thrust angle**.

Any time the centerline of the front axle is not parallel to the rear axle, handling will be affected.

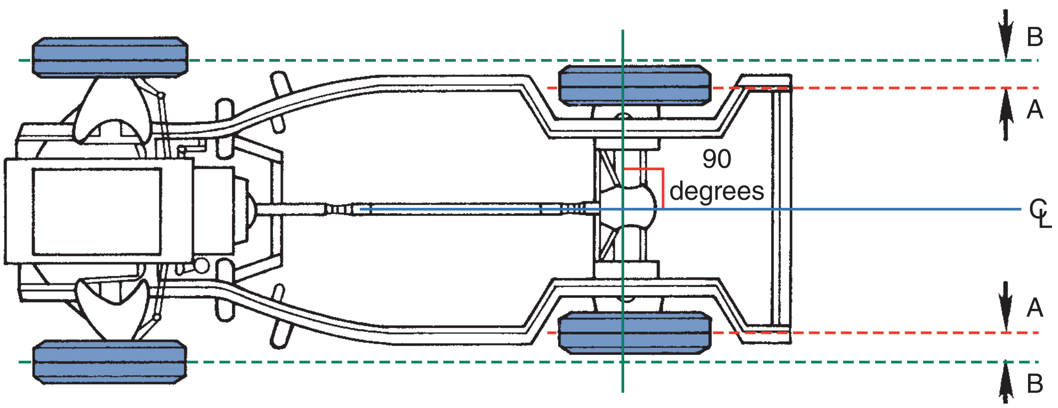


FIGURE 49–6 When a car is tracking correctly, its rear wheels are the same distance from the front wheels on both sides.

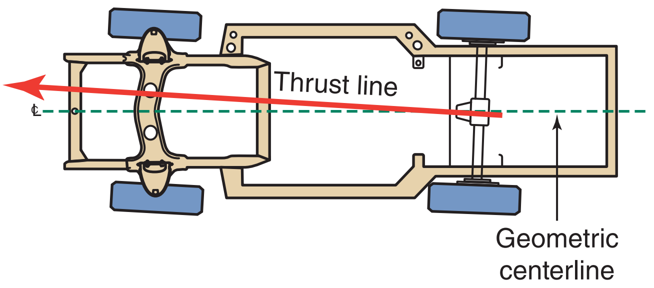


FIGURE 49-7 The thrust line or driving direction of the rear wheels.

This is because the vehicle will tend to travel according to the angle of the rear axle. This causes the vehicle to pull in the opposite direction as the thrust angle. If the thrust line is to the right, the vehicle will pull to the left; when the thrust line is to the left, the vehicle will pull to the right. This can also cause tire wear similar to that of incorrect toe settings. As a general rule, minor variations between the thrust line and centerline are not noticeable and do not cause handling problems as long as the front wheels are aligned parallel with the thrust line.

This problem can cause tire wear and poor directional stability on ice, snow, or wet pavement. It can also make a vehicle pull during braking or hard acceleration. Also, if the thrust angle is not zero, the steering wheel will not be centered. Nonparallel axles, or thrust line deviations, are usually caused by the shifting of the rear axle on its spring supports, rear wheel misalignment, or damage from an accident.

Steering Axis Inclination (SAI)

Steering axis inclination (SAI) locates the vehicle weight to the inside or outside of the vertical centerline of the tire. The SAI is the angle between true vertical and a line drawn between the steering pivots as viewed from the front of the vehicle. It is an engineering angle designed to project the weight of the vehicle to the road surface for stability. The SAI helps the vehicle's steering system return to straight ahead after a turn.

On a short-long arm suspension, SAI is the angle between a true vertical line and a line drawn from the upper ball joint through the lower ball joint. In a strut-equipped vehicle this line is drawn through the center of the strut's upper mount down through the center of the lower ball joint **(Figure 49–8)**.

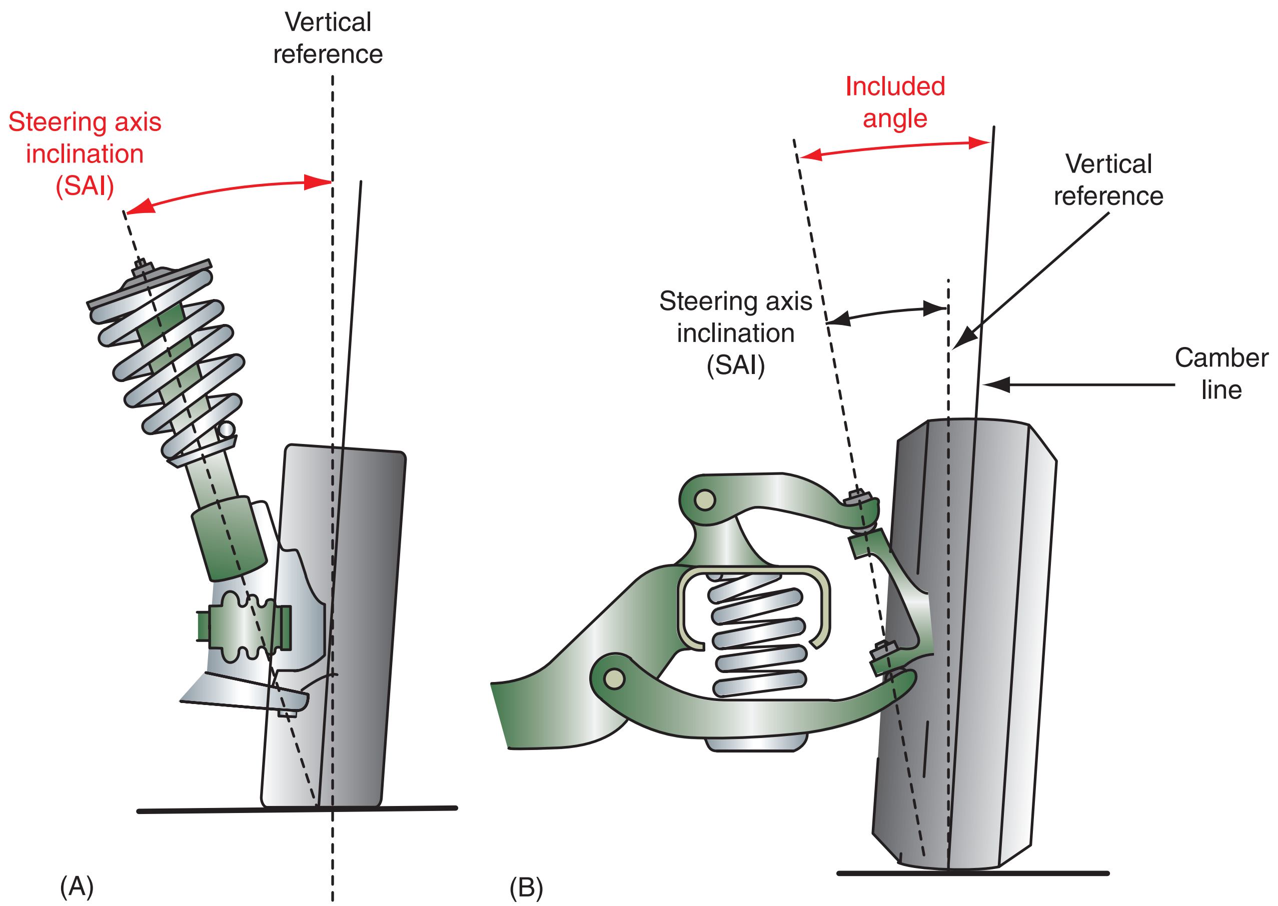


FIGURE 49-8 (A) SAI and (B) included angle (IA) are used to diagnose geometry problems.

If the vehicle has 0 (zero) SAI, the upper and lower ball joints (or strut pivot points) would be located directly over one another. Problems associated with this simple relationship include tire scrub in turns, lack of control, and increased effort during turn recovery. If the SAI is tilted, a triangle is formed between ball joints and spindle. An arc is then formed when turning. There is a high point at straight-ahead position and a drop downward turning to each side. This motion travels through the control arms to the springs and, finally, to the weight of the vehicle. The forces generated in a turn are actually trying to lift the vehicle. The tilting and loading effect of SAI offsets the lifting forces and helps to pull the tires back to straight ahead when the turn is finished.

Front-wheel drive vehicles with strut suspensions typically have a higher SAI angle (12 to 18 degrees) than a short-long arm rear-wheel drive suspension (6 to 8 degrees). This is because the extra leverage provided by a larger angle helps directional stability.

If the SAI angles are unequal side-to-side, torque steer, brake pull, and bump steer (jerking from side to side) can occur even if static camber angles are within specifications.

Checking the SAI angle can help locate various problems that affect wheel alignment. For example, an SAI angle that varies from side to side may indicate an out-of-position upper strut tower, a bowed lower control arm, a bent strut, a bent steering knuckle or spindle, or a shifted center crossmember or cradle.

Scrub Radius

Scrub radius is the distance between the center of the tire and where the SAI angle intersects the ground **(Figure 49–9)**. The scrub radius must be equal on both sides of the vehicle otherwise the vehicle will pull to one side. Scrub radius is not adjustable or measured; rather, it is observed. Scrub radius is part of the suspension's design. There is positive scrub when the tire's contact patch is outside the SAI angle and negative when the patch is inside the angle. Most FWD vehicles have a negative scrub radius. This is done to reduce torque steer. To the contrary, most SLA suspensions have a positive scrub radius. If a vehicle pulls after it has been properly aligned, look for offset wheels or a problem that would affect SAI.

Included Angle

When the camber angle is added to the SAI angle, the sum of the two is called the **included angle (Figure 49–10)**. This angle is not measured by an alignment machine; it is simply obtained by adding the camber and SAI on one side of the vehicle together. The included angle must be the same on each side of the vehicle even if the camber on each side is different. If it is not, the vehicle will pull.

Comparing the SAI, included, and camber angles can help identify damaged or worn components. For example, if the SAI reading is correct but the camber and included angles are less than

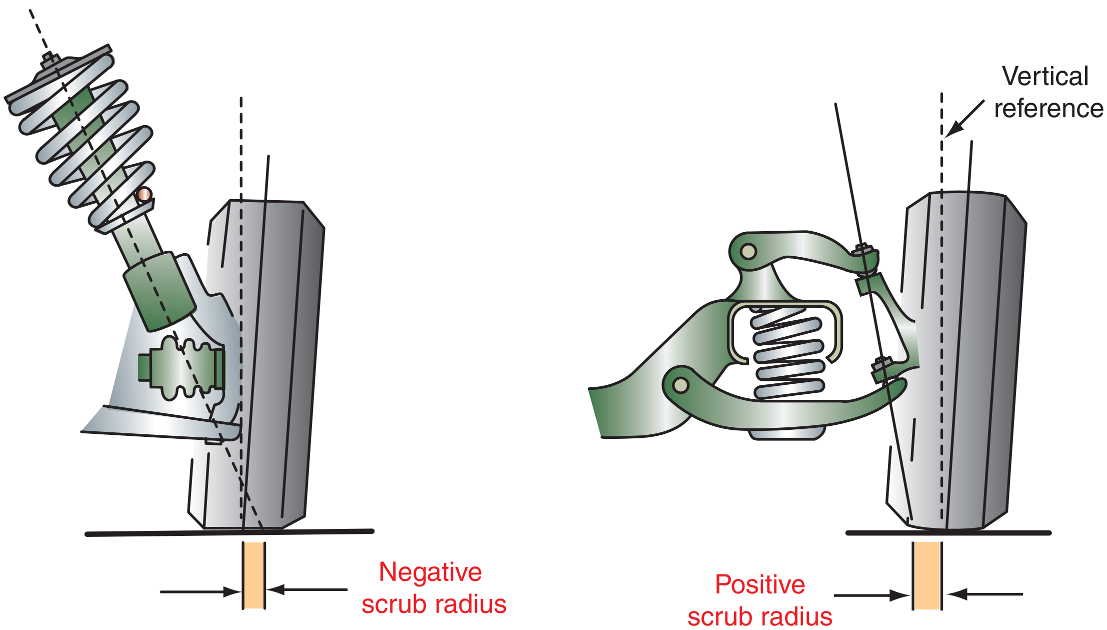


FIGURE 49–9 Scrub radius is affected by wheel size and offset.

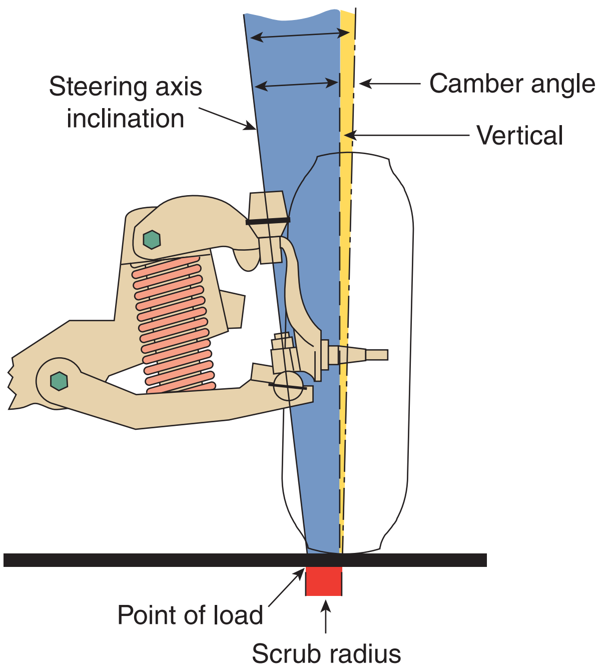


FIGURE 49–10 The included angle is the sum of the camber and SAI angles.

specifications, the steering knuckle or strut tower may be bent. **Table 49–1** summarizes the various angle combinations used to troubleshoot short-long arm, strut, and twin I-beam suspension system alignment problems.

Turning Radius

Turning radius relates to the amount of toe-out present in turns **(Figure 49–11)**. This is also called "toe-out on turns" or "turning angle." As a car goes

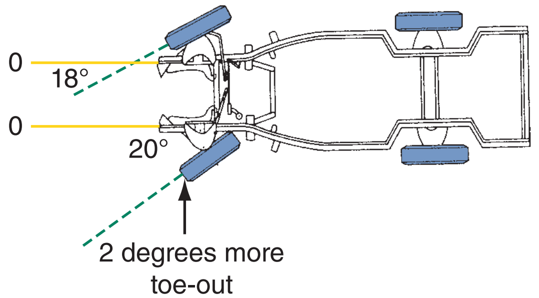


FIGURE 49–11 Turning angle is affected by toe-out on turns.

TABLE 49–1 ALIGNMENT ANGLE DIAGNOSTIC CHART

Suspension Systems	SAI	Camber	Included Angle	Probable Cause
Short Arm/Long	Correct	Less	Less	Bent knuckle
	Less	Greater	Correct	Bent lower control arm
	Greater	Less	Correct	Bent upper control arm
	Less	Greater	Greater	Bent knuckle
MacPherson Strut Suspension	Correct	Less	Less	Bent knuckle and/or bent strut
	Correct	Greater	Greater	Bent knuckle and/or bent strut
	Less	Greater	Correct	Bent control arm or strut tower (out at top)
	Greater	Less	Correct	Strut tower (in at top)
	Greater	Greater	Greater	Strut tower (in at top) and spindle and/or bent strut
	Less	Greater	Greater	Bent control arm or strut tower (out at top) plus bent knuckle and/or bent strut
	Less	Less	Less	Strut tower (out at top) and knuckle and/or strut bent or bent control arm
Twin I-Beam Suspension	Correct	Greater	Greater	Bent knuckle
	Greater	Less	Correct	Bent I beam
	Less	Greater	Correct	Bent I beam
	Less	Greater	Greater	Bent knuckle

around a corner, the inside tire must travel in a smaller radius circle than the outside tire. This is accomplished by designing the steering geometry to turn the inside wheel sharper than the outside wheel. The result can be seen as toe-out in turns. This eliminates tire scrubbing on the road surface by keeping the tires pointed in the direction they have to move.

Turning radius is not an adjustable angle. If the angle is not correct, the tie-rods, steering arm, or steering knuckle are damaged and will need to be replaced.

Load Distribution

Load distribution refers to the load placed on each wheel. Every vehicle is engineered to operate at a designed curb height (also called trim height). At this height, each wheel must carry the correct amount of weight. Excessive loading to the front, rear, or one side of the vehicle changes the curb height, upsetting vehicle balance and steering geometry.

In correct alignment, sagging springs and bent suspension parts can also change this condition, upsetting the geometry and placing excessive load on only one or two wheels.

All of these elements—springs, shocks, suspension, and geometry—are engineered to work together as a balanced team to provide safe and comfortable riding and handling. Quite naturally, if one wheel is running under a different condition of weight load and steering geometry, the vehicle does not ride and handle as it is capable of doing.

Prealignment Inspection

Before beginning to align a vehicle, make sure you know why the vehicle needs to be aligned or why the customer has requested an alignment. Often the symptoms will lead to identifying the reason the wheels need to be aligned. Follow the customer interview with a test drive. While driving the car, check to see that the steering wheel is straight. Feel for vibrations in the steering wheel as well as in the floor or seats. Notice any pulling or abnormal handling problems, such as hard steering, tire squeal while cornering, or mechanical pops or clunks. This helps find problems that must be corrected before proceeding with the alignment.

An extremely important part of a wheel alignment is the prealignment inspection. During this inspection, if any parts are found to be defective, they should be replaced before proceeding with the alignment. The inspection should include a careful look at the tires, wheel, suspension system, and steering system. The procedures for inspecting these are detailed in the previous three chapters. A typical alignment inspection report is shown in **Figure 49–12**.

It is important that all abnormal loads be removed before taking any measurements. Obviously, added weight will affect the vehicle's ride height and, therefore, the alignment angles. If the vehicle is normally used to carry heavy objects, such toolboxes, leave them in the vehicle. In some cases, the vehicle manufacturer will specify that a certain amount of weight be added to the vehicle during an alignment. This is done to better reflect the actual driving conditions the vehicle will experience.

Ride Height

Check the vehicle's ride height. Every vehicle is designed to ride at a specific curb height. Curb height specifications and the specific measuring points are given in the service information. Proper alignment is impossible if the ride height is incorrect. This is especially true for camber because as the height of a vehicle changes, so does the camber of the wheels.

GO TO Chapter 46 for a discussion of and the procedure for checking ride height.

Some alignment machines have adapters that allow the unit to measure ride height. This is done without a tape measure; the machine's sensors are installed on the fenders and the measurements are instantly transmitted to the alignment machine **(Figure 49–13)**.

Results of Poor Alignment

If no problems were found during the inspection, a good alignment may take care of the customer's concerns. Poor wheel alignment will cause many different things. Use the chart in **Table 49–2** when checking your work after the alignment.

PREALIGNMENT INSPECTION CHECKLIST

Owner ______________________ Phone ______________ Date __________

Address ______________________________ VIN ______________________

Make __________ Model __________ Year ______ Lic. number ___________ Mileage __________

1. Road test results	Yes	No	Right	Left
Above 30 MPH				
Below 30 MPH				
Bump steer				
When braking				
Steering wheel movement				
Stopping from 2-3 MPH (front)				
Vehicle steers hard				
Strg wheel returnability normal				
Strg wheel position				
Vibration	Yes	No	Frnt	Rear

2. Tire pressure	Specs	Frnt ____ Rear ____
Record pressure found		
RF ____ LF ____ RR ____ LR ____		

3. Chassis height	Specs	Frnt ____ Rear ____
Record height found		
RF ____ LF ____ RR ____ LR ____		

	Yes	No
Springs sagged		
Torsion bars adjusted		

4. Rubber bushings	OK
Upper control arm	
Lower control arm	
Sway bar/stabilizer link	
Strut rod	
Rear bushing	

5. Shock absorbers/struts	Frnt	Rear

6. Steering linkage	Frnt OK	Rear OK
Tie-rod ends		
Idler arm		
Center link		
Sector shaft		
Pitman arm		
Gearbox/rack adjustment		
Gearbox/rack mounting		

7. Ball joints		OK
Load bearings		
Specs	Readings	
Right ____ Left ____	Right ____ Left ____	
Follower		
Upper strut bearing mount		
Rear		

8. Power steering	OK
Belt tension	
Fluid level	
Leaks/hose fittings	
Spool valve centered	

9. Tires/wheels	OK
Wheel runout	
Condition	
Equal tread depth	
Wheel bearing	

10. Brakes operating properly	

11. Alignment	Spec		Initial reading		Adjusted reading	
	R	L	R	L	R	L
Camber						
Caster						
Toe						

Bump steer	Toe change right wheel		Toe change left wheel	
	Amount	Direction	Amount	Direction
Chassis down 3"				
Chassis up 3"				

	Spec		Initial reading		Adjusted reading	
	R	L	R	L	R	L
Toe-out on turns						
SAI						
Rear camber						
Rear total toe						
Rear indiv. toe						
Wheel balance						
Radial tire pull						

FIGURE 49–12 A checklist for a prealignment inspection and wheel alignment.

Courtesy of Hunter Engineering Company.

FIGURE 49-13 The sensors used to measure ride height with a wheel aligner.

TABLE 49-2 EFFECTS OF INCORRECT ALIGNMENT

Problem	Effect
Incorrect camber setting	Tire wear Ball joint/wheel bearing wear Pull to side of most positive/least negative camber
Too much positive caster	Hard steering Excessive road shock Wheel shimmy
Too much negative caster	Wander Weave Instability at high speeds
Unequal caster	Pull to side most negative/ least positive caster
Incorrect SAI	Instability Poor return Pull to side of lesser inclination Hard steering
Incorrect toe setting	Tire wear
Incorrect turning radius	Tire wear Squeal in turns

Wheel Alignment Equipment

There are many different ways to measure the alignment angles on a vehicle. The most common way is the use of an alignment machine or rack. The equipment used for checking alignment angles has evolved from string and measuring tapes to computerized machines. Today, computerized machines are the most commonly used **(Figure 49–14)**. A typical computerized system gives information on a screen to guide the technician step-by-step through the alignment process.

Alignment Machine Care

The alignment machine is a precise piece of equipment; therefore, it needs to be taken care of. Failure to do so will lead to incorrect measurements and adjustments. Alignment racks and machines should be periodically checked and calibrated. This can be done by a technician from the manufacturer, or the shop may purchase a calibration fixture for its own use.

The turn tables and slip plates on the rack should be checked for dirt buildup and wear. Both of these can cause them to bind, which will cause incorrect settings. Also, never use the console as a workbench, even for small parts. Extra care should be paid to the alignment heads. They may fall while connecting and disconnecting them. Older machines have delicate electronics contained in the heads;

FIGURE 49-14 A computer-based wheel alignment machine.

FIGURE 49–15 A wheel alignment machine that relies on high-imaging cameras and targets to gather measurements.

they can be easily damaged. If the heads are dropped, they should be recalibrated before they are used again.

The heads on newer alignment machines **(Figure 49–15)** do not contain electronic parts. Rather, the heads serve as targets **(Figure 49–16)** for cameras mounted above the console **(Figure 49–17)**. Light from LEDs on the alignment machine is reflected back and picked up by the digital cameras. Damaged or dirty targets lose their reflectivity and the light may not be picked up by the cameras.

Turning Radius Gauges

Turning radius gauges measure how many degrees the front wheels are turned. They are commonly used to measure camber, caster, and toe-out on turns. Turning radius gauges (sometimes called turn tables) may be portable but are commonly found as part of an alignment rack. To use these gauges, the front wheels are centered on the gauge plates. Then the locking pins are removed to allow the plate to turn with the tires. As the tires are turned, a pointer will indicate how many degrees the tires have turned. To check toe-out on turns, turn one of the tires to 20 degrees. Then look at the gauge on the other tire.

Modern wheel alignment equipment may check toe-out-on-turns automatically when checking caster or there may be a separate test menu. When the wheels are turned, the sweep of the targets is used to check toe-out-on-turns.

FIGURE 49–16 These targets are similar to those shown in Figure 49–15 and work by reflecting light back up to digital cameras.

FIGURE 49–17 These high-imaging cameras are positioned on a beam above the console of the machine shown in Figure 49–15.

Miscellaneous Tools

Figure 49–18 shows an assortment of the special tools required for wheel alignment and other steering and suspension system work.

FIGURE 49–18 An assortment of steering and suspension tools.

Alignment Machines

There are many varieties of alignment machines that have been used through the years. Some are equipped to measure alignment angles at all four wheels of the vehicle, and others measure the angles at only two wheels. Some alignment machines simply display the angle readings, whereas most current models give much more **(Figure 49–19)**, such as:

- A model-specific inspection screen with photos and illustrations
- Caster, camber, SAI, included angle, setback, and toe readings
- A printed analysis for the customer explaining what should be done
- Displays the required hand tools, special tools, and parts needed to make adjustments
- Photos and videos showing how to make the adjustment
- The steps required to correct the alignment, including:
  - The correct size and placement of shims (front and rear)
  - How much to turn an eccentric
  - How much to move an arm mounted in the slot
  - How much and in what direction to adjust the tie-rod
- Prints a summary and the results of the work

Normally an alignment rack is part of the alignment machine's package. The rack is best described as a limited-purpose vehicle hoist (lift) equipped with turning radius plates. Some alignment racks incorporate features such as powered locking and unlocking of turn plates and inflation stations for checking and setting tire pressure.

CUSTOMER CARE

Many of the alignment machines have printers that allow the customer to see a before-and-after picture of what the technician did. Along with these readings are the specifications. This is a great tool to gain a customer's confidence in your service, so offer him or her a copy when you have completed an alignment.

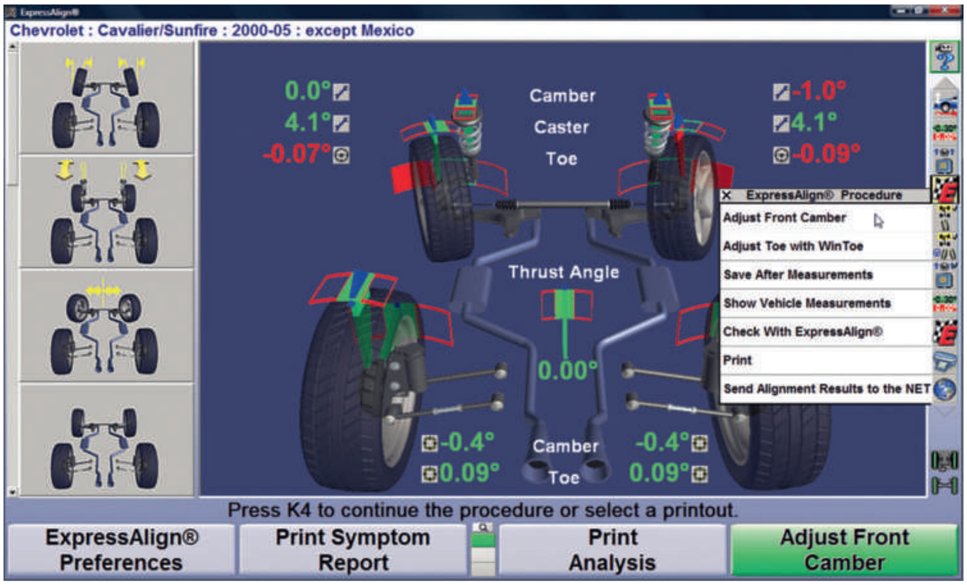


FIGURE 49–19 Examples of the screens available on the latest alignment machines.

Two-Wheel Alignment

Two-wheel alignment equipment aligns the front wheels to the geometric centerline, assuming that the rear wheels are square with respect to the centerline. If this is true, this type of alignment produces satisfactory results. If not, steering and tracking might be a problem.

Four-Wheel Alignment

Four-wheel (or **total wheel) alignment** sets the alignment angles on all four wheels so they are positioned straight ahead with the steering wheel centered. The wheels and axles must also be parallel to one another and perpendicular to a common centerline. More than 85 percent of all new vehicles require that all four wheels be aligned.

Four-wheel alignment is the best approach in terms of both accuracy and completeness for wheel alignment because it references the front wheels to the rear wheels. The first step during an alignment is adjusting rear camber and toe or bringing the rear axle or wheels into square with the chassis. The front caster, camber, and toe settings can then be adjusted.

Performing an Alignment

All wheel alignment angles are interrelated. Regardless of the make of a car or the type of suspension, the same adjustment order—rear camber, rear toe, front caster, camber, toe—should be followed. Some MacPherson suspensions do not provide for caster or camber adjustments. However, there are some aftermarket kits that allow for these adjustments. Additionally, adjustment methods vary from model to model and, occasionally, even among different model years.

After the vehicle is properly placed on the rack and turn tables, vehicle information is input into the machine and the wheel units (heads) are installed. On some machines, the wheel units or heads must be compensated for wheel run-out. When compensation is complete, caster and toe-out-on-turns is checked and alignment measurements are displayed. Also displayed are the specifications for that vehicle. In addition to the normal alignment specifications, the machine may display asymmetric tolerances, different left- and right-side specifications, and cross specifications (the difference allowed between the left and right sides). Graphics and text on the screen show the technician where and how to make adjustments **(Figure 49–20)**. As the adjustments are made on the vehicle, the technician can observe the center block slide toward the target. When the block aligns with the target, the adjustment is within half the specified tolerance. A typical procedure for checking the alignment of all four wheels with a computerized alignment machine is shown in Photo Sequence 47.

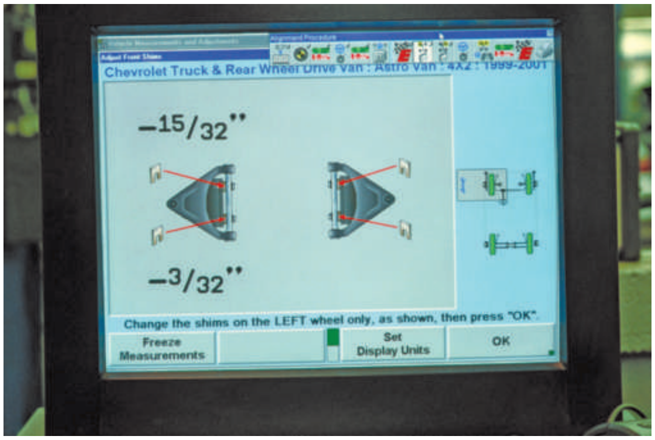


FIGURE 49–20 On many wheel alignment machines, the screen shows how and where to make adjustments.

Specifications

All angles and measurements should be set to the manufacturer's specifications. These specifications usually list a preferred angle for camber, caster, and toe. They are also listed with a minimum and maximum specification, sometimes listed as a plus or minus **(Figure 49–21)**. When making adjustments, you should attempt to achieve the preferred angle. If this is not possible, make sure the measurements are within the minimum and maximum range. If you cannot make an adjustment within that range, something is wrong and the suspension and frame should be careful checked.

In most cases, the bolts or nuts need to be loosened to make the necessary adjustments. Make sure that all of these are retightened to the required torque.

Toe-in (total): 0 ± 0.08 in. (0 ± 2 mm)
Wheel turning angle–inside wheel: 38.37° ± 2°
  Outside wheel reference: 33.55°
Camber: −0.67° ± 0.75°
  Right-left difference: 0.75° or less
Caster: 3.00° ± 0.75°
  Right-left difference: 0.75° or less
Steering axis inclination: 12.25° ± 0.75°
  Right-left difference: 0.75° or less
Rear toe-in (total): 0.16 ± 0.08 in. (−4 ± 2 mm)
Rear camber: −1.30° ± 0.75°
  Right-left difference: 0.75° or less

FIGURE 49–21 An example of alignment specifications.

PHOTO SEQUENCE 47

Typical Procedure for Performing Four-Wheel Alignment with a Computer Wheel Aligner

P47-1 Position the vehicle on the alignment rack.

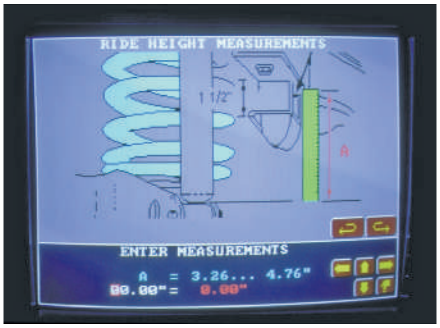
P47-2 Make sure the front tires are positioned properly on the turn tables.

P47-3 Position the rear wheels on the slip plates.

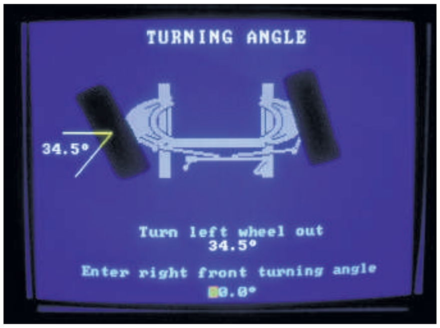
P47-4 Attach the wheel units. Make sure the wheel is raised before attaching an electronic wheel unit.

P47-5 Select the vehicle make and model year.

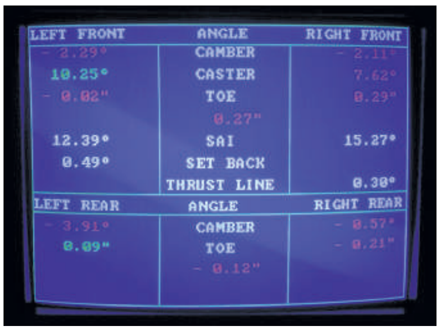
P47-6 Check the items on the screen before the preliminary inspection.



P47-7 Display the ride height screen. Check the tire condition for each tire on the tire condition screen.



P47-8 Measure the turning angle.



P47-9 Display the front- and rear-wheel alignment angle screen.

P47-10 Display the adjustment screen.

Performance TIP *If you want to improve the vehicle's handling, for the street only, you can do this by aligning the wheels to improve the tire's road contact, while staying within the manufacturer's acceptable ranges. To do this, set negative camber to the maximum allowable, the maximum positive caster, and the preferred toe settings.*

Rear-Wheel Camber Adjustments

Like front camber, rear camber affects both tire wear and handling. The ideal situation is to have zero running camber on all four wheels to keep the tread in full contact with the road for optimum traction and handling.

Camber is not a static angle. It changes as the suspension moves up and down. Camber also changes as the vehicle is loaded and the suspension sags under the weight.

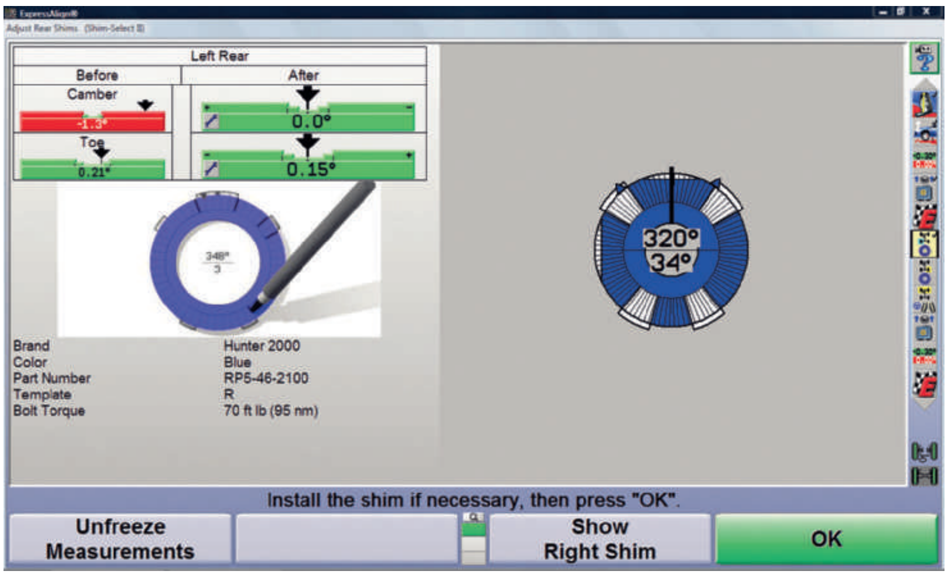
To compensate for loading, some vehicles with independent rear suspension often call for a slight amount of positive camber. Other vehicles, particularly sports cars, tend to use negative camber. This enhances the handling abilities of the car. A collapsed or mislocated strut tower, bent strut, collapsed upper control arm bushing, bent upper control arm, sagging spring, or an overloaded suspension can cause the rear wheels to have negative camber. A bent spindle or strut or bowed lower control arm can cause too much positive camber. Even rigid rear axle housings in rear-wheel drive vehicles can become bowed by excessive torque, severe overloading, or road damage.

Caution! Before lifting the rear of a FWD vehicle, make sure you are using the correct lift point. Never jack on rear control arm rods or rear tie-rods. The weight of the vehicle may cause the parts to bend and result in misalignment of the rear wheels. Always lift the vehicle at the recommended lifting points.

Besides wearing the tires unevenly across the tread, uneven side-to-side camber (as when one wheel leans in and the other does not) creates a steering pull just like it does when the camber readings on the front wheels do not match. It is like leaning on a bicycle. A vehicle always pulls toward a wheel with the most positive camber. If the mismatch is at the rear wheels, the rear axle pulls toward the side with the greatest amount of positive camber. If the rear axle pulls to the right, the front of the car drifts to the left, and the result is a steering pull even though the front wheels may be perfectly aligned.

The methods used to adjust rear suspensions vary. On some semi-independent suspensions, camber and toe are adjusted by inserting different sizes of shims or a full contact shim between the rear spindle and the spindle mounting **(Figure 49–22)**. The shim thickness is changed between the top or bottom of the spindle to adjust camber. Many shims are now available that are round but have different thicknesses through their diameters. Most alignment computers can display exactly how to install a rear shim to set camber and toe at the same time.

On others, a camber adjustment can be made by installing a wedge spacer between the top of the knuckle and the strut. Many rear suspensions have



Courtesy of Hunter Engineering Company.

FIGURE 49–22 A computer screen showing how the adjusting shim should be installed to correct camber and toe at the rear of the vehicle.

eccentric bolts and cams at the mounting points for the control and/or trailing arms **(Figure 49–23)**.

Remember that rear camber is adjusted first. Once the rear camber is set, rear toe is adjusted. Once the rear wheels are properly aligned, the thrust line should be parallel with the vehicle centerline and the front-wheel alignment checked and adjusted.

Rear Toe Rear toe, like front toe, is a critical tire wear angle. If toed-in or toed-out, the rear tires scuff just like the front ones. Either condition can also contribute to steering instability as well as reduced braking effectiveness. Keep this in mind with antilock brake systems.

Like camber, rear toe is not a static alignment angle. It changes as the suspension goes through jounce and rebound. It also changes in response to rolling resistance and the application of engine torque. With FWD vehicles, the front wheels tend to toe-in under power while the rear wheels toe-out in response to rolling resistance and suspension compliance. With RWD vehicles, the opposite happens, the front wheels toe-out while the rear wheels on an independent suspension try to toe-in as they push the vehicle ahead.

If rear toe is not within specifications, it affects tire wear and steering stability just as much as front toe. A total toe reading that is within specifications does not necessarily mean the wheels are properly aligned—especially when it comes to rear toe measurements. If one rear wheel is toed-in while the other is toed-out by an equal amount, total toe would be within specifications. However, the vehicle would have a steering pull because the rear wheels would not be parallel to center. The thrust line will also show as off, in this case.

FIGURE 49–23 An independent rear suspension may have eccentric cams at all of its control arms, one for camber adjustment and another for toe adjustment.

Remember, the ideal situation is to have all four wheels at zero running toe when the car is traveling down the road. This is especially true with antilock brakes, where improper toe can affect brakes; such a condition can affect brake balance when braking on slick or wet surfaces, causing the antilock brakes to cycle on and off to prevent a skid. Without antilock brakes, this condition may upset traction enough to cause an uncontrollable skid.

Rear toe may be adjusted by adjusting a tie-rod, similar to those found in the front steering linkage, by eccentric bolts, or by moving slotted control arms.

Thrust Line

If both rear wheels are square to one another and the rest of the vehicle, the thrust line is perpendicular to the rear axle and coincides with the vehicle's centerline. But if one or both rear wheels are toed in or out, or one is set back slightly with respect to the other, the thrust line is thrown off-center.

The thrust angle **(Figure 49–24)** is eliminated by aligning the rear axle with the geometric centerline of the vehicle and then adjusting the toe of the front wheels. This is normally done during a four-wheel alignment if the rear toe is adjustable. In most cases, doing this will also center the steering wheel. If the thrust angle is ignored and front toe is set to the geometric centerline, the steering wheel will be off-center.

Four-wheel-alignment machines check the toe at each wheel. An incorrect thrust line may be caused by unequal amounts of toe at the rear wheels. Therefore, each rear wheel should be adjusted to the same toe specification. On most FWD vehicles and those with adjustable rear toe, this can be easily done by using the factory-provided toe adjustments, by placing toe/camber shims between the rear spindles and axle, or by using eccentric bushing kits.

On RWD vehicles that have a solid rear axle, changing rear toe is not as easy **(Figure 49–25)**. Sometimes the floor pan or frame rails are misaligned from the factory or from collision damage. Short of straightening the chassis on a collision bench to restore the correct control arm or spring-mount geometry, the only other options are to try some type of offset trailing arm bushing with the coil springs, or to reposition the spring shackles or U-bolts with leaf springs.

If rear toe cannot be easily changed, the next best alternative is to align the front wheels to the rear axle thrust line rather than the vehicle centerline. Doing this puts the steering wheel back on center and eliminates the steering pull—but it does not eliminate tracking.

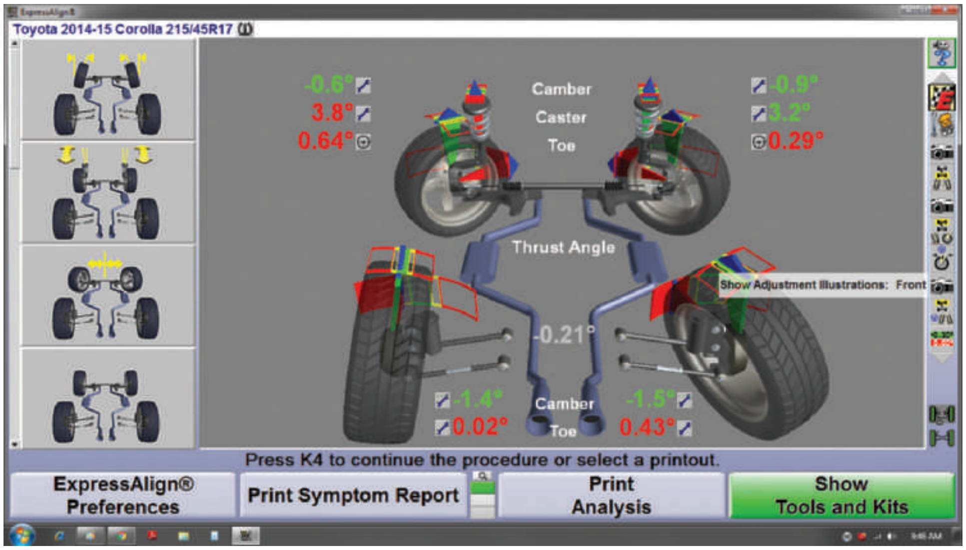


FIGURE 49–24 The thrust angle is the angle between the geometric centerline of the vehicle and the thrust line.

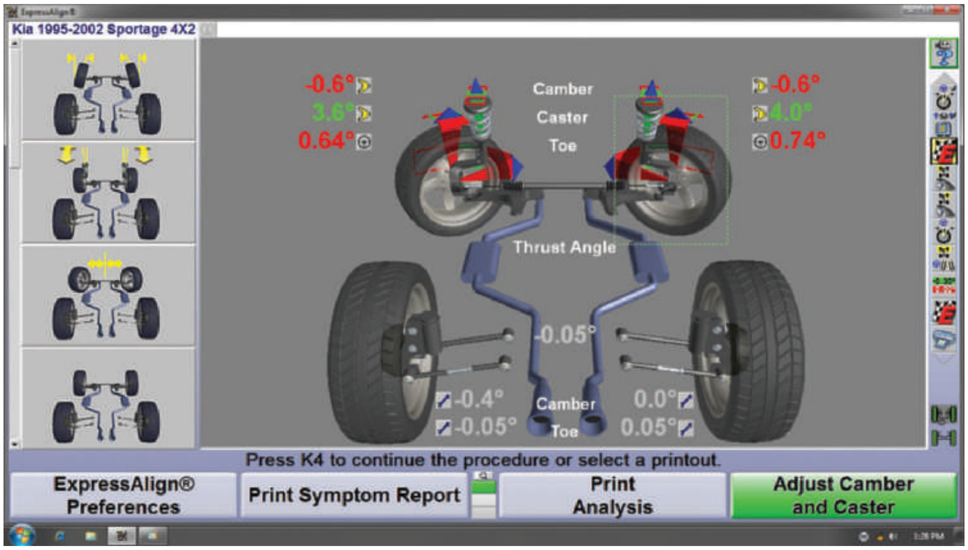


FIGURE 49–25 Thrust angle and a vehicle with non-adjustable rear toe.

Caster/Camber Adjustment

Caster affects steering stability and steering wheel returnability. Zero (0) caster is present when the upper ball joint or top strut bearing and lower ball joint are in the same plane as viewed from the side of the vehicle. Positive caster exists when the upper ball joint or top strut bearing is toward the rear of the vehicle in relationship to the lower ball joint. When the upper ball joint or top strut bearing is toward the front of the vehicle in relationship to the lower ball joint, negative caster is present. If the caster at both wheels is not equal, the vehicle will tend to drift toward the side with the lowest caster.

Camber is the inward or outward tilt of the top of the wheel. Adjusting camber centers the vehicle's weight on the tire. Proper camber adjustment minimizes tire wear. Zero (0) camber is present when the wheel is at a perfectly vertical position. The tires have positive camber when the top of the tire is tilted out, or away from the engine. When the top of the tire is tilted in, there is negative camber. Incorrect camber will cause excessive stress and wear on suspension parts. Too much negative camber will cause wear on the inside tread of the tire, whereas too much positive camber will cause tire wear on the outside tread. If camber is not the same on both wheels, the vehicle will pull toward the side with the most positive camber.

SHOP TALK

Sometimes it is impossible to adjust the camber to specifications. When this happens, suspect a poorly seated wheel hub and hearings, a bent frame, weak springs, a bent steering knuckle, or a bent control arm.

Adjusting for Road Crown To compensate for road crown, most alignment specifications allow for slightly different caster and camber specifications on each side of the vehicle. This difference causes the vehicle to naturally pull slightly to the left to overcome the natural pull of the road to the right.

Typically, specifications call for slightly more negative camber (approximately ¼ degree) on the right side of the vehicle. Or the caster on the left should be set with slightly more negative caster (approximately ¼ degree).

Adjusting Caster and Camber

Several methods are used to adjust caster and camber; always check the service information to determine how the alignment angles can be changed. Most current wheel alignment machines feature illustrations, pictures, or videos of what should happen and where.

Camber on nearly all front suspensions is adjustable, although installing special bolts or making modifications to the strut or knuckle may be needed. On strut-equipped vehicles, camber can be adjusted by moving the top of the strut mount or by adjusting an eccentric bolt located where the strut attaches to the steering knuckle. Caster is adjustable on some strut-equipped vehicles. This is done by again moving the top of the strut. Typically, there is no provision for adjusting caster. Vehicles that have no simple means for adjusting camber or caster require the installation of special kits from the aftermarket to obtain the correct angles. These kits basically contain an adjustable strut mount that permits the top of the strut to move front to back and left to right.

On other vehicles, the upper or lower control arm is used to adjust camber and caster. This is done by adding or removing shims between the control arm and the frame or by rotating an eccentric shaft or eccentric washers. Two bolts attach the control arm to the frame. An equal amount of shims is placed behind or in front of both bolts to correct camber. To gain more negative camber, the lower control arm must be moved outward or the upper arm moved inward. The opposite is true for gaining positive camber.

Caster is adjustable on all vehicles with an upper and a lower control arm. This is done by rotating an eccentric bushing at one of the pivot points for the control arm or adding or subtracting shims between a control arm and the frame.

SHOP TALK

When the vehicle has been aligned to compensate for road crown, it will pull to the left when it is traveling on a flat road or on a road that is angled to the left.

Shims Many cars use shims for adjusting caster and camber **(Figure 49–26)**. The shims can be located between the control arm pivot shaft and the inside of the frame. Both caster and camber can be adjusted in one operation requiring the loosening of the shim bolts just once. Caster is changed by adding or subtracting shims from one end of the pivot shaft only. Then, camber is adjusted by adding or subtracting an equal amount of shims from the front and rear bolts. This procedure allows camber to change without affecting the caster setting.

Some cars use shims located between the control arm pivot shaft and the outside of the frame.

SHOP TALK

A feature of some alignment machines makes the job of adjusting camber and caster much easier and quicker. The feature has many names; the most common one is “jack and hold.” This allows for caster and camber adjustments with the wheels off the ground. The advantage here is simply more room to work, and the vehicle’s weight is off the adjusting points. Although camber and caster will change when the wheel is lifted, the machine will display the reading before the wheel was raised. This allows you to make adjustments and monitor them just as if the vehicle was sitting flat. Of course all measurements should be verified after the wheels are back on the ground.

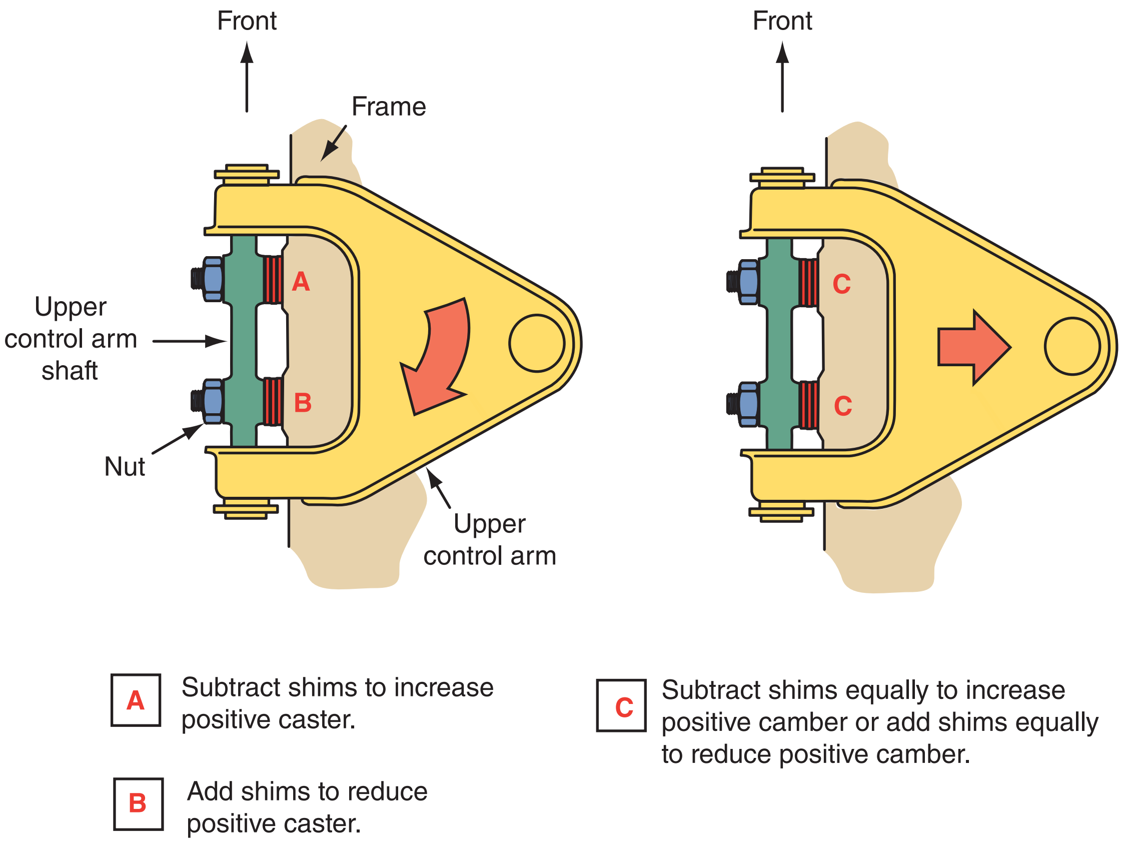


FIGURE 49–26 Adding and subtracting shims between the control arm and the frame will change caster and camber.

The adjustment procedure is the same as just described. Always look at the shim arrangements to determine the desired direction of change before loosening the bolts.

Eccentrics and Shims Eccentrics and shims are used on some vehicles to adjust caster and camber. In some designs, an eccentric bolt and cam on the upper control arm adjust both caster and camber. To adjust, the nuts on the upper control arm are loosened first. Then, one eccentric bolt at a time is turned to set caster. Both bolts are turned equally to set camber.

The eccentric bolt and cam assembly **(Figure 49–27)** can be located on the inner lower or upper control arm. Unlike other designs, camber is adjusted first. Some car models have a camber eccentric between the steering knuckle and the upper control arm. The camber eccentric is rotated to set camber **(Figure 49–28)**. Caster is set with an adjustable strut rod.

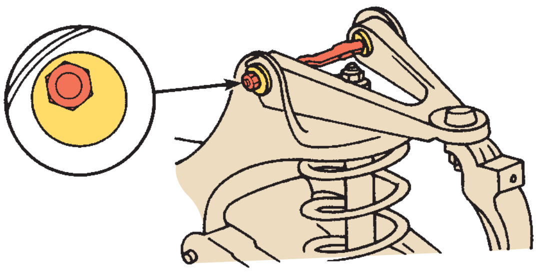


FIGURE 49–27 Eccentric bolt and cam, shown on an upper control arm.

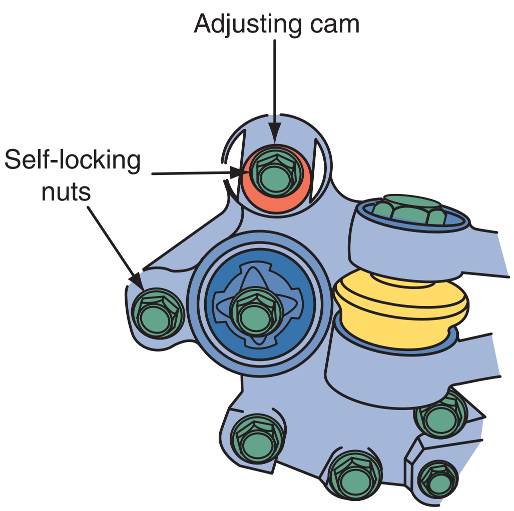


FIGURE 49–28 Graduated cam for adjusting camber.

Slotted Frame The slotted frame adjustment has slotted holes under the control arm inner shaft that allow the shaft to be repositioned to the correct caster and camber settings. Caster and camber adjusting tools help in making adjustments. One end of the shaft is moved for caster adjustment. Both ends of the shaft are moved for camber adjustment. Turning a nut on one end of the rod changes its length and adjusts caster. Camber is set by an eccentric at the inner end of the lower control arm, or by a camber eccentric in the steering knuckle of the upper support arm, as described earlier.

Ball Joint Stud Bushings Some suspension systems have an eccentric bushing at the top of the steering knuckle. This bushing can be used to adjust camber and camber. The bore for the ball joint stud through the bushing is off-center. Rotating the bushing moves the wheel's geometry. If the correct alignment cannot be attained by rotating the bushing, replacement bushings are available. You will need to obtain a bushing that changes the caster and/or camber specific amounts.

MacPherson Suspension Adjustments

Caster/camber adjustments are made only on certain models with MacPherson suspensions. There are two general OEM procedures for doing this, although aftermarket kit adapters are available for some models. Service information must be consulted for an accurate listing of models on which adjustments can be made.

In one version, a cam bolt at the base of the strut assembly is used to adjust camber **(Figure 49–29)**.

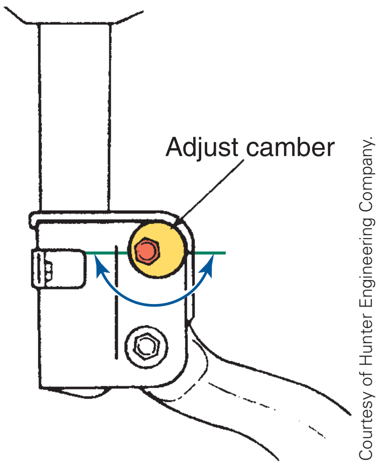


FIGURE 49–29 Some MacPherson suspensions use cam bolts at the connection to the steering knuckle for camber adjustments.

On different models, this bolt can be either the upper or the lower of the two bolts connecting the strut assembly to the steering knuckle. Both bolts must be loosened to make the adjustment, and the wheel assembly must be centered. Turn the cam bolt to reach the correct alignment, then retighten the bolts to the appropriate torque specifications. There is no caster adjustment on this version.

To change the camber on some struts, the mounting holes in the strut where it attaches to the steering knuckle are enlarged. Extending the holes allows the strut to move relative to the knuckle, changing the camber.

In the other form of kit adapter, both caster and camber are adjustable at the strut upper mount. Slots in the mounting plate permit the strut assembly to be shifted to reach the alignment specifications. To adjust caster, loosen the three locknuts on the mounting studs and relocate the plate. Do not remove the nuts **(Figure 49–30)**. Loosen the center locknut and slide it toward or away from the engine as needed to adjust camber correctly.

While caster cannot be adjusted on many MacPherson strut front suspensions, camber can be adjusted. The camber is such that, although it is locked in place with a pop rivet, it can be adjusted by removing the rivet from the camber plate and loosening the three nuts that hold the plate to the body apron **(Figure 49–31)**. Camber is changed by moving the top of the shock strut to the position in which the desired camber setting is achieved. The nuts are then tightened to specifications. (It is not necessary to install a new pop rivet.)

Toe Adjustment

Toe is the last alignment angle to be set. The same procedure is followed on all vehicles, except those with bonded ball stud sockets. Correct toe will minimize tire wear and rolling friction.

To adjust toe, start by being sure the steering wheel is centered **(Figure 49–32)** when the front wheels point straight ahead. Using a steering wheel holder, secure the steering wheel in that position. Many steering wheel holders are installed between the steering wheel and the top of the front seat. Then loosen the retaining bolts on the tie-rod adjusting sleeves. Turn the sleeves to move the tie-rod ends **(Figure 49–33)**.

Some manufacturers of alignment machines recommend that a steering wheel holder not be used. Instead, a steering wheel angle gauge is used to ensure that the steering wheel is centered.

On many rack and pinion systems, the tie-rod locknut must be loosened and the tie rod rotated to

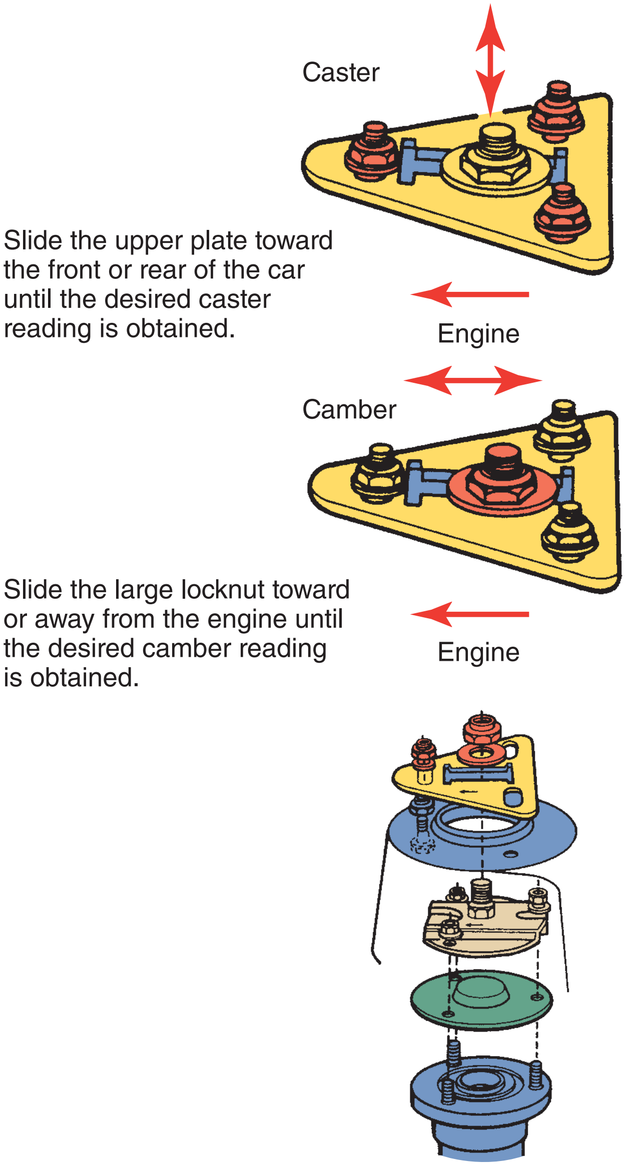


FIGURE 49-30 Caster and camber adjustment of locknuts.

FIGURE 49-31 An upper strut mount with a camber plate. Note the location of the rivet and the attaching bolts.

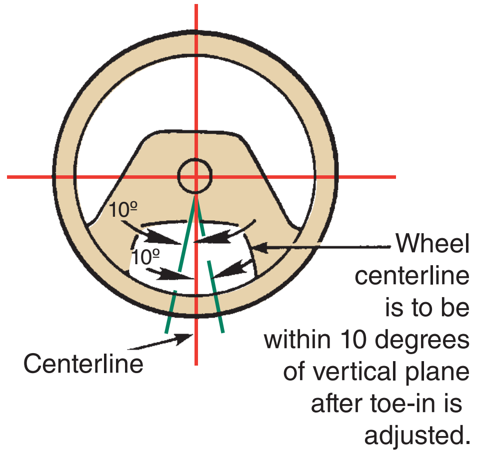


FIGURE 49-32 A typical acceptable steering wheel position—measured from a normal spoke angle.

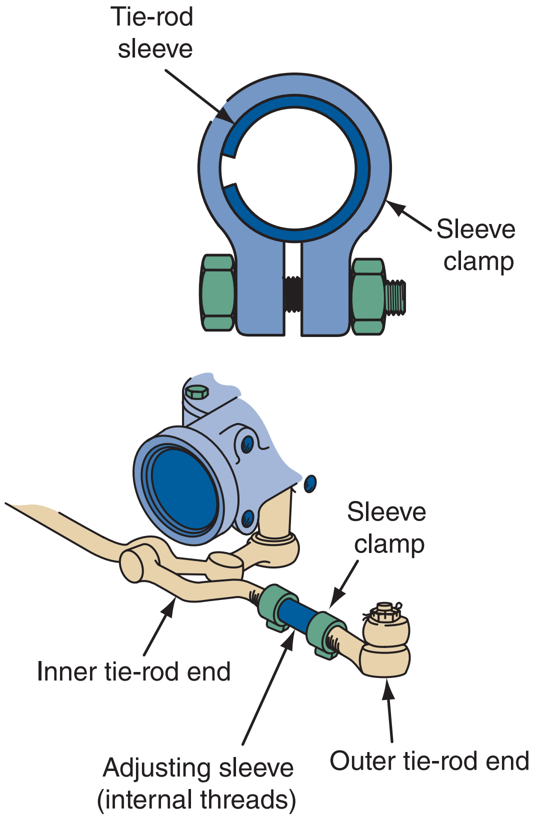


FIGURE 49-33 To adjust toe, the sleeve clamps on the tie-rod assembly are loosened and the sleeve is rotated.

adjust toe at each wheel **(Figure 49–34).** Before rotating the tie-rod, the small outer bellows clamp must be loosened to prevent the boot from twisting.

Other rack and pinion tie-rod ends have internal threads and a threaded adjuster. One end of the adjuster has right-hand threads, the other has left-hand threads. As the adjuster is turned, it changes the overall length of the tie-rod, thereby changing toe.

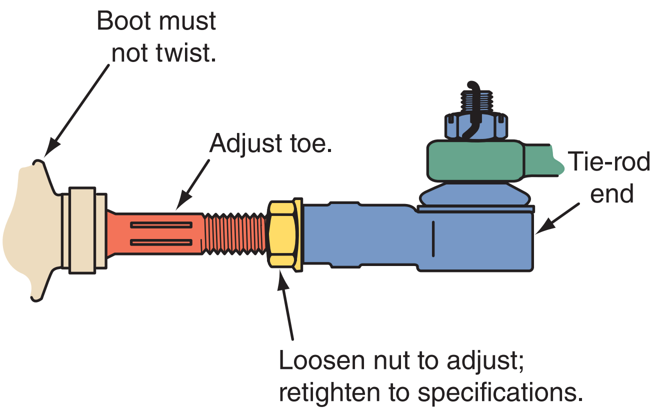


FIGURE 49-34 Rotating the tie-rod to adjust the toe on a rack and pinion steering gear.

> **SHOP TALK** If you are unable to adjust the toe to specifications, check for a bent lower control arm, worn or stripped tie-rod sleeves, a bent tie-rod, or a bent frame.

An ideal toe condition is both wheels exactly straight ahead, which would minimize tire wear. This, however, is not possible because of the many factors affecting alignment. As a result of these numerous conditions dealing with both tire wear and handling, all suspensions are designed with a slight toe-in or toe-out.

Any misalignment of the steering linkage pivot point or control arm pivot point (such as the center link or rack and pinion out of place) causes the condition known as **toe-change**. Toe-change involves turning the wheels from their straight-ahead position as the suspension moves up and down.

The change might be only one wheel, both wheels in the same direction, or both wheels in the opposite direction. Regardless of the condition, any change of one or more wheels is a toe-change condition. The results are tire wear and a hard-to-handle vehicle. The poor handling effects can get to the point that the vehicle is dangerous to drive.

Toe change is not a specification; it is a condition in which the toe setting constantly varies. It must be determined by equipment or a method that measures individual wheel toe at all suspension heights. There must be a change in suspension heights for any changes to occur.

Lightweight front-wheel drive vehicles can be affected greatly by toe-change. With these vehicles, the front wheels are no longer being pushed. They actually pull the vehicle forward and, as a result, if the wheels are not maintaining a straight-ahead position, they affect directional control. Adverse road conditions, such as wet or icy conditions, can also increase the handling effects created by toe-change in the front-wheel drive car.

Setback

Setback is a condition when one wheel on an axle is set behind the other **(Figure 49–35)**. This means the distance between the centers of the tires on one side of the vehicle will be different than on the other side. Like the thrust angle, setback will cause an off-centered steering wheel. Most alignment machines measure setback. Excessive setback is evident by a reading of more than ¼ inch (6.35 mm). Setback is typically caused by a bent suspension part, problems with the upper strut mount, or a misaligned lower control arm. It can also be caused by a misaligned front cradle **(Figure 49–36)**. If the setback is slight, the difference will be compensated during a good four-wheel alignment.

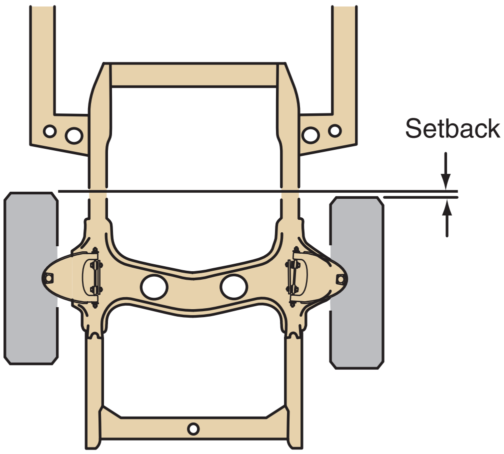


FIGURE 49-35 Setback is a condition when one wheel on an axle is set behind the other.

FIGURE 49-36 Collision damage or dropping the powertrain can cause cradle misalignment concerns.

Four-Wheel Drive Vehicle Alignment

With front-wheel drive and AWD vehicles, the front wheels are also driving wheels. As the front wheels pull the vehicle, the wheels tend to toe-in when torque is applied. To offset this tendency, the front wheels usually need less static toe-in to produce zero running toe. In fact, the preferred toe alignment specifications in this instance can be zero to slightly toed-out ($^1/_{16}$-inch [1.5 mm]) toe-out.

It is important to note that when the front wheels of a part-time 4WD system are freewheeling, they behave the same as the front wheels in a rear-wheel drive vehicle. That is, they roll rather than pull. The wheels tend to toe-out, so the static toe setting would have to toe-in to achieve zero running toe when driving in the two-wheel mode.

The tires suffer in proportion to toe misalignment. For a tire that is only ⅛-inch (3 mm) off (¼ degree), the tire is scrubbed sideways 12 feet (3.6 meters) for every mile traveled. That may not sound like much, but 12 feet (3.6 meters) of sideways scrub every mile can cut a tire's life in half.

If rapid tire wear seems to be the problem, look for the telltale feathered wear pattern **(Figure 49–37)**. If the wheels are running toe-in, the feathered wear pattern leaves sharp edges on the inside edges of the tread. If the wheels are running toe-out, the sharp edges are toward the outside of the tread. It is usually easier to feel the feathered wear pattern than to see it. To tell which way the wear pattern runs, rub your fingers sideways across the tread.

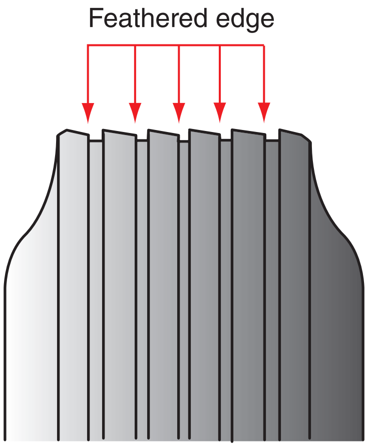


FIGURE 49–37 Incorrect toe can cause a feathered wear pattern.

On most heavy-duty 4WD vehicles, caster is not adjustable. After-market companies do provide caster adjustment kits for some pickups. These kits may contain shims or eccentric cam and bolt. For some pickups, the aftermarket cam kit will also provide for camber adjustments.

On other 4WD vehicles, camber is adjusted by installing adjustment shims between the spindle and the steering knuckle or by installing and/or adjusting an eccentric bushing at the upper ball joint. Most aftermarket parts manufacturers have camber adjustment shims available in various thicknesses and diameters. Never stack the shims. Only one shim per side should be used.

Steering Angle Sensor Calibration

Cars and light trucks that have electric power steering assist and/or vehicle stability control use sensors in the steering column or rack to measure steering shaft angle and torque. When performing an alignment or after work is performed on the steering system, these sensors may require calibration. This includes the removal, replacement or reinstallation of any steering component.

Sensor recalibration procedures vary from relatively simple to requiring a factory scan tool to access the system. Refer to the manufacturer's service information for procedures specific to the vehicle being aligned. Newer alignment machines can alert you to if a vehicle needs calibration **(Figure 49–38)**. The alignment machine may also have the ability to recalibrate the sensor by connecting to the DLC. Some vehicles do not require connecting to the on-board computer system. If the sensor is not recalibrated after an alignment, steering pull, return, and inconsistent effort issues can result.

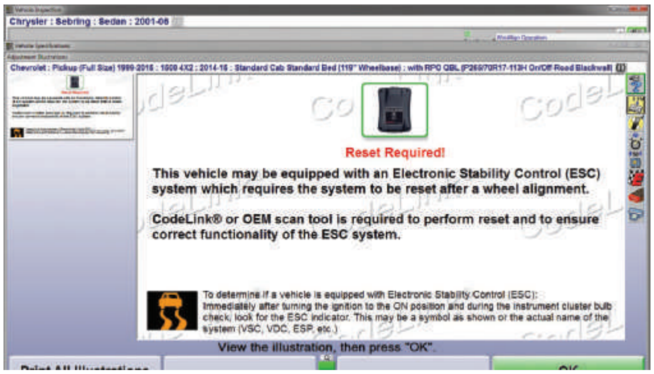


FIGURE 49–38 An example of a vehicle requiring steering sensor recalibration.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2010	**Make:** Honda	**Model:** Civic	**Mileage:** 102,301	**RO:** 19384
Concern:	Customer requested wheel alignment, steering wheel off-center.			
The technician performs a test drive and notes several issues, including aftermarket wheels and non-standard tire sizes, the car appears lower than normal, and confirms the steering wheel is off-center. Once on the alignment rack, the technician notices that lowering springs have been installed and that ride height is much lower than specified. After setting up the alignment machine, the readings indicate excessive negative front and rear camber and that thrust angle and toe are incorrect.				
Cause:	Vehicle has aftermarket suspension components installed affecting camber. Front camber –1.75, rear camber –2.1. No provision for setting camber to specs. Rear toe –0.45, front toe 0.66.			
Correction:	Set rear toe to specs, centered steering wheel and set front toe to specs.			

KEY TERMS

Camber
Caster
Four-wheel alignment
Included angle
Road crown
Setback
Steering axis inclination (SAI)
Thrust angle
Thrust line
Toe
Toe-change
Tracking

SUMMARY

- Caster is the angle of the steering axis of a wheel from the vertical, as viewed from the side of the vehicle. Tilting the wheel forward is negative caster. Tilting backward is positive.
- Camber is the angle represented by the tilt of either the front or rear wheels inward or outward from the vertical as viewed from the front of the car.
- Toe is the distance comparison between the leading edge and trailing edge of the front tires. If the edge distance is less, then there is toe-in. If it is greater, there is toe-out.
- The difference of rear toe from the geometric centerline of the vehicle is called the thrust angle. The vehicle tends to travel in the direction of the thrust line, rather than straight ahead.
- Steering axis inclination (SAI) angles locate the vehicle weight to the inside or outside of the vertical centerline of the tire. The SAI is the angle between the true vertical and a line drawn between the steering pivots as viewed from the front of the vehicle.
- Turning radius or cornering angle is the amount of toe-out present on turns.
- In correct tracking, all suspensions and wheels are in their correct locations and conditions and are aligned so that the rear wheels follow directly behind the front wheels while moving in a straight line.
- It is important to remember that approximately 85 percent of today's vehicles not only undergo front-end alignment but require rear-wheel alignment as well.
- The primary objective of four-wheel or total-wheel alignment, whether front or rear drive, solid axle, or independent rear suspension, is to align all four wheels so the vehicle drives and tracks straight with the steering wheel centered. To accomplish this, the wheels must be parallel to one another and perpendicular to a common centerline.

REVIEW QUESTIONS

Short Answer

1. Define camber.
2. What tire wear pattern will result from excessive toe-in?
3. What can be caused by excessive negative caster?

4. Describe the difference between toe-in and toe-out.
5. Describe thrust angle and why it is important for wheel alignment.
6. What can cause incorrect toe-out-on-turns?
7. In what direction must the bottom of a tire and wheel assembly be moved to add more positive camber?
8. What is scrub radius and why is it important?
9. Define the term *tracking* as it applies to vehicle handling.
10. Describe how caster adjustment may be used to compensate for road crown.
11. A 3-degree difference in the SAI angle on each side of the front suspension may cause a FWD vehicle to have increased ___ during hard acceleration.
12. What is the correct sequence for adjusting alignment angles during a four-wheel alignment?

Multiple Choice

1. Which of the following is a good definition of SAI?
   a. Forward tilt of the top of the steering knuckle
   b. Rearward tilt of the spindle steering arm
   c. Inward tilt of the top of the ball joint or strut
   d. Outward tilt of the top of the ball joint or strut
2. Unequal SAI angles on the left and right sides of the front suspension may cause ___.
   a. tread wear on the front tires
   b. brake pull during sudden stops
   c. ball joint wear
   d. steering wander while driving straight ahead
3. While driving straight, a FWD car pulls to the right. The most likely cause is ___.
   a. more positive camber on the left front wheel compared to the right front wheel
   b. sagged front springs and improper front-wheel toe setting
   c. less positive caster on the right front wheel compared to the left front wheel
   d. the SAI on the right front wheel is 1½ degrees more than the SAI on the left.

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that negative caster provides directional stability. Technician B says that positive caster results from excessive positive camber. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Technician A says that the purpose of the steering wheel holder is to make sure that the steering wheel is centered after the alignment. Technician B says that if the steering wheel is not centered after an alignment, it should be pulled off the column and positioned correctly. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. Technician A says that the presence of a thrust angle can cause poor directional stability on ice, snow, or a wet pavement. Technician B says that it can also increase tire wear because the front wheels fight the rear ones for steering control. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. Technician A says that camber changes as the suspension moves up and down. Technician B says that camber changes as the vehicle is loaded and the suspension sags under the weight. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

5. Technician A says that caster can be adjusted on nearly all front suspensions. Technician B says that toe can only be adjusted on front suspensions. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. Technician A says that on FWD vehicles, the front wheels toe-out while the rear wheels on an independent suspension try to toe-in as the vehicle moves ahead. Technician B says that on RWD vehicles, the front wheels tend to toe-in while the rear wheels toe-out in response to rolling resistance and suspension compliance. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. Technician A says that if caster at both wheels is not equal, the vehicle will tend to drift toward the side with the most positive caster. Technician B says that if camber is not the same on both wheels, the vehicle will pull toward the side with the most positive camber. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. While discussing front-wheel caster: Technician A says that high amounts of positive caster increases the steering effort and can increase tire wear. Technician B says that excessive negative caster causes front-wheel shimmy. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. While performing a prealignment inspection: Technician A says that improper front-wheel bearing adjustment may affect wheel alignment angles. Technician B says that worn ball joints affect only the camber angle. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. While performing a prealignment inspection: Technician A says that a prealignment inspection should include checking the vehicle interior for heavy items. Technician B says that tools and other items normally carried in the vehicle should be included during an alignment. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

BRAKE SYSTEMS

CHAPTER 50

OBJECTIVES

- Explain the basic principles of braking, including kinetic and static friction, friction materials, application pressure, and heat dissipation.
- Describe the components of a hydraulic brake system and their operation, including brake lines and hoses, master cylinders, system control valves, and safety switches.
- Perform both manual and pressure bleeding of the hydraulic system.
- Describe the operation of drum and disc brakes.
- Inspect and service hydraulic system components.
- Describe the operation and components of both vacuum-assist and hydraulic-assist braking units.

It is commonly believed that the purpose of a brake system is to slow or halt the motion of a vehicle. However, that is really not true. The friction of the tires against the road is what slows down and stops a vehicle. The brake system slows or stops the rotation of the wheels. This is a minor point but one that extends the responsibility for braking to the tires as well as the brake system.

The brake system converts the momentum of the vehicle into heat by slowing and stopping the vehicle's wheels. This is done by causing friction at the wheels. The application of the friction units is controlled by a hydraulic system. This chapter looks at the basics of all brake systems and gives a detailed look at the hydraulic systems required to stop a vehicle.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2007	**Make:** Chevy	**Model:** Colorado	**Mileage:** 128,787	**RO:** 19028
Concern:	Customer states vehicle lost braking ability—pedal went to the floor several times while towing a trailer on vacation.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

GO TO Chapter 3 for a detailed discussion on friction and its effects.

Friction

There are two basic types of friction that explain how brake systems work: kinetic, or moving, and static, or stationary **(Figure 50–1)**. The amount of friction, or resistance to movement, depends on the type of materials in contact, the smoothness of their rubbing surfaces, and the pressure holding them together (often gravity or weight). Friction always converts moving, or kinetic, energy into heat. The greater the friction between two moving surfaces, the greater the amount of heat produced.

As the brakes on a moving automobile are applied, rough-textured pads or shoes are pressed against rotating parts of the vehicle—either rotors (discs) or drums. The kinetic energy, or momentum, of the vehicle is then converted into heat energy by the kinetic friction of the rubbing surfaces and the car or truck slows down.

When the vehicle comes to a stop, it is held in place by **static friction**. The friction between the surfaces of the brakes and between the tires and the road resists any movement.

Factors Governing Braking

Four basic factors determine the braking power of a system. The first three factors govern the generation of friction: pressure or force against the friction materials, coefficient of friction, and frictional contact surface. The fourth factor is a result of friction. It is heat or, more precisely, heat dissipation.

An additional factor—weight transfer—influences how well a vehicle will stop when the brakes are applied. When the brakes are applied while the vehicle is moving forward, the weight of the vehicle shifts forward. This causes the front of the vehicle to drop or "nose dive." It also means that the front brakes will need the most stopping power. If the vehicle is overloaded or if the front suspension is weak, more weight will be thrown forward and the brakes will need to work harder.

Pressure The amount of friction generated between moving surfaces in contact with each other depends

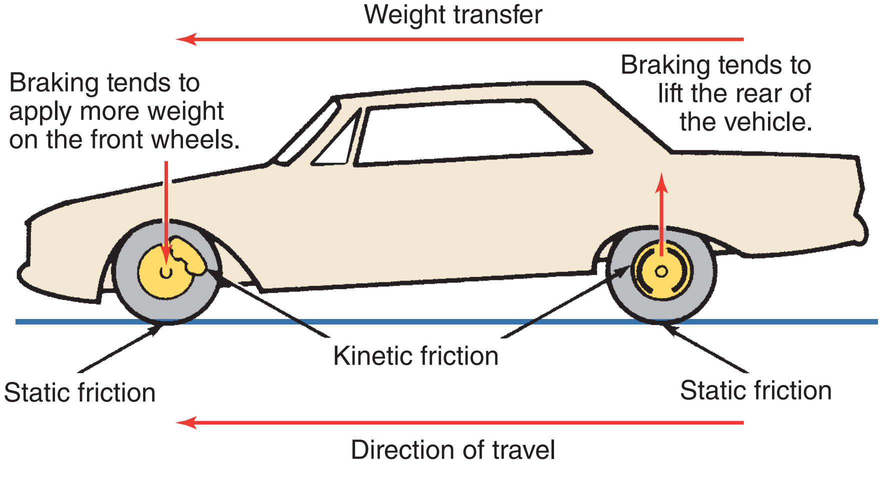


FIGURE 50–1 Braking action creates kinetic friction in the brakes and static friction between the tire and road to slow the vehicle. When brakes are applied, the vehicle's weight is transferred to the front wheels and is unloaded on the rear wheels.

in part on the pressure exerted on the surfaces. For example, if you slowly increase the downward pressure on the palm of your hand as you move it across a desk, you will feel a gradual increase in friction.

In a brake system, hydraulic systems provide application pressure. Hydraulic force is used to move brake pads or brake shoes against spinning rotors or drums mounted to the wheels. The amount of pressure is determined by the pressure on the brake pedal and the design of the brake system.

Coefficient of Friction The amount of friction generated between two surfaces is expressed as a **coefficient of friction (COF)**. The COF is determined by dividing the force required to pull an object across a surface by the weight of the object **(Figure 50–2)**. For example, if it requires 100 pounds (455 N) of pull to slide a 100-pound (45.4 kg) metal part across a concrete floor, the COF is 100 ÷ 100 or 1. To pull a 100-pound (45.4 kg) block of ice across the same surface may require only 2 pounds (9 N) of pull. The COF then would be only 0.02.

As it applies to automotive brakes, the COF expresses the frictional relationship between pads and rotors or shoes and drums. The required COF depends on the vehicle and other factors and is carefully chosen by the manufacturer to ensure safe and reliable braking. Therefore, when replacing pads or shoes, it is important to use replacement parts with similar COF. If, for example, the COF is too high, the brakes will be too sticky to stop the car smoothly. Premature wheel lockup or grabbing would result. If the coefficient is too low, the friction material tends to slide over the surface of the drum or rotor rather than slowing it down. Most automotive friction materials are engineered with a COF of between 0.25 and 0.55.

Frictional Contact Surface The third factor is the amount of surface area that is in contact. Simply put, bigger brakes stop a car more quickly than smaller brakes used on the same car. For the most part, the vehicle's weight and potential speed determines the size of the friction surface areas. Also, the greater the surface areas of the wheel brake units, the faster heat can be dissipated.

Heat Dissipation Any braking system must be able to effectively handle the heat created by friction within the system. The tremendous heat created by the rubbing brake surfaces must be conducted away from the pad and rotor (or shoe and drum) and be absorbed by the air. Brakes that do not effectively dissipate heat experience brake fade during hard, continuous braking.

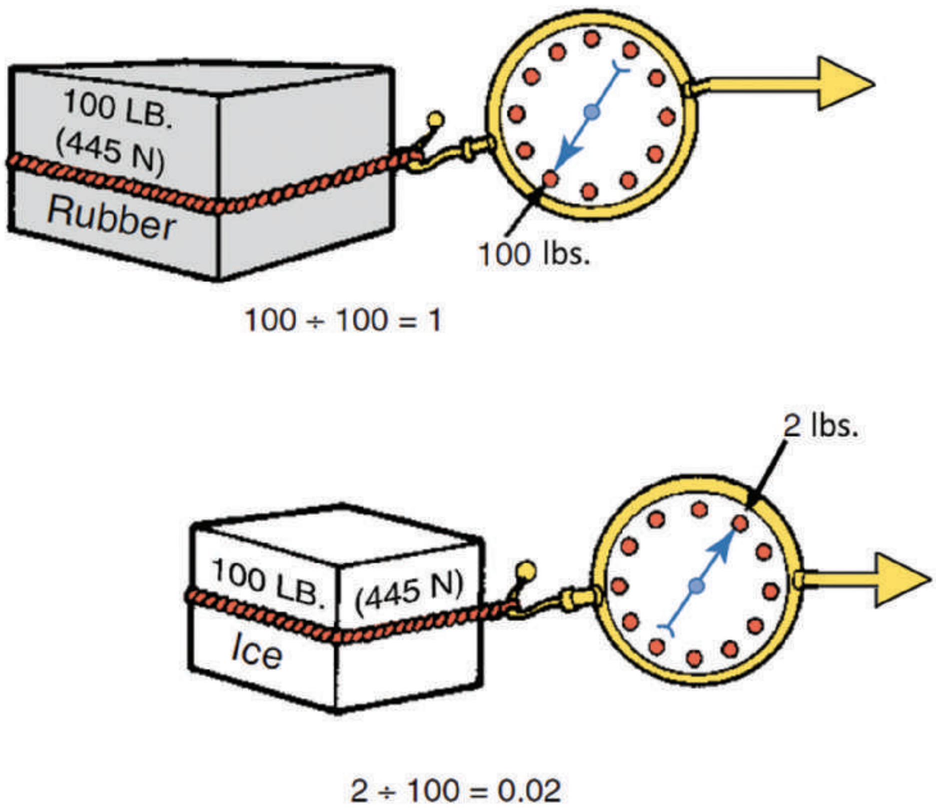


FIGURE 50–2 Coefficient of friction is equal to the pounds of pull divided by the weight of the object.

Brake fade is a condition where the stopping power of the brakes has been drastically reduced. This is commonly caused by excessive heat buildup. With brake fade, the brake pedal seems normal but there is reduced stopping ability. Brake fade may become worse as heat builds up; this may be due to outgassing. As the shoes or pads become extremely hot, they can generate a gas. This gas can become an air bearing between the frictional material and the rotor or drum. Rather than clamp on the wheel brake, the friction elements will slip on the air (gas buildup). Fade can also be caused by overheating the brake fluid because gases form in the fluid.

The friction materials must be able to dissipate heat and the system must be designed to allow the material to get rid of its heat. This may be done by allowing ample airflow past the brake units. Another way is to ventilate the rotors. Ventilated rotors have internal vanes that move the hot air from the disc to the outside **(Figure 50–3)**. Some rotors are cross-drilled or slotted. Both of these designs allow the rotor to run cooler and reduce the chances of gas buildup.

Heat can also cause the linings of the pads and shoes to become glazed and harden the rotor and drum. Therefore, the COF is reduced and excessive

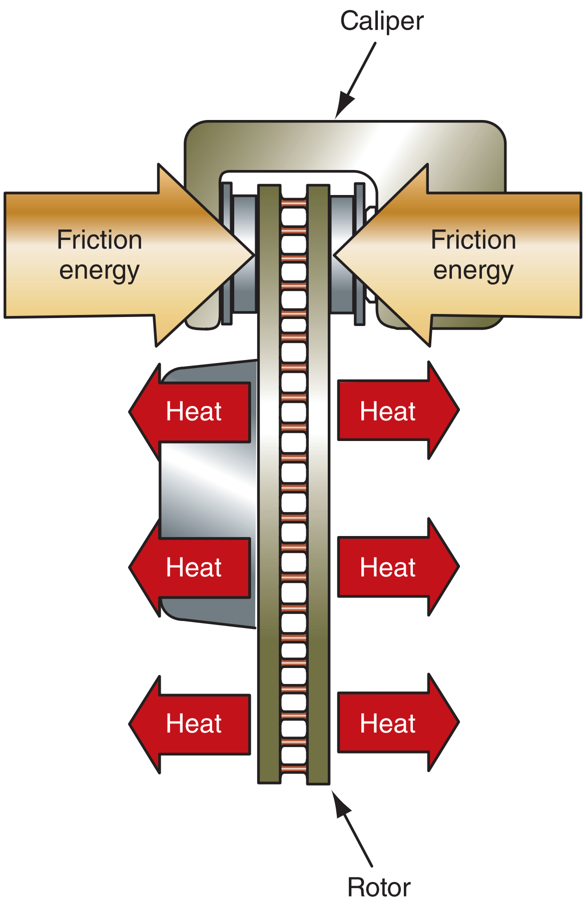


FIGURE 50–3 Heat generated during braking is dissipated as air moves through the rotor.

foot pressure must be applied to the brake pedal to produce the desired braking effect.

Brake Lining Friction Materials

Brake linings are made up relatively soft but tough and heat-resistant material with a high coefficient of friction. The lining is typically attached to a metal backing with rivets or high-temperature adhesives. For many decades, asbestos was the standard brake lining material. It offers good friction qualities, long wear, and low noise. But new materials are being used because of the health hazards of breathing asbestos dust. Asbestos has not been used in brake linings or pads since 2003. Many different materials are used as lining material and the type of lining is defined by its composition. Each type has different heat dissipation, fade resistance, rotor wear, noise generation, and braking force characteristics.

Nonasbestos Organic **Nonasbestos organic (NAO)** linings are installed on many vehicles by the OEM. Organic linings are made of nonmetallic fibers bonded together to form a composite material. Today's organic brake linings contain the following types of materials:

- *Friction materials and friction modifiers.* Some common examples of these are graphite, powdered metals, and even nut shells.
- *Fillers.* Fillers are secondary materials added for noise reduction, heat transfer, and other purposes.
- *Binders.* Binders are glues that hold the other materials together.
- *Curing agents.* These accelerate the chemical reaction of the binders and other materials.

Organic linings have a high COF, and they are economical, quiet, wear slowly, and are only mildly abrasive to rotors and drums. However, organic linings fade more quickly than other materials and do not operate well at high temperatures. High-temperature organic linings are available for high-performance use but they do not work as well at low temperatures. They also wear faster than regular organic linings.

Metallic Linings Fully metallic materials were used for many years in racing. **Metallic lining** is made of powdered metal that is formed into blocks by heat and pressure. These materials provide excellent resistance to brake fade but require high brake pedal pressure; they create the most wear on rotors and drums. Metallic linings work very poorly until they are fully warmed. Improved high-temperature organic linings

and semimetallic materials have made metallic linings almost obsolete for late-model automotive use. Metallic linings are also extremely noisy, which is something that must be considered by customers when choosing the type of brake lining to install on their vehicle.

Semimetallic Linings Semimetallic materials are made of a mixture of organic or synthetic fibers and certain metals molded together. **Semimetallic linings** are harder and more fade resistant than organic materials but require higher brake pedal effort.

Most semimetallic linings contain about 50 percent iron and steel fibers. Copper also has been used in some semimetallic linings and, in smaller amounts, in organic linings. Concerns about copper contamination of the nation's water systems has led to its reduced use in brake linings, however.

Semimetallic linings operate best above 200 °F (93.3 °C) and actually must be warmed up to bring them into full efficiency. Consequently, they are typically less efficient than organic linings at low temperatures.

Semimetallic linings were sometimes used on older heavy or high-performance vehicles with four-wheel drum brakes. Currently, semimetallic linings are used only on the front disc brakes of passenger cars and light trucks. The lighter braking loads on rear brakes, particularly on FWD cars, may never heat semimetallic linings to their required operating efficiency. Semimetallic linings also have a lower static COF than organic linings, which makes them less efficient with parking brakes.

Synthetic Linings The goals of improved braking performance and the disadvantages of the other lining materials have led to the development of **synthetic lining** materials. They are classified as synthetic because they are made of nonorganic, nonmetallic, and nonasbestos materials. Two types of synthetic materials are commonly used as brake linings for drum brakes: fiberglass and **aramid fibers**.

Fiberglass was introduced as a brake lining material to help eliminate asbestos. Like asbestos, it has good heat resistance, good COF, and excellent structural strength. The disadvantages of fiberglass are its higher cost and its reduced friction at very high temperatures. Overall, fiberglass linings perform similarly to organic linings and are used primarily in rear drum brakes.

Aramid fibers are a family of synthetic materials that are five times stronger than steel, pound for pound, but weigh little more than half what an equal volume of fiberglass weighs. Friction materials made with aramid fibers are made similarly to organic and fiberglass linings. Aramid fibers have a COF similar to semimetallic linings when cold and close to that of organic linings when hot. Overall, the performance of aramid linings is somewhere between organic and semimetallic materials but with much better wear resistance and longevity than organic materials.

Ceramic Ceramic linings are found on many FWD vehicles, because they have high heat resistance. Most ceramic pads are made of a ceramic material mixed with copper fibers. These pads are quiet and produce little dust, making them popular as both OE and as aftermarket replacement parts.

Carbon-Metallic/Ceramic Carbon-metallic pads are often used on high-performance cars due to their good COF and high heat resistance. Carbon linings are also able to withstand very high temperatures without causing brake fade. A few aftermarket companies offer linings made of carbon, Kevlar, and various other materials. These also have ceramic heat shields that reduce the amount of heat that can transfer from the linings to the rest of the brake system. Some high-performance cars are fitted with carbon-ceramic pads. These pads are comprised of a ceramic composite of carbon fiber reinforced with silicon carbide. These pads offer excellent braking performance and are extremely lightweight. They also provide a consistent COF through a wide range of temperature and weather conditions.

Low-Copper Compliance Pads

Since 2014, California and Washington States require that brake pad manufacturers phase out linings with copper and other hazardous materials. This is due to the brake dust material contaminating water sources and harming aquatic life.

There are three levels of low-copper pads:

- Level A pads comply with requirements for cadmium, chromium, lead, mercury, and asbestos.
- Level B pads meet Level A requirements and copper content must be reduced to less than 5 percent of the pad material by 2021.
- Level N pads will have less than 0.5 percent total copper by 2025.

Principles of Hydraulic Brake Systems

A hydraulic system **(Figure 50–4)** uses brake fluid to transfer pressure from the brake pedal to the pads or shoes. This transfer of pressure is reliable and consistent because liquids are not compressible. That is,

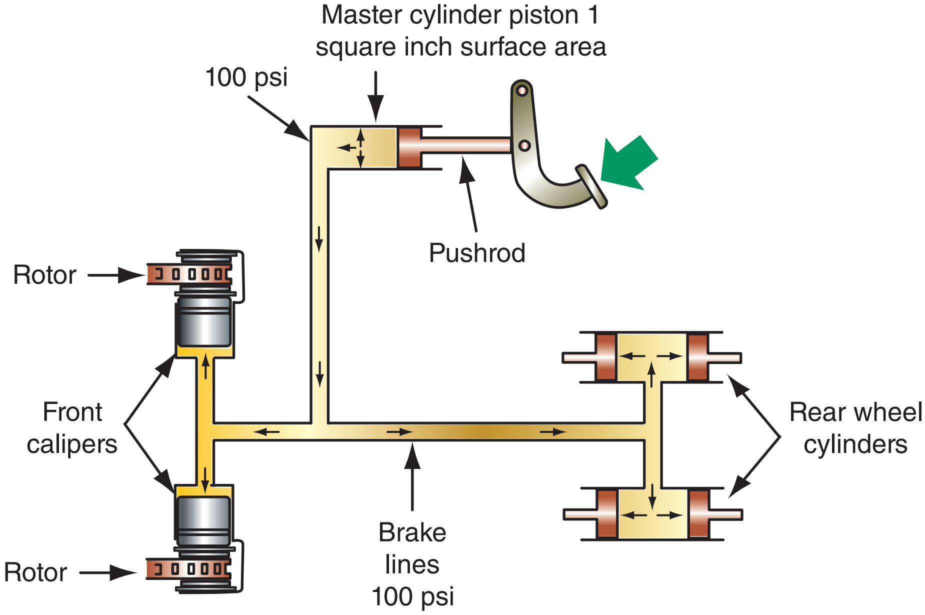


FIGURE 50–4 A schematic of a basic automotive hydraulic brake system.

pressure applied to a liquid in a closed system is transmitted by that liquid equally to every other part of that system. Apply a force of 100 pounds per square inch (psi) (690 kPa) through the master cylinder and you can measure 100 psi (690 kPa) anywhere in the lines and at each wheel where the brakes operate.

GO TO Chapter 3 for a discussion of Pascal's law.

The force can be increased at the output (i.e., at the wheel) by increasing the size of the piston, though piston travel decreases. The force at the output can be decreased by decreasing the size of the piston, but the piston travel increases **(Figure 50–5)**.

To increase the output force of the 100 psi (690 kPa) at the master cylinder to 500 psi (3,450 kPa) at the front wheels, simply use a caliper piston with a surface area of 5 square inches (32 sq. cm). To reduce the force of 100 psi (690 kPa), use a piston with 0.75 square inches (5 sq. cm) and 75 pounds (517 kPa) of output will result. No matter what the fluid pressure is, the output force can be increased with a larger piston, though piston travel decreases proportionately. In this example, 1 inch of travel of the master cylinder piston will result in $^1/_5$ of an inch movement by the caliper piston. In actual practice, fluid movement in an automotive hydraulic brake

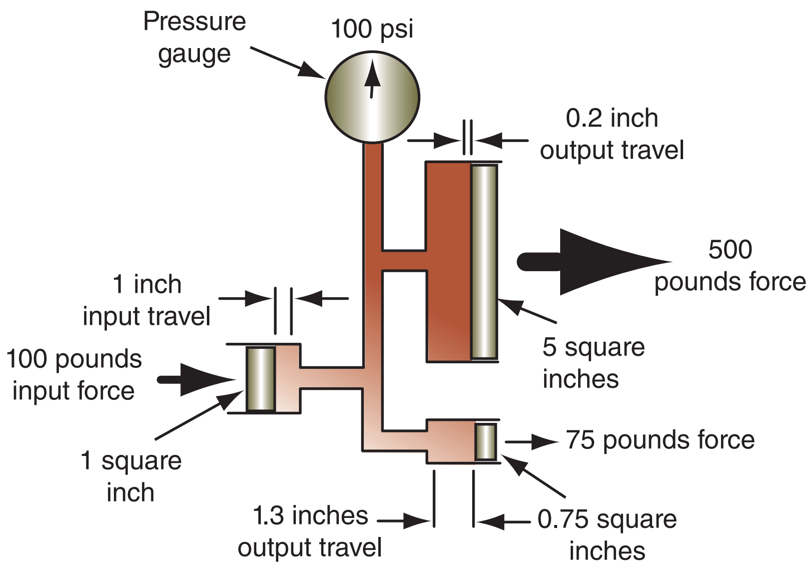


FIGURE 50–5 Output force increases with piston size.

system is very slight. In an emergency, when the pedal goes all the way to the floor, the volume of fluid displaced amounts to only about 20 cubic centimeters. About 15 cubic centimeters goes to the front discs and 5 cubic centimeters goes to the rear drums. Even under these conditions, the wheel cylinder and caliper pistons move only slightly.

Of course, the hydraulic system does not stop the car all by itself. In fact, it really just transmits the action of the driver's foot on the brake pedal out to the wheels. In the wheels, sets of friction pads are forced against rotors or drums to slow their turning and bring the car to a stop. Mechanical force (the driver stepping on the brake pedal) is changed into hydraulic pressure, which is changed back into mechanical force (brake shoes and disc pads contacting the drums and rotors).

The amount of force acting on the friction pads and shoes is determined by the input pressure and output piston sizes. The input pressure is based on $P = F/A$ or pressure is equal to force divided by the area. An input force of 100 pounds acting on a piston with 1 square inch of surface area creates 100 psi. If the piston size is reduced, say to 0.8 inches, pressure increases to 125 psi. Increasing input piston size decreases pressure as the force is applied over a larger area. Output force is equivalent to the pressure applied to the output piston multiplied by the area of the piston or $F = P{\cdot}A$. One hundred psi of pressure in the brake line applied to a caliper piston with 5 square inches of surface area will result in the caliper piston moving with 500 pounds of force.

Dual Braking Systems

Since 1967, federal law has required that all cars be equipped with two separate brake systems. If one circuit fails, the other provides enough braking power to safely stop the car.

The dual system differs from the single system by employing a tandem master cylinder, which is essentially two master cylinders formed by installing two separate pistons and fluid reservoirs into one cylinder bore. Each piston applies hydraulic pressure to two wheels **(Figure 50–6)**.

Front/Rear Split System In early dual systems, the hydraulic circuits were separated front and rear. Both front wheels were on one hydraulic circuit and both rear wheels on another. If a failure occurred in one system, the other system was still available to stop the vehicle. However, the front brakes do approximately 70 percent of the braking work. A failure in the front brake system would only leave 20 percent to 40 percent braking power. This problem was somewhat reduced with the development of diagonally split systems.

Diagonally Split System The diagonally split system operates on the same principles as the front and rear split system.

The hydraulic brake lines on this system, however, have been diagonally split front to rear (left front to right rear and right front to left rear). The circuit split can occur within the master cylinder or

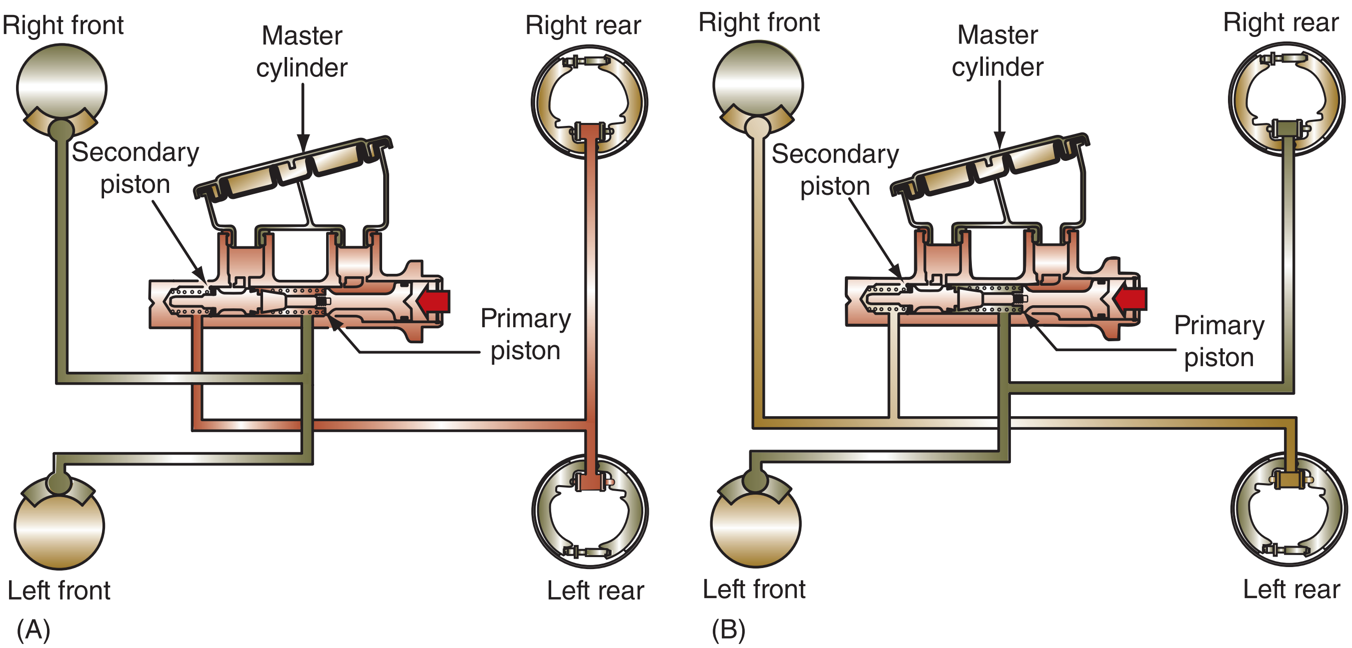


FIGURE 50–6 (A) A front/rear split of the braking system. (B) A diagonal split. The master cylinder is also split to allow pressure only to its designated wheel units.

externally at a proportioning valve or pressure differential switch.

In the event of a system failure, the remaining good system would do all the braking on one front wheel and the opposite rear wheel, thus maintaining 50 percent of the total braking force.

Hydraulic Brake System Components

The following sections describe the major components of a hydraulic brake system, including power-assisted systems and antilock braking systems.

Brake Fluid

Brake fluid is the lifeblood of any hydraulic brake system. It is what makes the system operate properly. Brake fluid is specially blended to perform a variety of functions. Brake fluid must be able to flow freely at extremely high temperatures (500 °F [260 °C]) and at very low temperatures (–104 °F [–75 °C]). Brake fluid also serves as a lubricant for many parts to ensure smooth and even operation. In addition, brake fluid must fight corrosion and rust in the brake lines and various assemblies and components. Another important property of brake fluid is that it must resist evaporation.

Most brake fluids are hygroscopic; that is, they readily absorb water. Moisture can enter the fluid when the fluid is exposed to the atmosphere and while it is in the brake system. For this reason, brake fluid should always be kept in a sealed container and should only be exposed to outside air for limited periods. Moisture also builds up in the fluid due to condensation. The fluid gets hot because of brake applications, and then when at rest it cools. This change in temperature causes condensation. Today's vehicles are more prone to hot brake fluid because there is little airflow under the hood to cool the fluid and braking system.

The performance of brake fluid is affected by moisture. As the amount of water in the fluid increases, the boiling point of the fluid decreases **(Figure 50–7)**. This can cause vapor to build in the system, which could lead to sudden brake failure or an unpredictable spongy pedal. Vapor is a gas and therefore is compressible. When pressure is applied to the brake fluid, it will compress the vapor before moving on through the system if it is able to do so.

The viscosity of the fluid at low temperatures is also affected by the amount of moisture. The viscosity increase, which means the fluid will have a harder time moving through the system, when it is cold. This means poor cold weather braking.

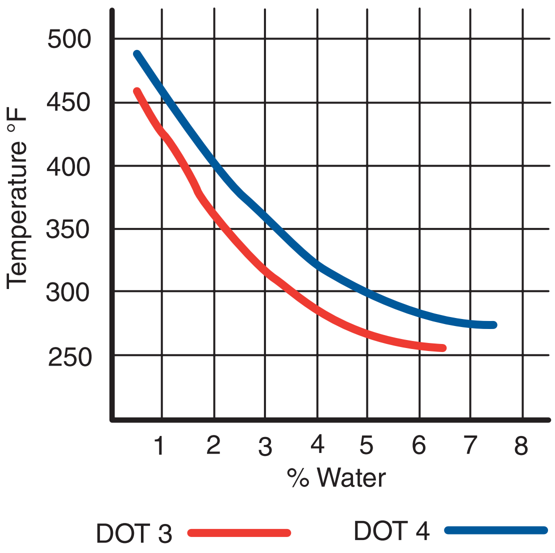


FIGURE 50–7 Moisture affects the boiling point of brake fluid.

Moisture may cause corrosion to build on internal parts of the system. This also decreases the efficiency of the brake system.

Tests have shown that within 1 year of service in a typical vehicle, the water content of the fluid is about 2 percent. It takes approximately 2 years for the fluid to have moisture levels that lower the fluid's boiling point to a dangerous level.

Brake fluid must be compatible with the materials used within the brake system to avoid damage to them. It must provide a controlled amount of swell to the brake system cups and seals. There must be just enough swell to form a good seal. However, the swell cannot be too great. If it is, brake drag and poor brake response occur.

Every can of brake fluid carries the identification letters of SAE and DOT. These letters (and corresponding numbers) indicate the nature, blend, and performance characteristics of that particular brand of brake fluid. Always use the fluid recommended by the manufacturer. The most commonly used brake fluids are DOT 3 and DOT 4. DOT 3 has a minimum dry boiling point of 401 °F (205 °C) and a minimum wet boiling point of 284 °F (140 °C). DOT 4 has a dry boiling point of 446 °F (230 °C) and a wet boiling point of 311 °F (155 °C). Dry boiling point means that the fluid has not absorbed any moisture and wet boiling point is when the fluid has absorbed 3 percent water by volume. Both DOT 3 and 4 are used as factory fill brake fluids and are clear to amber color when new.

DOT 5 is a silicone-based fluid and is purple in color and is not compatible with antilock brake systems or with DOT 3 or DOT 4 fluids. Some newer

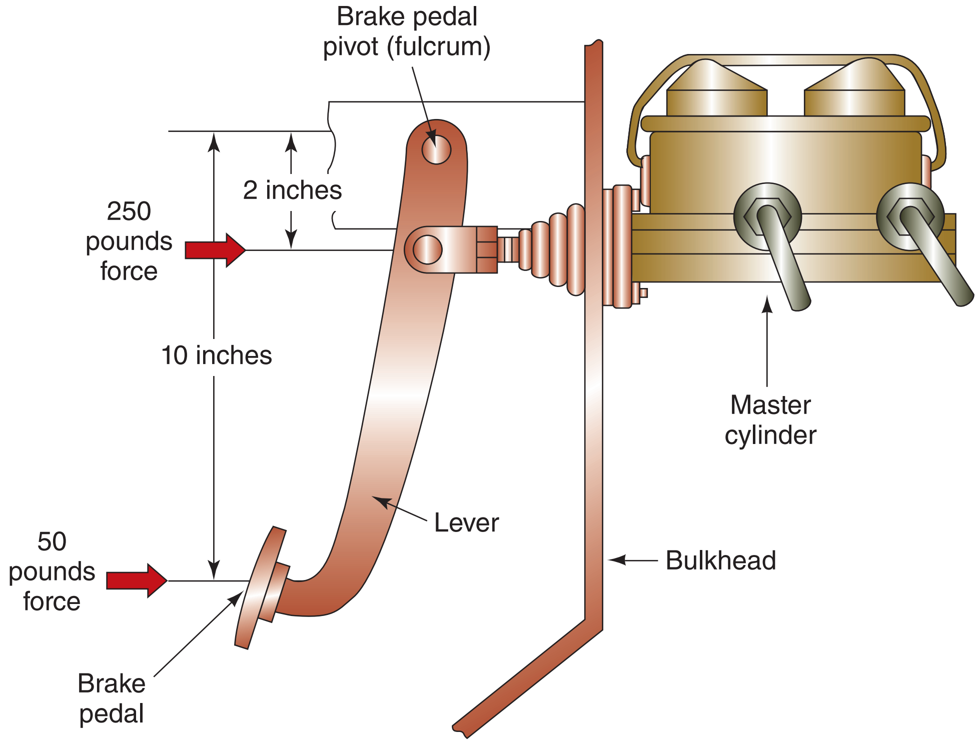


FIGURE 50–8 The brake pedal uses leverage to increase the force applied to the master cylinder.

vehicles specify DOT 5.1, which has a similar chemical make up to DOT 3 and 4. DOT 5.1 has a dry boiling point of 500 °F (260 °C) and a wet boiling point of 356 °F (180 °C).

GO TO Chapter 8 for details on the types of brake fluids.

GO TO Go to Chapter 53 for more information on ABS operation.

Warning! Use only approved brake fluid in a brake system. Any other lubricant that has a petroleum base must never be used. Petroleum-based fluids attack the rubber components in the brake system and cause them to swell and disintegrate.

Most vehicles have brake fluid level sensors that provide the driver with an early warning message when the brake fluid in the master cylinder reservoir has dropped below the normal level.

As the brake fluid in the master cylinder reservoir drops below the designated level, the sensor closes the warning message circuit. This illuminates the red BRAKE light or a LOW BRAKE FLUID lamp on the instrument panel. At this time, the fluid level should be checked.

Brake Pedal

The brake pedal is where the brake's hydraulic system gets its start. When the brake pedal is depressed, force is applied to the master cylinder. On a basic hydraulic brake system (where there is no power assist), the force applied is transmitted mechanically. As the pedal pivots, the force applied to it is multiplied mechanically. The force that the pushrod applies to the master cylinder piston is, therefore, much greater than the force applied to the brake pedal **(Figure 50–8)**.

Master Cylinders

The master cylinder **(Figure 50–9)** transmits the pressure on the brake pedal to each of the four wheel brakes to stop the vehicle. It changes the driver's mechanical pressure on the pedal to hydraulic

FIGURE 50-9 A brake master cylinder.

force, which is changed back to mechanical force at the wheel brake units. The master cylinder uses the fact that fluids are not compressible to transmit the pedal movement to the wheel brake units.

The master cylinder also uses hydraulics to increase the pedal force applied by the driver. A 100-pound force on the brake pedal can be used to push on a 1 sq. in. master cylinder piston to create a 100 psi pressure in the hydraulic system. This 100 psi can be used to push on 4 sq. in. output pistons at a wheel brake. The result is a 400-pound force at the 4 sq. in. output pistons. The driver's 100-pound force has been multiplied to a force of 400 pounds.

Dual-Piston Master Cylinders

Figure 50–10 is a simplified illustration of a dual master cylinder. A pushrod is connected to a piston inside the cylinder, and hydraulic fluid is in front of the piston. When the pedal is pressed, the piston is pushed forward. The fluid transmits the force of the piston to all the inner surfaces of the system. Only the pistons in the drum brake wheel cylinders and/or disc brake calipers can move, and they move outward to force the brake shoes or pads against the rotating brake drums and/or rotors.

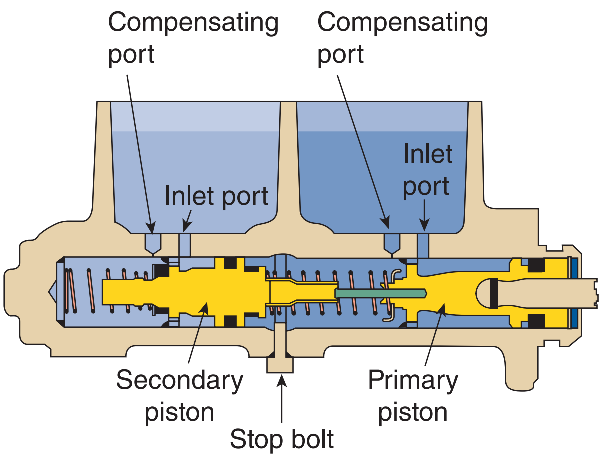


FIGURE 50-10 The basic components of a dual master cylinder.

Master Cylinder Reservoir The reservoir may be cast as one piece with the cylinder body, or it may be a separate molded nylon or plastic container **(Figure 50–11)**. The one-piece body and reservoir casting is usually made of cast iron, and are mostly found on older vehicles. The cylinder is directly below the reservoir. All reservoirs have a removable cover so that brake fluid can be added to the system. One-piece reservoirs typically have a single cover that is held on the reservoir with a retainer bail. Nylon or plastic reservoirs typically have two screw caps on top of the reservoir. Separate reservoirs may be clamped or bolted to the cylinder body, or they may be pressed into holes at the top of the body and sealed with grommets or O-rings.

The caps or covers are vented to prevent a vacuum lock as the fluid level drops in the reservoir. A flexible rubber diaphragm at the top of the reservoir is incorporated in the caps or covers. The diaphragm separates the brake fluid from the air above it while remaining free to move up and down with changes in fluid level. The diaphragm keeps the moisture and air from entering the brake fluid in the reservoir.

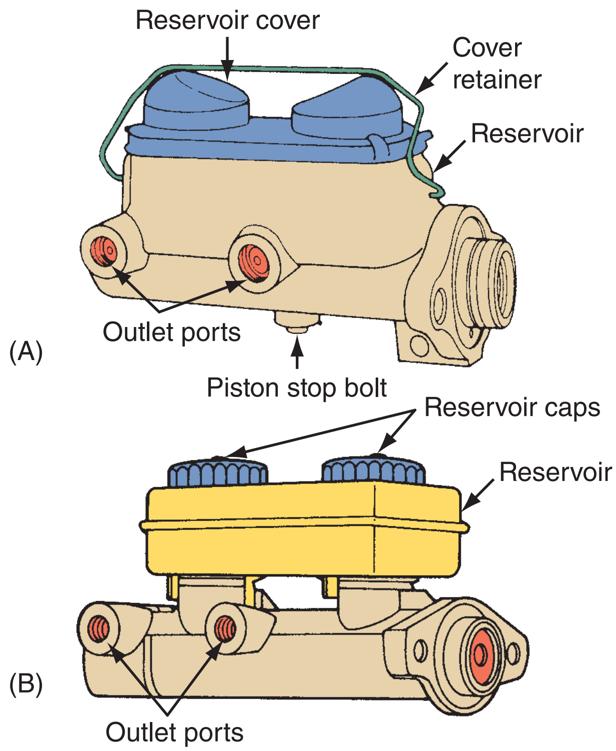


FIGURE 50-11 (A) A typical cast-iron dual master cylinder and (B) a typical aluminum/composite dual master cylinder.

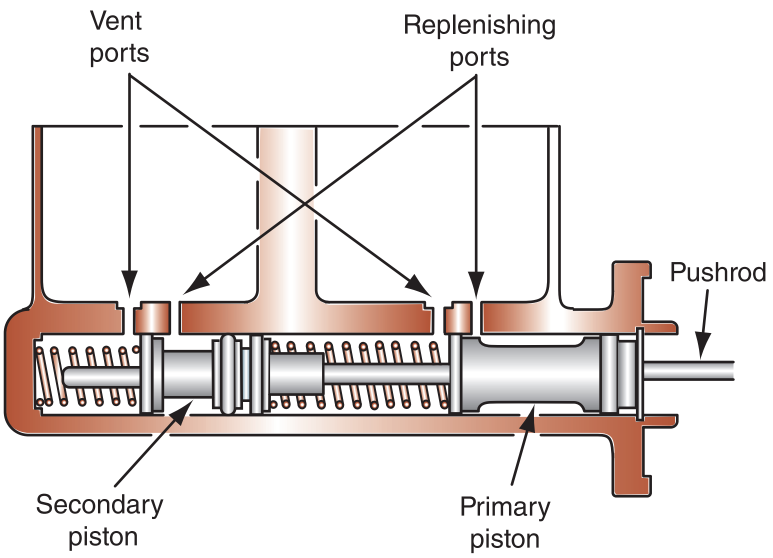


FIGURE 50–12 Fluid from the reservoir fills the cylinder through the replenishing ports.

If a vehicle with front disc and rear drum brakes has a hydraulic system split front to rear, the reservoir chamber for the disc brakes is larger than the chamber for the drum brakes. As disc pads wear, the caliper pistons move out farther in their bores. More fluid is then required to keep the system full in the master cylinder. With drum brake wheel cylinder pistons, the volume of fluid does not increase much with lining wear because the pistons always fully retract into the cylinders regardless of brake lining wear. Vehicles with four-wheel disc brakes or diagonally split hydraulic systems usually have master cylinders with equally sized reservoirs because each circuit of the hydraulic system requires the same volume of fluid.

Plastic reservoirs are often translucent so that fluid level can be seen without removing the cover. Although this feature allows a quick check of fluid level without opening the system to the air, you should not rely on it for thorough brake fluid inspection. Stains inside the reservoir can give a false indication of fluid level, and contamination cannot be seen without removing the reservoir caps or cover.

Master Cylinder Ports Different names have been used for the ports in the master cylinder. This text refers to the forward port as the "vent" port and the rearward port as the "replenishing" port. These are the names established by SAE Standard J1153. The **vent port** has been called a compensating port or a replenishing port. To further confuse the issue, the **replenishing port** has been described by many manufacturers as the compensating port, as well as the vent port, the by-pass port or hole, the filler port, or the intake port **(Figure 50–12)**. The vent ports and replenishing ports let fluid pass between each pressure chamber and its fluid reservoir during operation. The names of these ports are not important as long as you understand their purposes and operations.

Master Cylinder Construction

A single cylinder bore contains two piston assemblies **(Figure 50–13)**. The piston assembly at the rear is the primary piston, and the one at the front is the secondary piston. Each piston has a return spring in front of it. There is a **cup seal** in front of each piston and a cup or seal at the rear of each piston. The seals retain fluid in the cylinders and prevent seepage between the cylinders.

Inside the cylinder are two spool-shaped pistons. The piston has a head on one end and a groove for

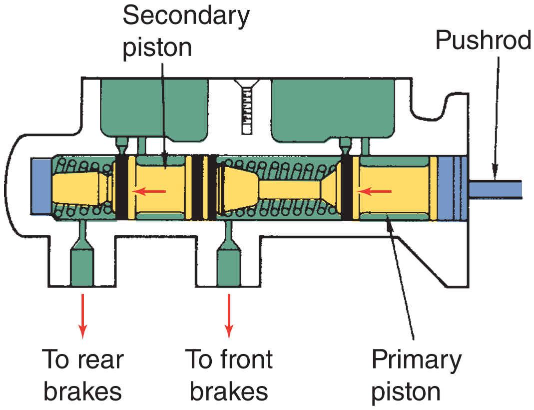


FIGURE 50–13 The position of the pistons in a master cylinder when the brakes are applied. Notice that the seals stop fluid flow throughout the master cylinder.

an O-ring seal on the other end. The seal seats against the cylinder wall and keeps fluid from leaking past the piston. The smaller diameter center of the piston is the valley or spool area, which lets fluid get behind the head of the piston.

Each master cylinder piston works with a rubber cup seal, which fits in front of the piston head. The cup has flexible lips that fit against the cylinder walls to seal fluid pressure ahead of the piston head. The cup lip also can bend to let fluid get around the cup from behind. When the brakes are applied, pressure in front of the cup forces the lip tightly against the cylinder wall, enabling it to hold very high pressure. The lip of a cup seal is always installed toward the pressure to be contained or away from the body of the piston. The cup seals in only one direction. If pressure behind the lip exceeds the pressure in front of it, the higher pressure will force the lip away from the cylinder wall and let fluid bypass the cup.

Pistons have small coil springs that return the pistons to the proper position when the brake pedal is released. Sometimes the springs are attached to the pistons; sometimes they are separate parts. A snapring holds the components inside the cylinder, and a rubber boot fits around the rear of the cylinder and pushrod to keep dirt from entering the cylinder **(Figure 50–14)**.

A two-piece master cylinder has an aluminum body. Because aluminum can be nicked or gouged easily, the bore of the aluminum cylinder is anodized to protect it from wear and damage. They are fitted with a removable nylon or plastic reservoir. Because

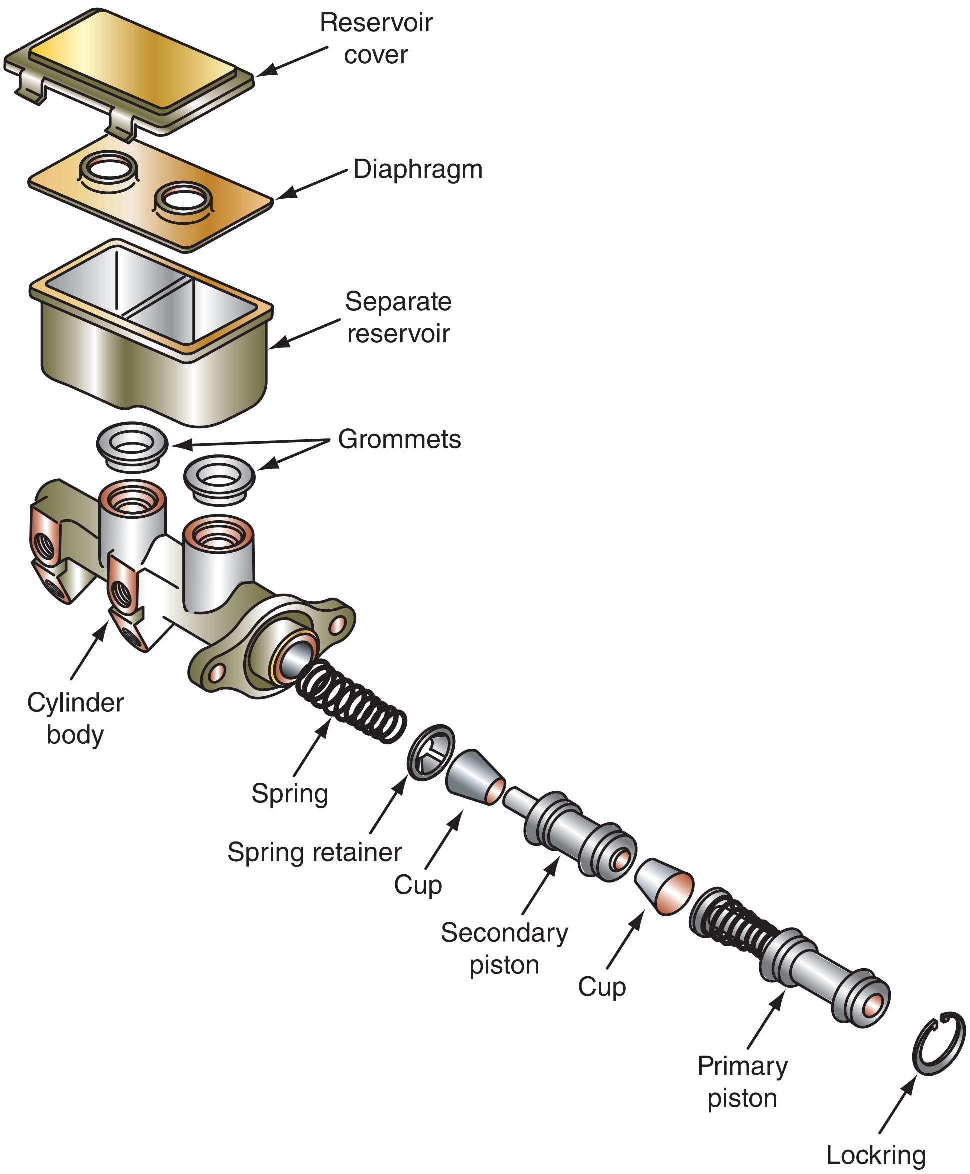


FIGURE 50–14 The basic construction of a dual master cylinder.

the master cylinder is made of two materials, it is often called a composite master cylinder. The pistons, cups, and springs used in a composite master cylinder are essentially the same and work the same way as those in a one-piece master cylinder.

Master Cylinder Operation

The vent port in the bottom of the reservoir is located just ahead of the piston cup. Fluid flows from the reservoir into the pressure chamber in front of the piston cup. The replenishing port is located above the valley area of the piston behind the piston head. The O-ring seal on the piston keeps the fluid from leaking out the rear of the cylinder. The return spring in front of the piston and cup returns the piston when the brakes are released.

When the driver depresses the brake pedal, the pushrod pushes the piston forward. As it moves forward, the piston pushes the cup past the vent port. As soon as the vent port is covered, fluid is trapped ahead of the cup. The fluid, which is under pressure, goes through the outlet lines to the wheel brake units to apply the brakes.

When the driver releases the brake pedal, the return spring forces the piston back to its released position. As the piston moves back, it pulls away from the fluid faster than the fluid can flow back from the brake lines to the pressure chamber. This creates a low pressure ahead of the piston.

The piston must rapidly move back to the released position so it can be ready for another forward stroke if necessary. The low-pressure area must be filled with fluid as the piston moves back. A path for fluid flow is provided by the valley area, past the primary cup protector washer and through several small holes in the head of the piston, or by having enough clearance between the piston head and the cylinder bore. Fluid flows through the piston or around the lip of the cup and into the chamber ahead of the piston. This flow quickly relieves the low-pressure condition.

The fluid that flows from the valley area to the pressure chamber must be replaced. When the piston is fully returned to its released position, the space in front of it is full of fluid. The piston cup again seals off the head of the piston. In the meantime, the fluid from the rest of the system has begun to flow back to the high-pressure chamber. If this pressure is not released, the brakes would not release. The returning fluid flows back to the reservoir through the vent port. The vent port is covered by the piston cup at all times, except when the piston is released.

Residual Pressure Check Valve

The pressure chamber in a master cylinder for some drum brake systems may have an additional part called a residual pressure check valve. This valve can be installed in the pressure chamber or the outlet line of the master cylinder. A residual pressure check valve is the oldest type of pressure control valve used in a brake system.

When you replace a master cylinder, it is very important to verify whether or not the vehicle requires a residual pressure check valve. Installing the wrong cylinder will cause improper brake operation and possible system failure.

Split Hydraulic Systems

Most late-model vehicles have a diagonally split hydraulic system. If there is a hydraulic failure in the brake lines served by the master cylinder's secondary piston, both pistons will move forward when the brakes are applied, but there is nothing to resist piston travel except the secondary piston spring. This lets the primary piston buildup only a small amount of pressure until the secondary piston bottoms in the cylinder bore. Then the primary piston will build enough hydraulic pressure to operate the brakes served by this half of the system.

In case of a hydraulic failure in the brake system served by the primary piston, the piston will move forward when the brakes are applied but will not buildup hydraulic pressure. Very little force is transferred to the secondary piston through the primary piston spring until the piston extension screw comes in contact with the secondary piston. Then, pushrod force is transmitted directly to the secondary piston and enough pressure is built up to operate its brakes.

Fast-Fill and Quick Take-Up Master Cylinders

Several manufacturers use fast-fill, or quick take-up, master cylinders. These cylinders fill the hydraulic system quickly to take up the slack in the caliper pistons of low-drag disc brakes. Low-drag calipers retract the pistons and pads farther from the rotor

than traditional calipers. This reduces friction and brake drag and improves fuel mileage.

If a conventional master cylinder were used with low-drag calipers, excessive pedal travel would be needed on the first stroke to fill the lines and calipers with fluid and take up the slack in the pads. To overcome this, fast-fill, or **quick take-up**, master cylinders provide a large volume of fluid on the first stroke of the brake pedal.

You can recognize a fast-fill, or quick take-up, master cylinder by the bulge, or larger diameter, on the outside of the casting **(Figure 50–15)**. The cylinder has a larger diameter bore for the rear primary piston than the front primary piston. Inside the cylinder, a fast-fill, or quick take-up, valve replaces the conventional vent and replenishing ports for the primary piston. Some master cylinders for four-wheel disc brakes also have a quick take-up valve for the secondary piston.

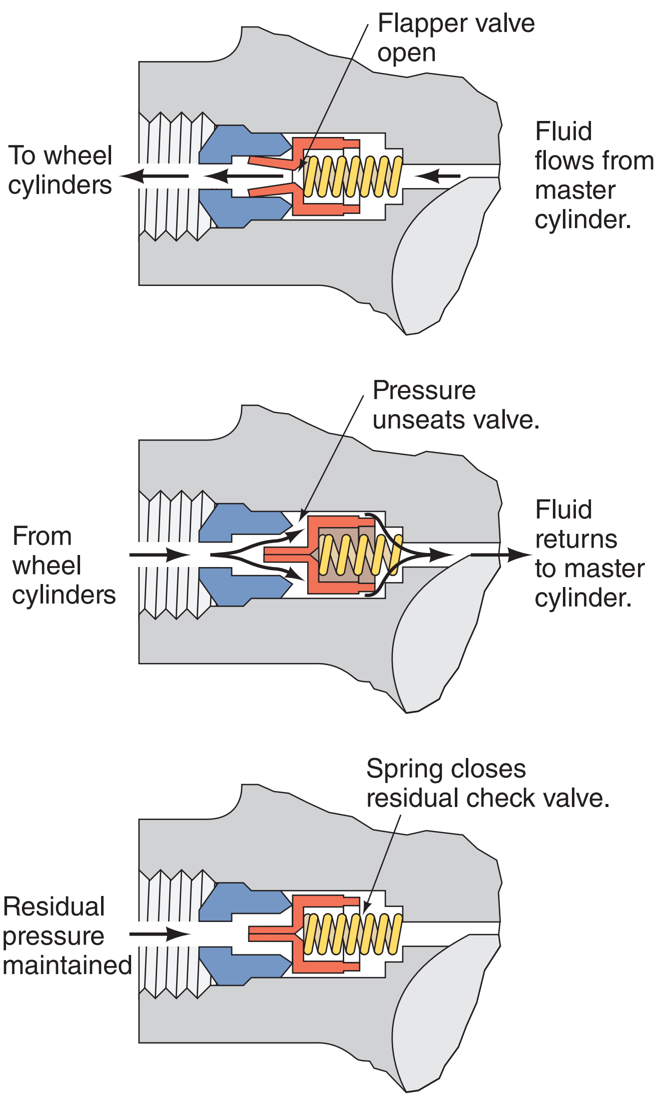


FIGURE 50–15 The operation of a master cylinder's residual valve.

The quick take-up valve contains a spring-loaded check ball that has a small by-pass groove cut in the edge of its seat. The outer circumference of the valve is sealed to the cylinder body with a lip seal. Several holes around the edge of the hole let fluid bypass the lip seal under certain conditions. Some valves (those more often called "fast-fill" valves) are pressed into the cylinder body and sealed tightly by an O-ring. A rubber flapper-type check valve under the fast-fill valve performs the same functions as a lip seal of a quick take-up valve.

Brakes Not Applied When the brakes are off, both master cylinder pistons are retracted, and all vent and replenishing ports are open. However, fluid to both ports of the primary piston must flow through the groove in the check ball seat.

Brakes Applied As the brakes are applied, the primary piston moves forward in its bore. Remember that the diameter of the primary chamber is larger than the diameter of the secondary. As the secondary piston moves forward, the volume is reduced. This causes hydraulic pressure to instantly rise in the low-pressure chamber. The higher pressure forces the large volume of fluid into the low-pressure chamber past the cup seal of the primary piston. This provides the extra volume of fluid to take up the slack in the caliper pistons.

The lip seal of the quick take-up valve keeps fluid from flowing from the low-pressure chamber back to the reservoir. Initially a small amount of fluid bypasses the check ball through the by-pass groove, but this is not enough to affect quick take-up operation.

As brake application continues, pressure in the low-pressure chamber rises to about 70 to 100 psi. The check ball in the quick take-up valve then opens to let excess fluid return to the reservoir. Pressures in both chambers of the primary piston equalize, and the piston moves forward to actuate the secondary piston.

All of the actions apply to the primary piston if it is serving front disc brakes and the secondary piston is serving drum brakes. If the hydraulic system is diagonally split, or if the car has four-wheel, low-drag discs, the quick take-up fluid volume must be available to both pistons. Some master cylinders have a second quick take-up valve for the secondary piston. Others provide the needed fluid volume through the design of the cylinder itself. As long as the primary quick take-up valve stays closed, the fluid bypassing the primary piston cup causes the secondary piston to move farther. This provides equal fluid displacement from both pistons and maintains equal pressure in the system. When the

quick take-up valve opens, both pistons move together just as in any other master cylinder.

Brakes Released When the driver releases the brake pedal, the return springs force the primary and secondary pistons to move back. Pressure drops in the high-pressure chambers, and fluid bypasses the piston cup seals from the low-pressure chambers. Low pressure is created in the low-pressure chamber, which allows atmospheric pressure to move past the lip seal of the quick take-up valve. Fluid from the reservoir then flows through both the vent and replenishing ports to equalize pressure in the pressure chambers and valley areas.

On the return stroke, fluid flows to the secondary piston through the replenishing port unless the secondary piston also has a quick take-up valve. If a secondary quick take-up valve is installed, it works in the same way as a primary quick take-up valve.

Central-Valve Master Cylinders

Some antilock brake systems (ABS) use master cylinders that have central check valves in the tops of the pistons **(Figure 50–16)**. These valves are designed to prevent seal damage and pedal vibration. If the master cylinder provides pressure during antilock operation and the system also has a motor-driven pump, the master cylinder's pistons may shift back and forth rapidly during antilock operation. This will cause excessive pedal vibration and—more importantly—wear on the piston cups where they pass over the vent ports.

FIGURE 50–16 You can recognize a quick take-up master cylinder by the bulge or step in the casting.

When the brakes are released, fluid flows from the replenishing ports to the low-pressure chambers, through the open central check valves, and into the high-pressure chambers. As the brakes are applied, the central valves close to hold fluid in the high-pressure chambers. When the brakes are released again, the check valves open to let fluid flow back through the pistons to the low-pressure chambers and the reservoir.

The central check valves provide supplementary fluid passages to let fluid move rapidly back and forth between the high- and low-pressure chambers during antilock operation. This is not much different in principle from non-ABS fluid flow, but the extra passages reduce piston and pedal vibration and cup seal wear.

Hydraulic Tubes and Hoses

Fluid transfer from the driver-actuated master cylinder is routed through one or more valves and then into the steel tubing and hoses **(Figure 50–17)**. The design of the brake lines offers quick fluid transfer response with very little friction loss. Engineering and installing the brake lines so they do not wrap around sharp curves is very important in maintaining this good fluid transfer.

Brake Line Tubing

Most brake line tubing consists of copper-fused double-wall steel tubing in diameters ranging from $^{1}/_{8}$ to $^{3}/_{8}$ inch (3 mm to 9 mm). Some OEM brake tubing is manufactured with soft steel strips, sheathed with copper. The strips are rolled into a double-wall assembly and then bonded in a furnace at extremely high temperatures. Corrosion protection is often added by tin-plating the tubing.

Fittings

Assorted fittings are used to connect steel tubing to junction blocks or other tubing sections. The most common fitting on older vehicles is the double or inverted flare style. Double flaring is important to maintain the strength and safety of the system. Single flare or sleeve compression fittings may not hold up in the rigorous operating environment of a standard vehicle brake system.

Fittings are constructed of steel or brass and use either the inverted flare or standard flare fitting **(Figure 50–18)**. The two types of flares are not

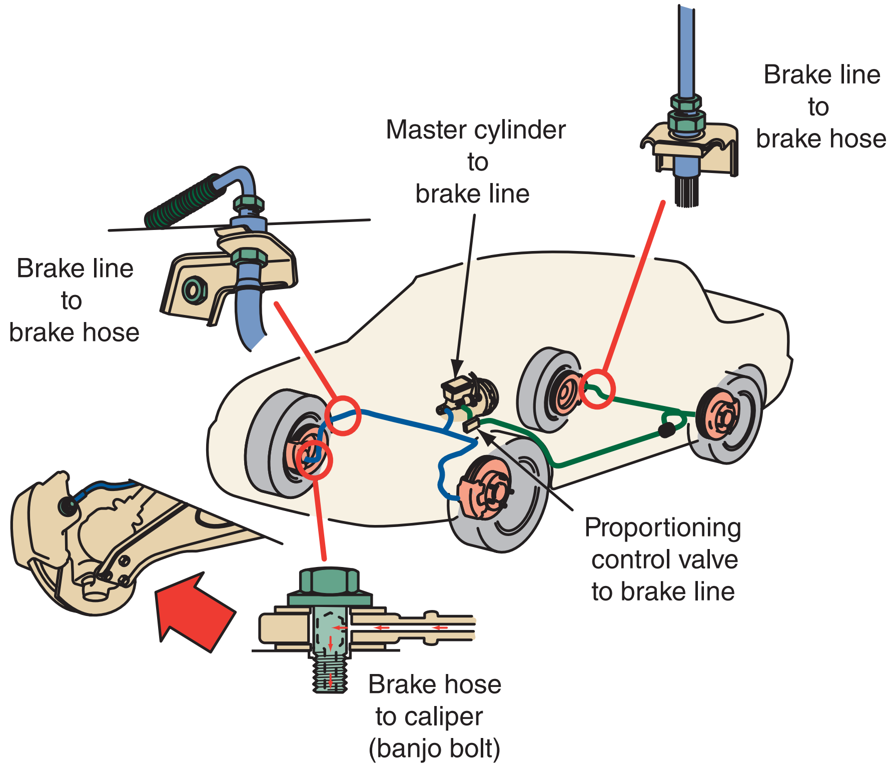


FIGURE 50-17 A typical layout of the hoses and tubes for the brake system.

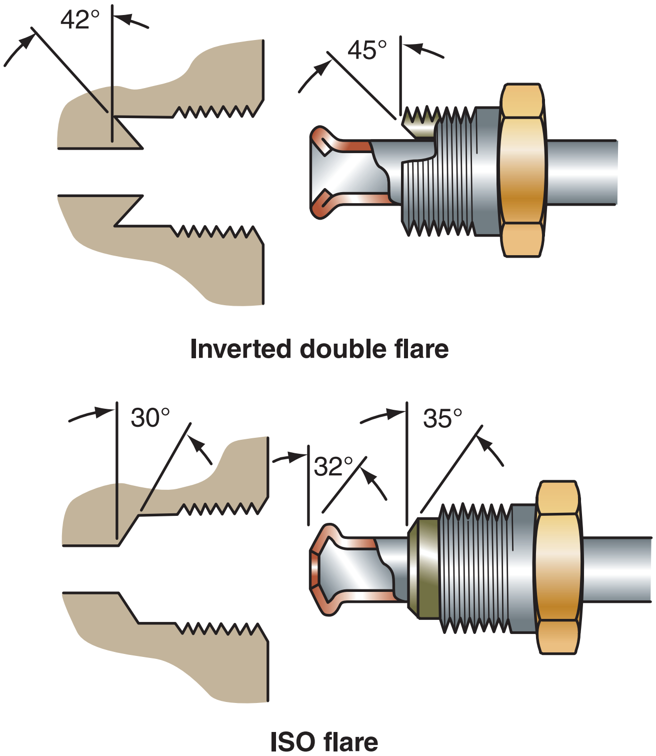


FIGURE 50-18 The two types of flares, double and ISO or bubble, are not interchangeable.

SHOP TALK

Never use copper tubing as a replacement for defective lines or hoses. This type of tubing is subject to fatigue, cracking, and corrosion. If a section of the brake tubing is damaged, the entire section must be installed with a new tube of the same type, size, shape, and length. Also, when installing tubing, hoses, or connectors, tighten all connections to specifications. This is especially important with the hollow bolts that connect brake hoses to the calipers. Overtightening these bolts, even a little, can cause them to snap. When installing a new hose, position the hose to avoid contact with other vehicle components. After installation, bleed the brake system.

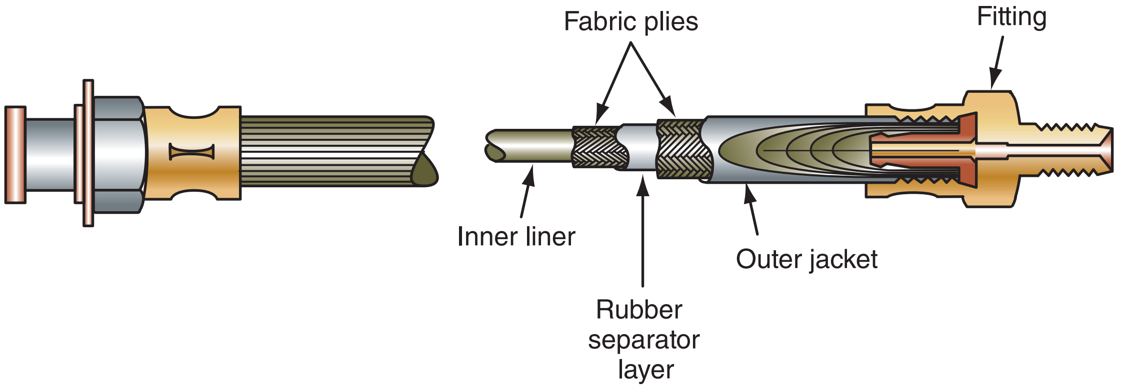


FIGURE 50–19 Flexible brake hoses are constructed of layers of reinforcement materials.

interchangeable and will not seal threaded together. Newer vehicles may use the ISO or metric bubble flare fitting though ISO fittings are now the most common.

Never change the style of fitting being used on the vehicle. Replace ISO fittings only with ISO fittings. Replace standard fittings with standard fittings.

The metal composition of the fittings must also match exactly. Using an aluminum-alloy fitting with steel tubing may provide a good initial seal, but the dissimilar metals create a corrosion cell that eats away the metal and reduces the connection's service life.

Brake Line Hoses

Brake line hoses offer flexible connections to wheel units so steering and suspension members can operate without damaging the brake system. Typical brake hoses range from 10 to 30 inches (25 to 76 mm) in length and are constructed of multiple layers of fabric impregnated with a synthetic rubber **(Figure 50–19)**. Brake hose material must offer high heat resistance and withstand harsh operating conditions.

SHOP TALK

Many brake hose failures can be traced to errors made during the replacement or repair of the hose. Twisted hoses become stressed and are prime candidates for leaks and bursting. Most manufacturers now print a natural lay indicator or line on the hose. By making sure this line is not spiralled after fittings are tightened, you can ensure the hose is not overly stressed. Also, always use a hose of the same length and diameter as the original during servicing to maintain brake balance at all wheels.

Hydraulic System Safety Switches and Valves

Switches and valves are installed in the brake system hydraulic lines to act as warning devices and as pressure control devices. Though the adoption of four-wheel disc brakes and antilock brake systems has decreased the use of most valves in the hydraulic system, some vehicles still use one or more valves for pressure control or to illuminate the brake warning light. Late-model vehicles with ABS and stability control use the ABS to control pressures to the wheel brakes and no external valves are used.

Pressure Differential Valve

A pressure differential valve, in the event of a hydraulic leak, is used to shut off one hydraulic circuit and operate a warning light switch. Its main purpose is to tell the driver if pressure is lost in either of the two hydraulic systems. Since each brake hydraulic system functions independently, it is possible the driver might not notice immediately that pressure and braking are lost. When a pressure loss occurs, brake pedal travel increases and pedal feel typically becomes soft, spongy, and much less firm. This

results in a more-than-usual effort to slow and stop the vehicle. Should the driver not notice the difference, the warning light is actuated by the hydraulic system safety switch.

Under normal conditions, the hydraulic pressure on each side of the pressure differential valve piston is balanced. The piston is located at its center point, so the spring-loaded warning switch plunger fits into the tapered groove of the piston. This leaves the contacts of the warning switch open. The brake warning light stays off.

If there is a leak in the front or rear braking system, the hydraulic pressure in the two systems is unequal. For example, if there is a leak in the system supplying the front brakes, there is lower pressure in the front system when the brake pedal is applied. The hydraulic pressure in the rear system then pushes the piston toward the front side, where the pressure is lower. As the piston moves, the plunger is pushed out **(Figure 50–20)**. This closes the switch and illuminates the brake warning light.

While all brake warning light switches serve the same function, there are three common variations in the design of these switches. These variations include switch with centering springs, without centering springs, and with centering springs and two pistons.

Metering and Proportioning Valves

Metering and proportioning valves are used to balance the braking characteristics of disc and drum brakes.

The braking response of the disc brakes is immediate when the brake pedal is applied. It is directly proportionate to the effort applied at the pedal. Drum brake response is delayed while rear brake hydraulic pressure moves the wheel cylinder pistons to overcome the force of their return springs and

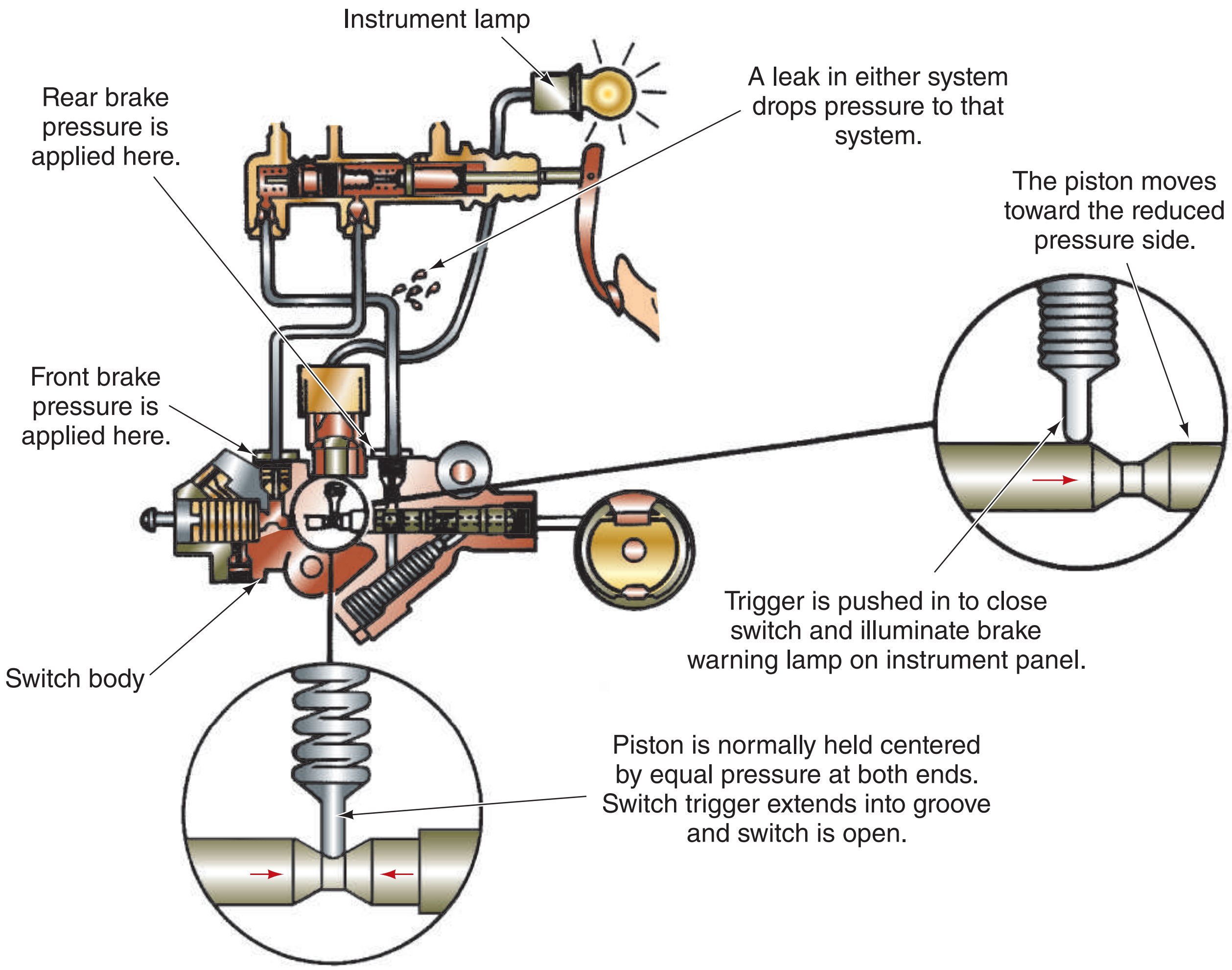


FIGURE 50–20 The action of a pressure differential valve when there is a leak in the system.

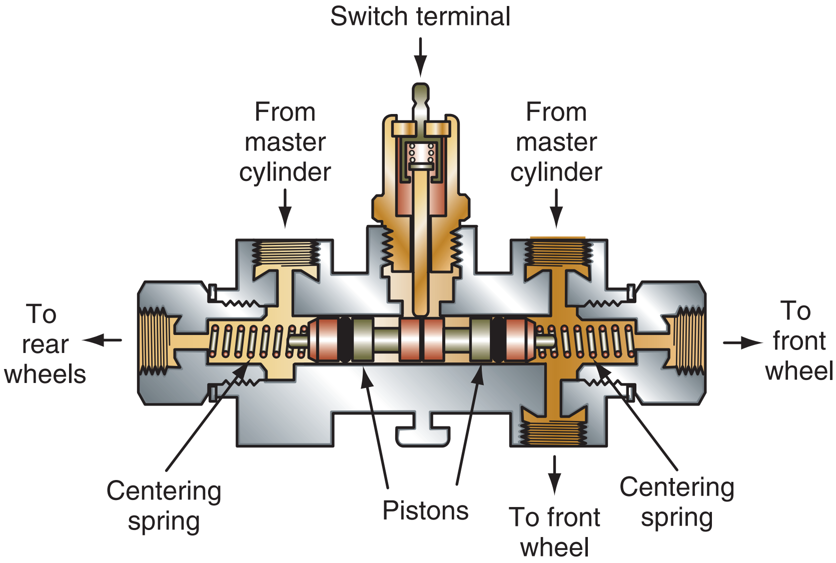


FIGURE 50–21 The pressure differential valve can turn on the brake warning light if a drop in pressure occurs in the hydraulic system.

force the brake shoes to contact the drum. Once applied, their actions may be self-energizing and tend to multiply the pedal effort. This reduces the need for increasing pressure to the rear brakes.

Metering Valve A **metering valve** (hold-off valve) in the front brake line holds off pressure going from the master cylinder to the front disc calipers. This delay allows pressure to buildup in the rear drums first. When the rear brakes begin to take hold, the hydraulic pressure builds to the level needed to open the metering valve **(Figure 50–21)**. When the metering valve opens, line pressure is high enough to operate the front discs. This process provides for better balance of the front and rear brakes. It also prevents lockup of the front brakes by keeping pressure from them until the rear brakes have started to operate. The metering valve has the most effect at the start of each brake operation and all during light braking conditions.

Proportioning Valve The self-energizing action of the delayed response rear drum brakes can cause them to lock the rear wheels at a lower hydraulic pressure than the front brakes. The **proportioning valve** (balance valve) **(Figure 50–22)** is used to control rear brake pressures, particularly during hard stops. When the pressure to the rear brakes reaches a specified level, the proportioning valve overcomes the force of its spring-loaded piston, stopping the flow of fluid to the rear brakes. By doing so, it regulates rear brake system pressure and adjusts for the difference in

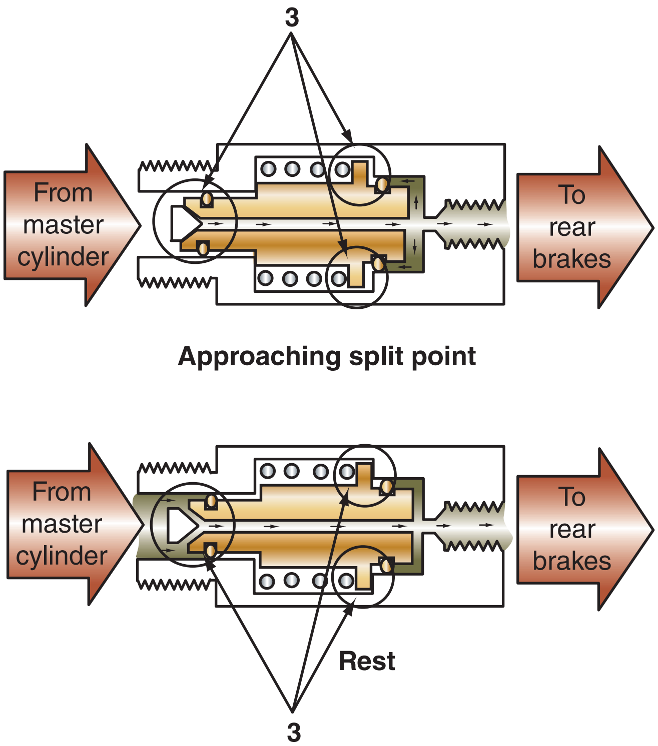


FIGURE 50–22 A proportioning valve.

pressure between front and rear brake systems. This keeps front and rear braking forces in balance.

Height-Sensing Proportional Valve The height-sensing proportional valve provides two different brake balance modes to the rear brakes based on

vehicle load. This is accomplished by turning the valve on or off. When the vehicle is not loaded, hydraulic pressure is reduced to the rear brakes. When the vehicle is carrying a full load, the actuator lever moves up to change the valve's setting. The valve now allows full hydraulic pressure to the rear brakes. The valve contains a plunger, cam, torsional clutch spring, and an actuator shaft **(Figure 50–23)**.

The valve is mounted to the frame above the rear axle and has an actuator lever connected by a link to the lower shock absorber bracket. The valve is turned on and off as the axle-to-frame height changes due to load in the vehicle. The torsional clutch spring attached to the valve shaft is used as an override. Once the valve is positioned during braking, the spring prevents the valve from changing position if the vehicle goes over a bump or moves off the road.

Height-sensing proportional valves are replaced when defective and are not adjustable.

Combination Valves Most older cars and trucks have a **combination valve (Figure 50–24)** in their hydraulic system. This valve is simply a single unit that combines the metering and proportioning valves with the pressure differential valve. Combination valves are described as three-function or two-function valves, depending on the number of functions they perform in the hydraulic system.

Three-Function Valve. This type of valve performs the functions of the metering valve, brake warning light switch, and proportioning valve.

Two-Function Valves. There are two variations of the two-function combination valve. One variation works the proportioning valve and brake warning light switch functions. The other performs the metering valve and brake warning light switch functions.

If any one of its several operations fail, the entire combination valve must be replaced, because these units are not repairable.

Warning Lights

A wide variety of electrical and electronic components are found in a brake system, especially with ABS. These include the warning lamp switch operation of a pressure differential valve and the electrical switches to operate the parking brake warning light, hydraulic failure warning lamp, as well as sensors to indicate low brake fluid level **(Figure 50–25)**.

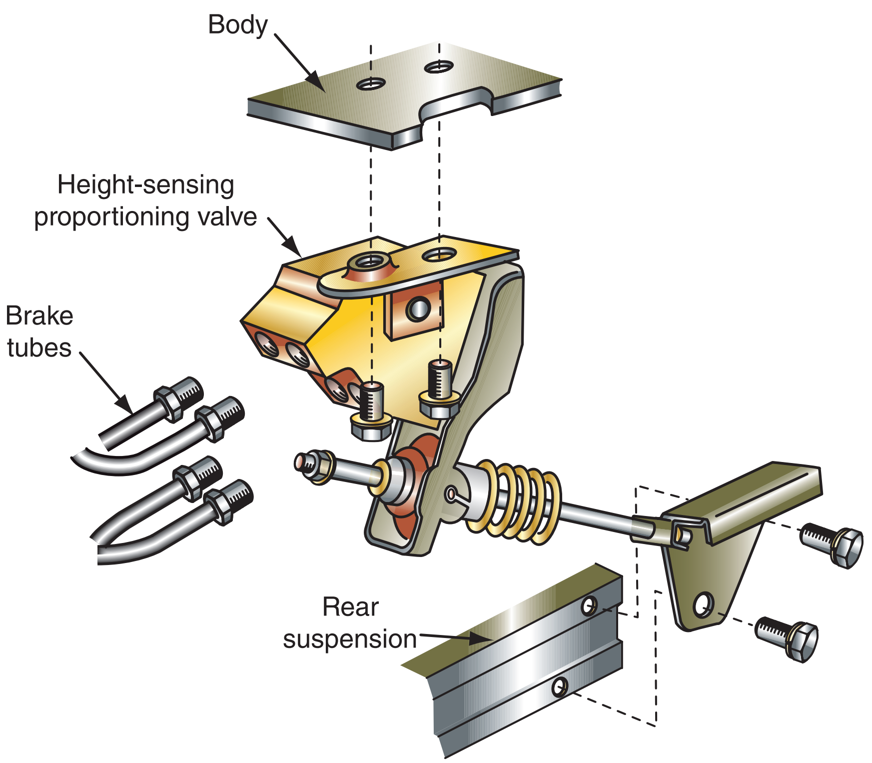


FIGURE 50–23 A height-sensing proportional valve.

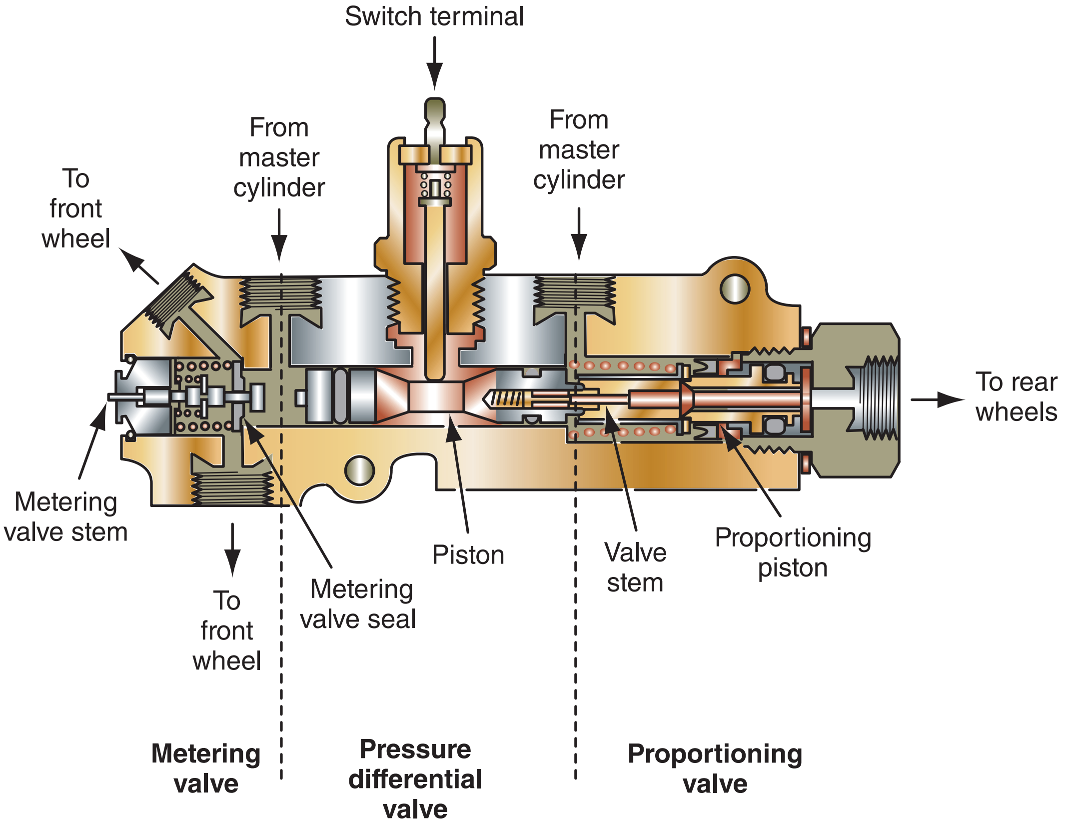


FIGURE 50–24 A typical combination valve.

Failure Warning Lamp Switch The pressure differential valve has a hydraulically operated switch that controls the brake failure warning lamp on the instrument panel. Each side of the pressure differential valve is connected to half of the hydraulic system (one chamber of the master cylinder). Each master cylinder piston provides pressure to a separate hydraulic system. If one of the circuits fails, the brake pedal travel will increase and more brake pedal effort will be required to stop the car. The driver might not notice a problem, however, but the lamp on the instrument panel will provide a warning in case of hydraulic failure.

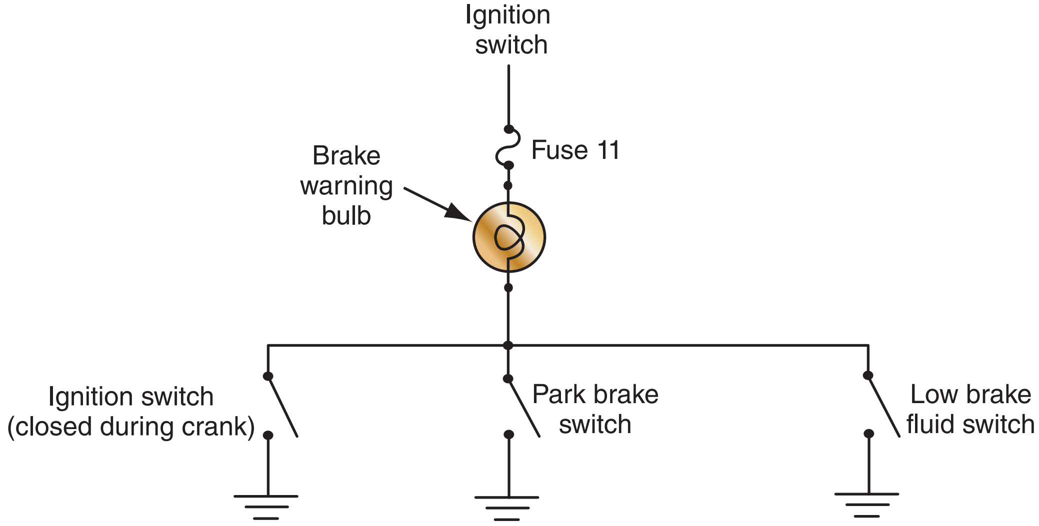


FIGURE 50–25 An example of a brake warning light circuit.

Failure in one half of the hydraulic system causes a pressure loss on one side of the pressure differential valve. Pressure on the other side moves the valve's plunger into contact with the switch terminal. This closes the circuit and the warning lamp is illuminated. All pressure differential valves work in this basic way but differ in the details of the shape of the piston and the use of centering springs.

The pressure differential valve on most late-model vehicles is part of a combination valve or built into the body of the master cylinder. Some vehicles have a switch in the float assembly of the fluid reservoir instead of a pressure differential valve. This float switch turns on the brake warning lamp when the fluid level changes to a dangerous point. This accomplishes the same thing as a pressure differential valve.

Master Cylinder Fluid Level Switch Because brake fluid level is important to safe braking, many vehicles have a fluid level switch that causes illumination of the instrument panel's red brake warning lamp when the fluid level is too low. This warning system is similar to the pressure differential valve because fluid level in the reservoir will drop from a leak caused by hydraulic failure. Therefore, a fluid level switch has replaced the pressure differential valve on many vehicles **(Figure 50–26)**. An added advantage of a fluid level switch is that it will alert the driver of a dangerous fluid level caused by inattention and poor maintenance practices.

Fluid level sensors are built into the reservoir body or cap. One type has a float with a pair of switch contacts on a rod that extends above the float. If the fluid level drops too low, the float will drop and cause the rod-mounted contacts to touch

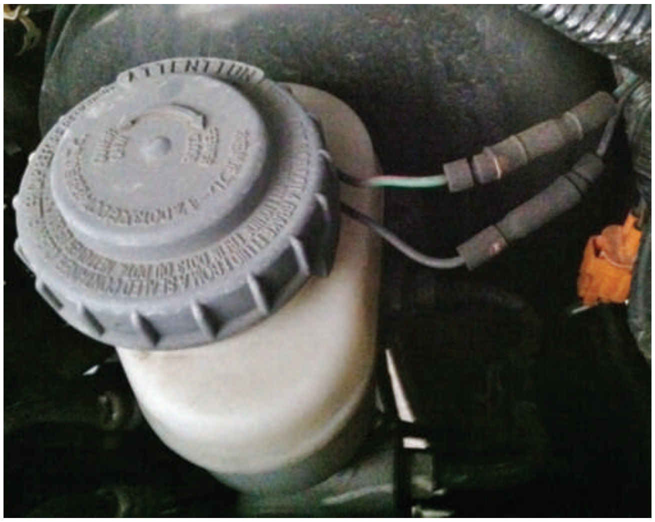


FIGURE 50–26 A reservoir cap with a fluid level sensor built in.

a set of fixed contacts and close the lamp circuit. Another type of switch uses a magnet in a movable float. If the float drops low enough, the magnet pulls a set of switch contacts together to close the lamp circuit. The contacts typically provide a ground path for the brake warning lamp.

Parking Brake Switch The parking brake should only be applied to hold a vehicle stationary. If the parking brake is even partially applied while the vehicle is moving, it will produce enough heat to glaze friction materials, expand drum dimensions, and increase pedal travel. On rear disc brake systems with integral parking brake actuators, driving with the parking brake applied will distort the brake rotors and reduce pad life.

A normally closed, single-pole, single-throw switch is used to ground the circuit of the red brake warning lamp in the instrument cluster. This switch is located within the parking brake handle or pedal assembly and is designed to turn on the light whenever the parking brake is applied.

Some vehicles with daytime running lights (DRL) use the parking brake switch to complete a circuit that prevents the headlights from coming on if the parking brake is applied when the engine is started. When the parking brake is released, the DRLs operate normally.

Stop Lamps

Stop lamps are included in the right and left tail lamp assemblies. Vehicles built since 1986 also have a center high-mounted stop lamp (CHMSL).

Brake stop lamp switches are operated hydraulically or mechanically. Hydraulic switches were used on older vehicles and were installed in the master cylinder's high-pressure chamber; they were activated by system pressure. A mechanical switch is mounted on the bracket for the brake pedal and activated by the movement of the pedal lever **(Figure 50–27)**.

Mechanical switches are found on some vehicles because they can be adjusted to illuminate the stop lamps with the slightest pedal movement. Stop lamp switches may be single-function or multifunction units. Single-function switches have only one set of switch contacts that control electric current to the stop lamps at the rear of the vehicle. Multifunction switches have one set of switch contacts for the stop lamps and at least one additional set of contacts for the CHMSL, cruise control, or ABS. Some multifunction switches have contacts for all of these functions.

Modern vehicles use brake pedal position sensors. The output from the sensor is used by the ABS,

FIGURE 50–27 An example of a brake pedal position sensor.

traction/stability control, lighting, transmission, engine, and other modules. BPP sensors often are used to monitor pedal position, force applied to the pedal, and the speed with which it is being applied so the ABS and stability control systems can correctly apply the wheel brakes based on operating conditions.

Drum and Disc Brake Assemblies

Although drum and disc brakes are explained in great detail in later chapters, a brief explanation of their components and operating principles is essential at this point.

Drum Brakes

A drum brake assembly consists of a cast-iron drum, which is bolted to and rotates with the vehicle's wheel, and a fixed backing plate to which the shoes, wheel cylinders, automatic adjusters, and linkages are attached **(Figure 50–28)**. Additionally, there might be

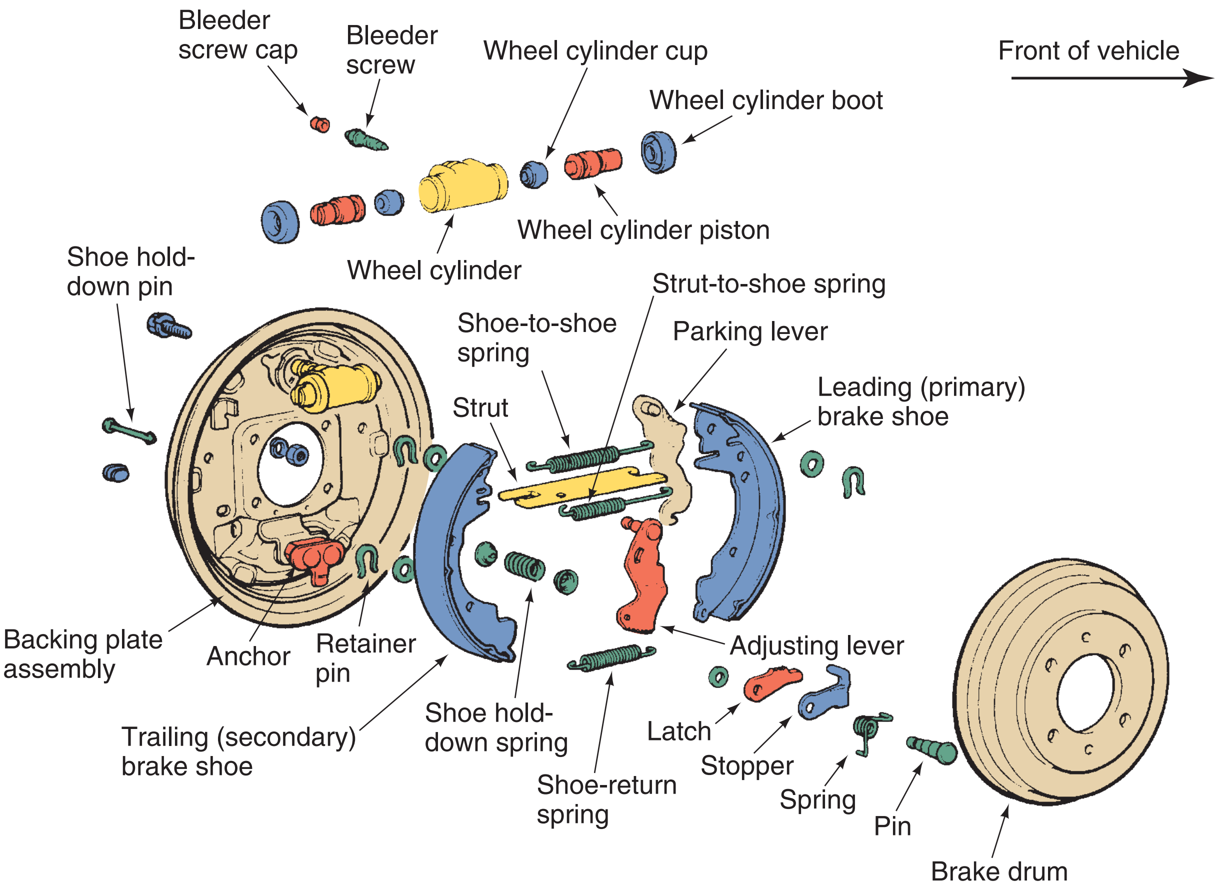


FIGURE 50–28 Typical nonservo drum brake assembly.

some extra hardware for parking brakes. The shoes are surfaced with frictional linings, which contact the inside of the drum when the brakes are applied. The shoes are forced outward by pistons located inside the wheel cylinder. The pistons are actuated by hydraulic pressure. As the drum rubs against the shoes, the energy of the moving drum is transformed into heat. This heat energy is passed into the atmosphere. When the brake pedal is released, hydraulic pressure drops and the pistons are pulled back to their unapplied position by return springs.

Disc Brakes

Disc brakes resemble the brakes on a bicycle: the friction elements are in the form of pads, which are squeezed or clamped about the edge of a rotating wheel. With automotive disc brakes, this wheel is a separate unit, called a **rotor**, inboard of the vehicle wheel **(Figure 50–29)**. The rotor is typically made of cast iron. Since the pads clamp against both sides of it, both sides are machined smooth. Usually the two surfaces are separated by a finned center section for better cooling (such rotors are called **ventilated rotors**). The pads are attached to a metal backing and held in place inside the body of the caliper. As with the drum brakes, the pads are actuated by pistons and hydraulic pressure. The pistons are contained within a caliper assembly, a housing that wraps around the edge of the rotor. The caliper is kept from rotating by way of bolts holding it to the car's suspension framework.

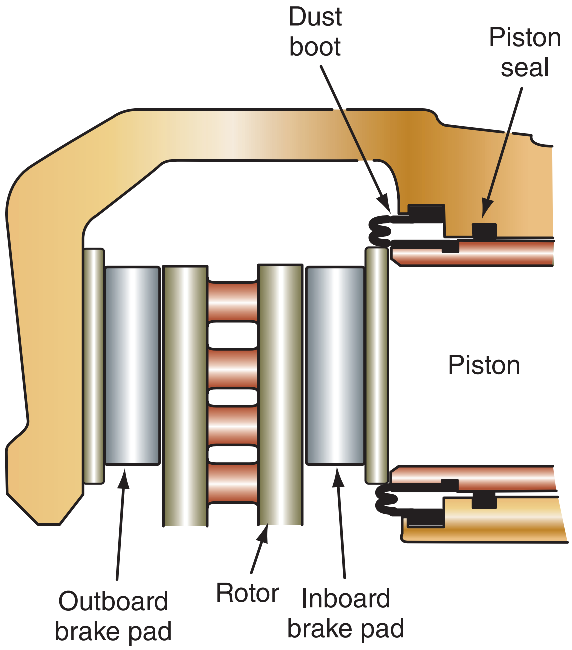


FIGURE 50–29 A view of how the disc brake caliper, pads, and rotor are arranged.

The **caliper** is a housing containing the pistons and related seals, springs, and boots as well as the cylinders and fluid passages necessary to force the friction linings or pads against the rotor. The caliper resembles a hand in the way it wraps around the edge of the rotor. It is attached to the steering knuckle. Some models use spring pressure to keep the pads close against the rotor. In other caliper designs this is achieved by a square-cut seal that distorts during brake application and returns to its original position as the brakes are released. This assists in retracting the piston into its cylinder and moves the pad off the rotor.

Unlike shoes in a drum brake, the pads act perpendicular to the rotation of the disc when the brakes are applied. This effect is different from that produced in a brake drum, where frictional drag actually pulls the shoe into the drum. Disc brakes are said to be non–self-energizing and so require more force to achieve the same braking effort. For this reason, they are ordinarily used in conjunction with a power brake unit.

Hydraulic System Service

Hydraulic system service is relatively uncomplicated, but it is vital to the vehicle's safe operation.

Warning! To check brake fluid level, you should observe the fluid through the reservoir and not remove the cap unless necessary. This helps prevent moisture from getting to the fluid. If the master cylinder cover must be removed, clean the cover before removal to avoid dropping dirt into the reservoir.

Brake Fluid Inspection

There are many ways to check for contaminated fluid. The color of the fluid is not always a good indication of its condition. Most brake fluids should be clear to amber in color but will darken with age. If the fluid is cloudy or thick, it is contaminated. The fluid can also be checked by placing a small amount of fluid in a clear glass jar. If the fluid is dirty or separates into layers, it is contaminated.


Courtesy of Phoenix Systems LLC.

FIGURE 50-30 A test strip can be used to check for copper contaminants in the brake fluid.

Test strips are also available. A strip of treated paper is dipped into the reservoir **(Figure 50–30)**. The paper will change colors corresponding to the condition of the fluid. The resulting color is then matched to the color chart that accompanies the test strips.

Special brake fluid testers are also available. These measure the fluid's boiling point, which is an indication of moisture content **(Figure 50–31)**.

FIGURE 50-31 Using a moisture tester to check brake fluid condition.

Contaminated brake fluid can damage rubber parts and cause leaks. To rid the system of contaminated brake fluid, the system should be flushed and refilled with new fluid.

If the brake fluid level is low and there are no signs of external leaks, it is likely the brake pads are nearing their wear limit. As the disc brake pad linings and rotors wear, the caliper pistons extend further out of the caliper bore. This increases the volume of fluid inside the calipers and reduces the fluid level in the master cylinder reservoir. If the fluid level is low, possibly causing the brake warning light to illuminate and no leaks are present, recommend to the customer to have the entire brake system inspected to check for worn linings.

Master Cylinder Inspection

Master cylinder problems are quite common but not always readily evident. However, there are times when the master cylinder is suspect and the problem lies elsewhere. Accurate and logical troubleshooting is the only way to truly determine if the master cylinder is working properly. Although brake pedal response and reservoir fluid levels are strong indicators of problems with the master cylinder or hydraulic system, other tests can be performed to help pinpoint the problem.

Check the master cylinder housing for cracks and damage **(Figure 50–32)**. Look for drops of brake

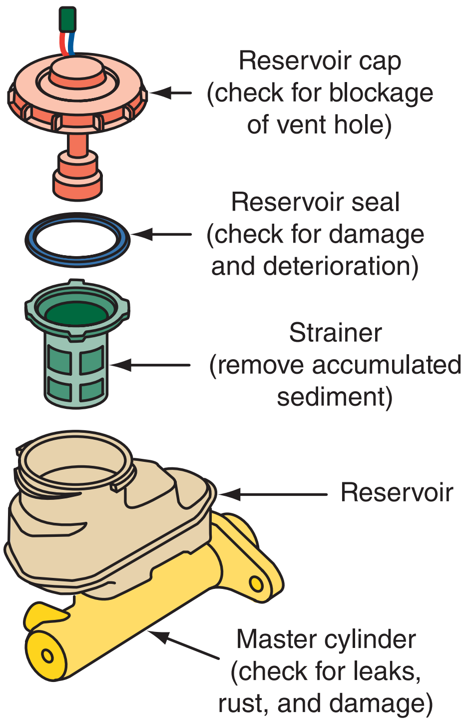


FIGURE 50-32 When inspecting a master cylinder, make sure to carefully check these items.

fluid around and behind the master cylinder. If a reservoir chamber is cracked, it may be completely empty and the surrounding area may be dry. This is because the fluid drained very quickly and has had time to evaporate or wash away. But with only one-half of the brake system operational, the brake warning lamp should be lit and a test drive should reveal the loss of braking power.

If the master cylinder has two separate fluid reservoirs, refill the master cylinder reservoir section that is empty and apply the brakes several times. Wait 5 to 10 minutes and check for leakage or fluid level drop in the reservoir.

Hydraulic brake system leaks can be internal or external. Most internal leaks are actually fluid bypassing the cups in the master cylinder. If the cups lose their ability to seal the pistons, brake fluid leaks past the cups and the pistons cannot develop system pressure **(Figure 50–33)**.

Internal and external rubber parts wear with use or can deteriorate with age or fluid contamination. Moisture or dirt in the hydraulic system can cause corrosion or deposits to form in the bore, resulting in the wear of the cylinder bore or its parts. Although internal leaks do not cause a loss of brake fluid, they can result in a loss of brake performance. Internal leakage will cause sinking pedal complaints and can be hard to pinpoint.

If the primary piston cup seal is leaking, the fluid will bypass the seal and move between the vent and replenishing ports for that reservoir or, in some cases, between reservoirs.

If there are no signs of external leakage, but the brake warning lamp is lit, the master cylinder may have an internal leak. To check for an internal leak in the master cylinder, remove the master cylinder cover and be sure the reservoirs are at least half full. Watch the fluid levels in the reservoirs while a helper slowly presses the brake pedal and then quickly releases it. If the fluid level rises slightly under steady pressure, the piston cups are probably leaking. Fluid level rising in one reservoir and falling in the other as the brake pedal is pressed and released also can indicate that fluid is bypassing the piston cups. Replace or rebuild the master cylinder if there is evidence of leakage.

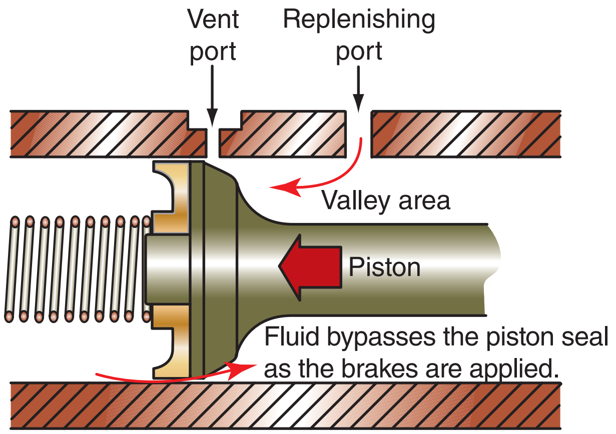


FIGURE 50–33 Fluid can leak or bypass around the piston seals in the master cylinder, causing a low pedal and poor braking.

Another quick test for internal leakage is to hold pressure on the brake pedal for about 1 minute. If the pedal drops but no sign of external leakage exists, fluid is probably bypassing the piston cups.

Quick Take-Up Valve Checks The quick take-up valve is used to provide a high volume of fluid on the first pedal stroke. This action takes up the slack in the low-drag caliper pistons. No direct test method exists for a quick take-up valve, but excessive pedal travel on the first stroke may indicate that fluid is bypassing the valve. If this symptom exists, check for a damaged or unseated valve. If the pedal returns slowly when the brakes are released, the quick take-up valve may be clogged so that fluid flow from the cylinder to the reservoir is delayed.

Air Entrapment Test

Poor pedal feel or action may be caused by trapped air in the system. Trapped air can be the result of a worn or defective master cylinder or other parts of the system. Air will also enter the system if there is a fluid leak. If there are no signs of leaks, check the system for trapped air.

To check for entrapped air, remove the cover of the master cylinder and make sure the reservoirs are filled to the proper level. Hold the cover and gasket against the reservoir top but do not secure it with its clamp or screws. Then have an assistant pump the brake pedal ten to twenty times rapidly and maintain pressure after the last pedal application. Remove the cover and have the assistant quickly release pedal pressure. Watch for a squirt of brake fluid from the reservoirs. If air is compressed in the system, it

> **Caution!** This test may result in brake fluid bubbling or spraying out of the master cylinder reservoir. Wear safety goggles. Cover the master cylinder reservoirs with clear plastic wrap or other suitable cover to keep brake fluid off the vehicle's paint.

will force fluid back through the compensating ports faster than normal and cause fluid to squirt in the reservoir. If a fluid squirt appears in one side of the reservoir but not the other, that side of the split hydraulic system contains the trapped air. If there is air trapped in the system, bleed the system and recheck.

System Flushing

Currently, more than a dozen manufacturers specify periodic brake fluid changes for some, or all, of their models built during the past 12 years. Change intervals vary from as often as every 12 months or 15,000 miles to as infrequently as every 60,000 miles. All brake systems accumulate sludge over some period of time. Flushing the system can remove this sludge and any moisture, but once you have disturbed the sludge, you want to be sure you get it *all* out of the system. Stirring up sludge from the master cylinder reservoir may cause it to get into ABS valves and pumps if you do not get it all out of the system.

Brake hoses for disc brakes usually enter the caliper near the top of the caliper body. The bleeder valve is also located at the top of the caliper bore. If sludge accumulates in the caliper bore, it collects at the bottom. A quick, superficial bleeding of the caliper will not flush out the sludge and all of the old fluid. To flush a caliper thoroughly, pump several ounces of fluid through it. On some vehicles during brake pad replacement, you may want to remove the caliper from its mounts and retract the piston to force out all the old fluid. Then reinstall it and thoroughly flush it with fresh fluid.

Flushing should be done at each bleeder screw in the same manner as bleeding. Open the bleeder screw approximately one and a half turns and force fluid through the system until the fluid emerges clear and uncontaminated. Do this at each bleeder screw in the system. After all lines have been flushed, bleed the system using one of the common bleeding procedures. All contaminated fluid should be drawn out of the master cylinder reservoir before bleeding. Make sure you dispose of the old brake fluid in the proper manner.

Brake Line Inspection Check all tubing, hoses, and connections from under the hood to the wheels for leaks and damage **(Figure 50–34)**. Rusted-through brake lines are common. Look closely where lines are held in place with clamps and brackets. Moisture and road salt can collect at these points and eat away at the lines. Check the flexible hoses for rotting, bulging, cracking, and damage from rubbing against other components. Also check for weak areas where the hose may balloon out under pressure. Many hoses have a white line along their length **(Figure 50–35)**. This line helps to show if the hose is twisted and kinked, a situation that can occur from improper disc brake service. Check parking brake linkage, cable, and connections for damage and wear. Replace parts where necessary.

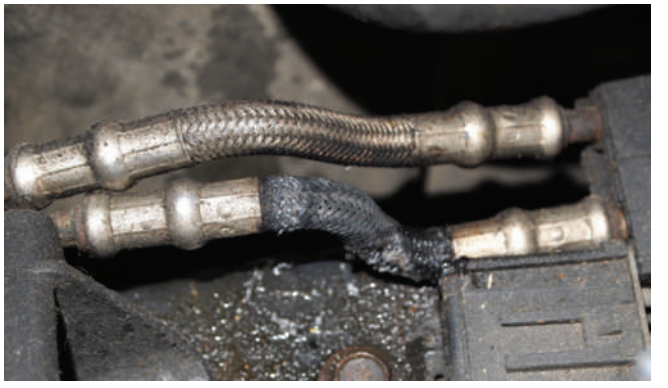


FIGURE 50-34 A leaking steel brake line.

Brake Pedal Inspection Depress and release the brake pedal several times (engine running for power brakes). Check for friction and noise. Pedal movement should be smooth, with no squeaks from the pedal or brakes. The pedal should return quickly when it is released.

When operating the engine, be sure the transmission lever is in neutral or park. Be sure the area is properly ventilated for the exhaust to escape.

FIGURE 50-35 The white line indicates the correct positioning of the hose.

Apply heavy foot pressure to the brake pedal (engine running for power brakes). Check for a spongy pedal and pedal reserve. Spongy pedal action is springy. Pedal action should feel firm. Pedal reserve is the distance between the brake pedal and the floor after the pedal has been depressed fully. The pedal should not go lower than 1 or 2 inches (25 or 50 mm) above the floor.

With the engine off, hold light foot pressure on the pedal for about 15 seconds. There should be no pedal movement during this time. Pedal movement indicates a leak. Repeat the procedure using heavy pedal pressure (engine running for power brakes).

If there is pedal movement but the fluid level is not low, the master cylinder has internal leakage. It must be rebuilt or replaced. If the fluid level is low, there may be an external leak somewhere in the brake system. The leak must be repaired.

Depress the pedal and check for proper stoplight operation.

To check power brake operation, depress and release the pedal several times while the engine is stopped. This eliminates vacuum from the system. Hold the brake down with moderate foot pressure and start the engine. If the power unit is operating properly, the brake pedal moves downward when the engine is started.

Master Cylinder Replacement To remove a master cylinder, disconnect the brake lines at the master cylinder. Install plugs in the brake lines and master cylinder to prevent dirt from entering. Remove the nuts that attach the master cylinder to the fire wall power brake unit and remove the cylinder.

Reassemble, install, and bleed the master cylinder according to the manufacturer's directions. Photo Sequence 48 is a typical procedure for bench bleeding a master cylinder.

Warning! Brake fluid can damage or even remove paint. Always use fender covers to protect the vehicle's finish and take extra care not to spill brake fluid under the hood on wiring or other components.

SHOP TALK

Master cylinders are seldom rebuilt; rather, they are replaced as a unit. In many cases rebuilding kits are not available for late-model vehicles, requiring the unit to be replaced.

Hydraulic System Bleeding

Fluids cannot be compressed, whereas gases are compressible. Any air in the brake hydraulic system is compressed as the pressure increases. This action reduces the amount of force that can be transmitted by the fluid, therefore it is very important to keep all air out of the hydraulic system. To do this, air must be bled from brakes. This procedure is called bleeding the brake system.

Bleeding is a process of forcing fluid through the brake lines and out through a bleeder valve or bleeder screw **(Figure 50–36)**. The fluid eliminates any air that might be in the system. Bleeder screws and valves are fastened to the wheel cylinders or calipers. Before attempting to open it, the bleeder should be cleaned. A drain hose then is connected from the bleeder to a glass jar **(Figure 50–37)**.

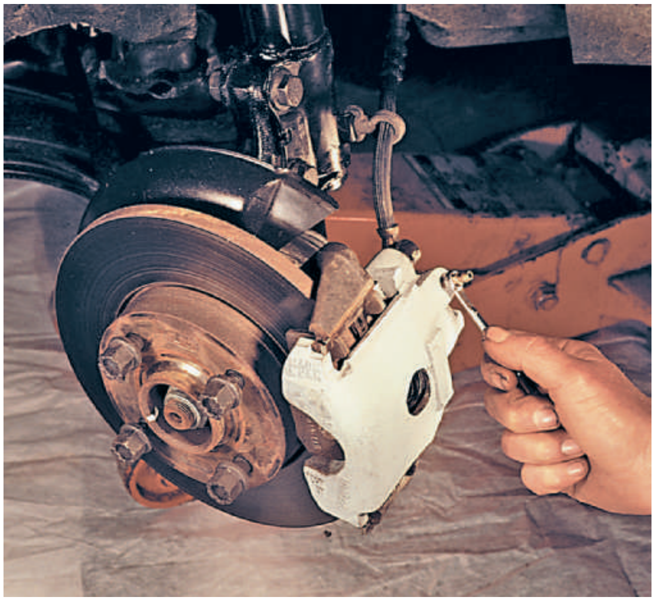


FIGURE 50–36 The wheel brake hydraulic units are fitted with bleeder screws.

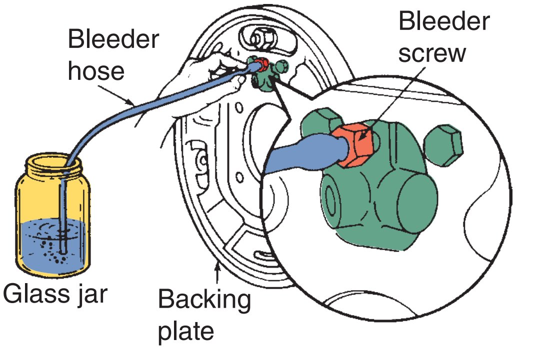
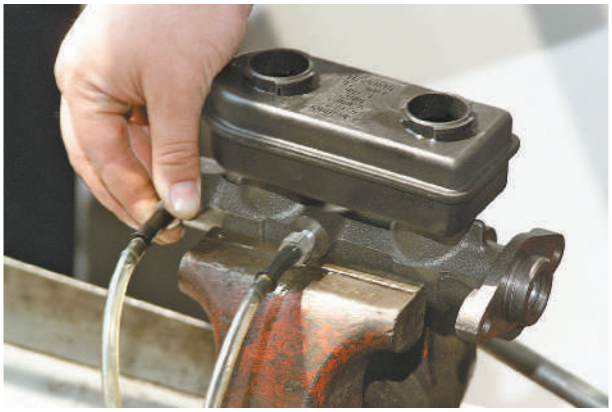


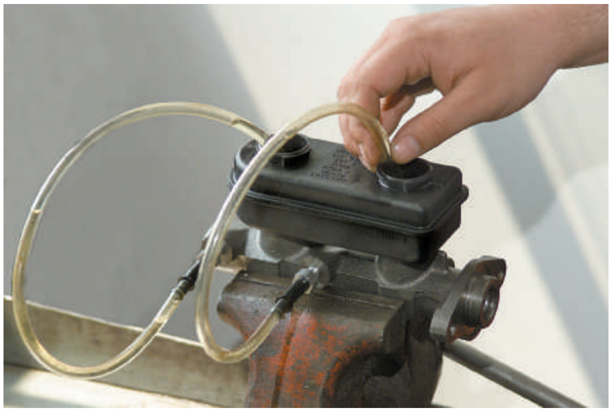
FIGURE 50–37 While bleeding the brake system, releasing the fluid into a glass jar will help to determine when the system is free of air.

Typical Procedure for Bench Bleeding a Master Cylinder

P48-1 Mount the master cylinder firmly in a vise, being careful not to apply excessive pressure to the casting. Position the master cylinder so the bore is horizontal.



P48-2 Connect short lengths of tubing to the outlet ports, making sure the connections are tight.



P48-3 Bend the tubing lines so that the ends are in each chamber of the master cylinder reservoir.

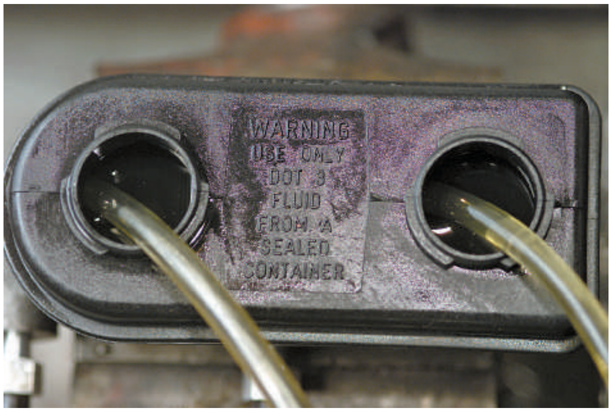
P48-4 Fill the reservoirs with fresh brake fluid until the level is above the ends of the tubes.

P48-5 Using a wooden dowel or the blunt end of a drift or punch, slowly push on the master cylinder pistons until both are completely bottomed out in their bore.

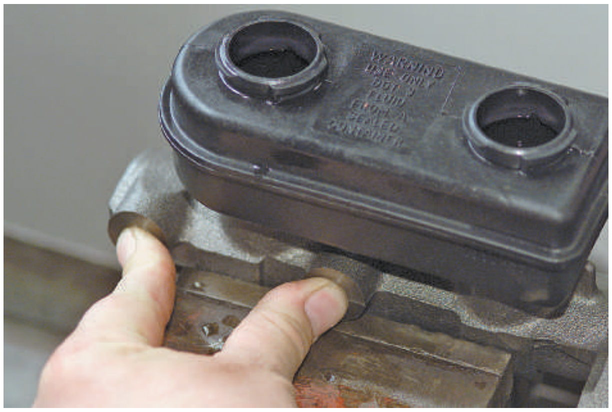
P48-6 Watch for bubbles to appear at the tube ends immersed in the fluid. Slowly release the cylinder piston and allow it to return to its original position. On quick take-up master cylinders, wait 15 seconds before pushing in the piston again. On other units, repeat the stroke as soon as the piston returns to its original position. Slow piston return is normal for some master cylinders.

PHOTO SEQUENCE 48

Typical Procedure for Bench Bleeding a Master Cylinder *(continued)*

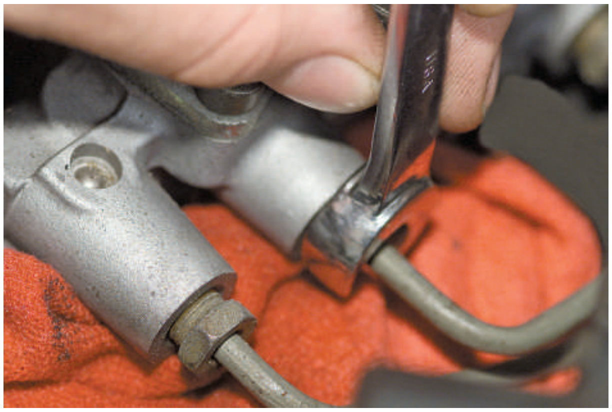


P48-7 Pump the cylinder piston until no bubbles appear in the fluid.



P48-8 Remove the tubes from the outlet ports and plug the openings with temporary plugs or your fingers. Keep the ports covered until you install the master cylinder on the vehicle.

P48-9 Install the master cylinder on the vehicle. Attach the lines, but do not tighten the tube connections.



P48-10 Slowly depress the pedal several times to force out any air that might be trapped in the connections each time the pedal is depressed. Before releasing the pedal, tighten the nut slightly and loosen it before depressing the pedal each time. Soak up the fluid with a rag to avoid damaging the car finish.

P48-11 When there are no air bubbles in the fluid, tighten the connections to the manufacturer's specifications. Make sure the master cylinder reservoirs are adequately filled with brake fluid.

P48-12 After reinstalling the master cylinder, bleed the entire brake system on the vehicle.

Two types of brake bleeding procedures are used: manual bleeding (including vacuum bleeding) and pressure bleeding. On some antilock brake systems, a scan tool is required to bleed the brakes. Always follow the manufacturer's recommendations when bleeding brakes. The sequence in which bleeding is performed can be critical. To remove vacuum from the vacuum-assist unit, the engine must be off, then pump the brake pedal several times.

Warning! Always use fresh brake fluid when bleeding the system. Do not use fluid that has already been opened. Do not use fluid that has been drained. Drained fluid may be contaminated and can damage the system.

Bleeding Sequence All manufacturers recommend a specific sequence to follow when bleeding a vehicle's brakes. These recommendations can be found in the service information and should be followed. If the manufacturer's recommendations are not available, the following sequence will work on most vehicles. This sequence starts at the wheel furthest from the master cylinder and works to the wheel closest:

1. Master cylinder
2. Combination valve or proportioning valve (if fitted with bleeder screws)
3. Right rear
4. Left rear
5. Right front
6. Left front
7. Height-sensing proportioning valve (if there is a bleeder screw)

Remember to stop after bleeding each wheel and refilling the fluid in the master cylinder. Failure to perform this step may result in running out of fluid and pulling air into the system.

This sequence is based on the principles of starting at the highest point in the system and working downward, then starting at the wheel farthest from the master cylinder and working to the closest. A couple of more general rules also are worth remembering.

If the brake system is split between the front and rear wheels, the rear wheels (which are farthest from the master cylinder) usually are bled first. If the brake system is split diagonally, the most common sequence is: RR-LF-LR-RF **(Figure 50–38)**. This sequence also applies to most systems with a quick take-up master cylinder. If you bleed a quick take-up

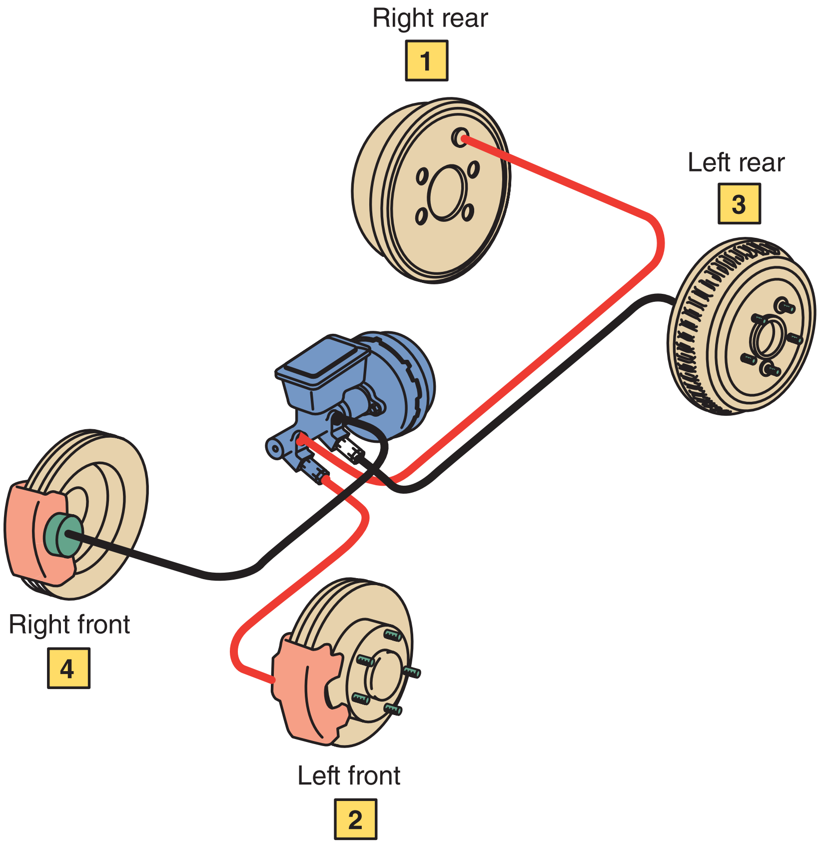


FIGURE 50–38 The recommended bleeding sequence for a diagonally split brake system.

system in any other sequence, you may chase air throughout the system.

Exceptions to the general rules exist, however. Chrysler, for example, recommends bleeding both rear brakes before the front brakes, regardless of how the hydraulic system is split.

Manual Bleeding A manual bleeding procedure requires two people. One person operates the bleeder; the other, the brake pedal. Bleed only one wheel at a time.

> **Warning!** Be sure the bleeder hose is below the surface of the liquid in the jar at all times. Do not allow the master cylinder to run out of fluid at any time. If these precautions are not followed, air can enter the system, and it must be bled again. The master cylinder cover must be kept in place.

Place the bleeder hose and jar in position. Have a helper pump the brake pedal several times and then hold it down with moderate pressure. Slowly open the bleeder valve. After fluid/air has stopped flowing, close the bleeder valve. Have the helper slowly release the pedal. Repeat this procedure until fluid that flows from the bleeder is clear and free of bubbles.

Discard all used brake fluid. Fill the master cylinder reservoir after bleeding each wheel brake. Check the brakes for proper operation.

> **Warning!** Clean the master cylinder and cover before adding fluid. This is important for preventing dirt from entering the reservoir.

Pressure Bleeding A pressure bleeding procedure can be done by one person. Pressure bleeding equipment uses pressurized fluid that flows through a special adapter fitted into the master cylinder **(Figure 50–39)**.

The use of pressure bleeding equipment varies with different automobiles and different equipment makers. Always follow the automobile manufacturer's recommendations when using pressure bleeding equipment.

On automobiles with metering valves, the valve must be held open during pressure bleeding. A special tool is used to hold open the metering section of a combination valve.

> **USING SERVICE INFORMATION**
> Consult the service information to be sure that the proper bleeding sequence is followed. If a vehicle requiring a special sequence is bled in the conventional manner, air might be chased throughout the system.

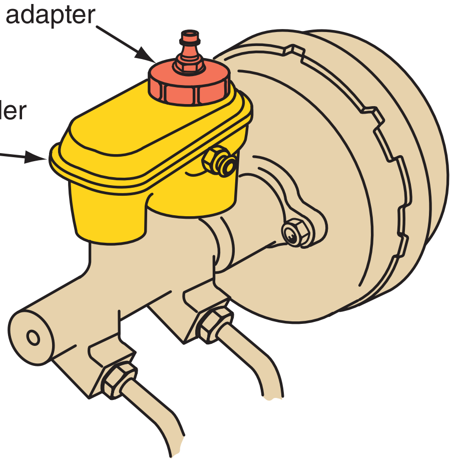


FIGURE 50–39 An adapter that installs onto the reservoir's fill opening is required to pressure bleed the brake system.

Open the bleeder valves one at a time until clear, air-free fluid is flowing. Progress from the wheel cylinder farthest from the master cylinder to the cylinder closest.

Do not exceed recommended pressure while bleeding the brakes. Always release air pressure after bleeding. Clean and fill the master cylinder after pressure bleeding. Check the brakes for proper operation. Be sure to remove the special tool used to hold the metering valve.

Power Brakes

Power brakes are nothing more than a standard hydraulic brake system with a booster unit located between the brake pedal and the master cylinder to help activate the brakes.

Three basic types of power-assist mechanisms are used. The first is vacuum assist. These systems use engine vacuum, or sometimes vacuum pressure developed by an external vacuum pump, to help apply the brakes. The second type of power assist is hydraulic assist. It is normally found on larger vehicles.

This system uses hydraulic pressure developed by the power steering pump or other external pump to help apply the brakes. The third type is a function of integral ABS units that combine the master cylinder, power assist, and ABS into one assembly.

Both vacuum and hydraulic assist act to multiply the force exerted on the master cylinder pistons by the driver. This increases the hydraulic pressure delivered to the wheel cylinders or calipers while decreasing driver foot pressure. Integral ABS units use an electric pump to provide pressure for brake assist and ABS functions.

GO TO Go to Chapter 53 for more on ABS operation.

Vacuum-Assist Power Brakes

All vacuum-assisted units are similar in design. They generate application energy by opposing engine vacuum to atmospheric pressure. A piston and cylinder, flexible diaphragm, or bellows use this energy to provide braking assistance.

All modern vacuum-assist units are vacuum-suspended systems. This means the diaphragm inside the unit is balanced using engine vacuum until the brake pedal is depressed. Applying the brake allows atmospheric pressure to unbalance the diaphragm and allows it to move generating application pressure.

Atmospheric pressure is normally between 14 and 15 psi (96.5 and 103 kPa). If the diameter of the diaphragm is 12 inches (305 mm), the area of the diaphragm is about 113 square inches (72,907 sq. mm). Since the vacuum to the booster is typically 17 inches of mercury (432 mm Hg) or about 7 psi (48 kPa), the pressure differential on the diaphragm is 7.7 psi (53 kPa). Therefore, the resulting force on the diaphragm would be 870 pounds (3870 N) (7.7×113).

Vacuum boosters may be single diaphragm or tandem diaphragm. The unit consists of three basic elements combined into a single power unit **(Figure 50–40)**.

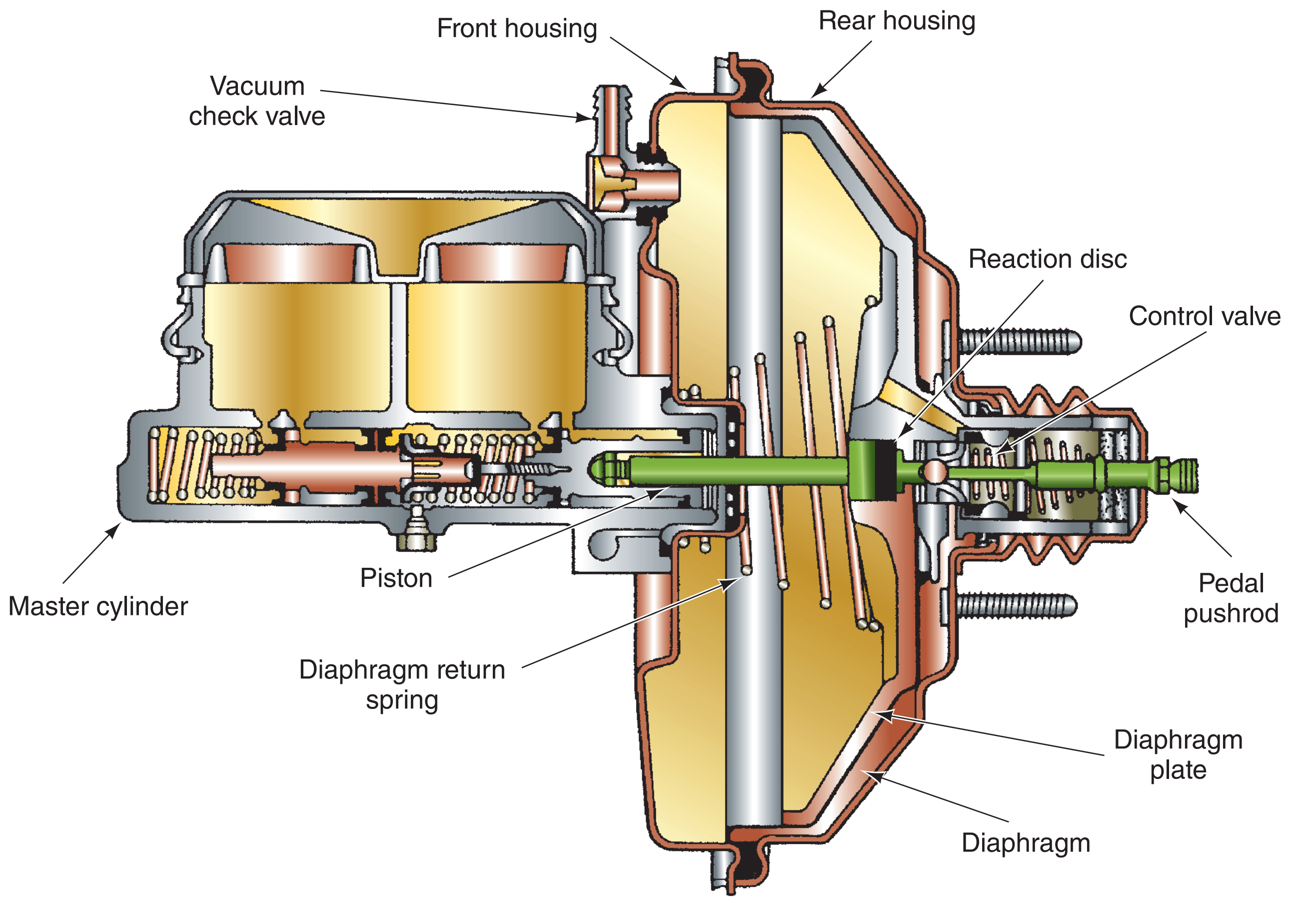


FIGURE 50–40 A typical vacuum brake booster.

The three basic elements of the single diaphragm follow:

1. A vacuum power section that includes a front and rear shell, a power diaphragm, a return spring, and a pushrod.
2. A control valve built as an integral part of the power diaphragm and connected through a valve rod to the brake pedal. It controls the degree of brake application or release in accordance with the pressure applied to the brake pedal.
3. A hydraulic master cylinder, attached to the vacuum power section that contains all the elements of the conventional brake master cylinder except for the pushrod. It supplies fluid under pressure to the pressure applied by the brake booster.

Operation When the brakes are applied, the valve rod and plunger move to the left in the power diaphragm. This action closes the control valve's vacuum port and opens the atmospheric port to admit air through the valve at the rear diaphragm chamber **(Figure 50–41)**. With vacuum in the rear chamber, a force develops that moves the power diaphragm, hydraulic pushrod, and hydraulic piston or pistons to close the compensating port or ports and force fluid under pressure through the residual check valve or valves and lines into the front and rear brake assemblies.

As pressure develops in the master cylinder, a counterforce acts through the hydraulic pushrod and reaction disc against the vacuum power diaphragm and valve plunger. This force tends to close the atmospheric port and reopen the vacuum port. Since this force is in opposition to the force applied to the brake pedal by the operator, it gives the operator a feel for the amount of brake applied.

Servicing Vacuum-Assist Booster Units The fact that a vehicle's brakes still operate when the vacuum-assist unit fails indicates that the hydraulic brake system and the vacuum-assist system are two separate systems. This means you should always check for faults in the hydraulic system first. If it checks out satisfactorily, start inspecting the vacuum-assist circuit.

For a fast check of vacuum-assist operation, press the brake pedal firmly and then start the engine.

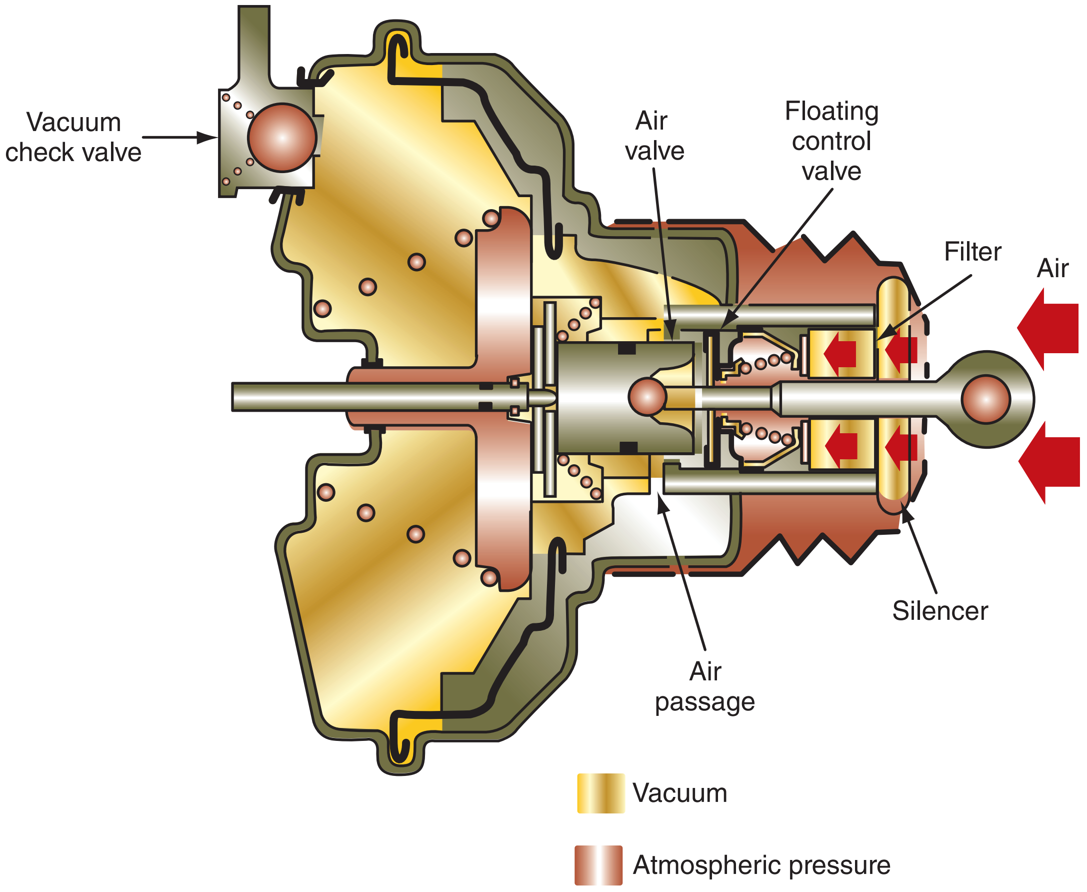


FIGURE 50–41 When the brakes are applied, atmospheric air pressure moves the diaphragm and piston forward, increasing the force applied to the pushrod.

The pedal should fall away slightly and less pressure should be needed to maintain the pedal in any position. This also checks the vacuum booster's check valve's operation. The pedal should be easy to press at least once or twice and then get very firm. If the check valve is not working, the pedal will be very hard to press the first time after the engine is off.

Some vehicles have a brake booster diaphragm position sensor, that if faulty, can set chassis system DTCs and pedal feel concerns. When testing a vacuum booster for a hard or soft/low pedal, check for DTCs and for proper sensor operation.

Pressure Check. Another simple check can be made by installing a suitable pressure gauge in the brake hydraulic system. Take a reading with the engine off and the power unit not operating. Maintain the same pedal height, start the engine, and read the gauge. There should be a substantial pressure increase if the vacuum-assist booster is operating correctly.

Pedal Travel. Pedal travel and total travel are critical on vacuum-assisted vehicles. Pedal travel should be kept strictly to specifications listed in the vehicle's service information.

Vacuum Reading. If the power unit is not giving sufficient assistance, take a manifold vacuum reading. If manifold vacuum level is below specifications, tune the engine and retest the unit. Loose or damaged vacuum lines and clogged air intake filters reduce braking assistance. Most units have a check valve that retains some vacuum in the system when the engine is off. A vacuum gauge check of this valve indicates if it is restricted or stays open.

Release Problems. Failure of the brakes to release is often caused by a tight or misaligned connection between the power unit and the brake linkage. Broken pistons, diaphragms, bellows, or return springs can also cause this problem.

To help pinpoint the problem, loosen the connection between the master cylinder and the brake booster. If the brakes release, the problem is caused by internal binding in the vacuum unit. If the brakes do not release, look for a crimped or restricted brake line or similar problem in the hydraulic system.

Hard Pedal. Power brakes that have a hard pedal may have collapsed or leaking vacuum lines of insufficient manifold vacuum. Punctured diaphragms or bellows and leaky piston seals all lead to weak power unit operation and hard pedal. A steady hiss when the brake is held down indicates a vacuum leak that causes poor operation.

Grabbing Brakes. First, look for the common causes of brake grab, such as greasy linings, or scored rotors or drums. If the trouble appears to be in the power unit, check for a damaged reaction control. The reaction control is made up of a diaphragm, spring, and valve that tend to resist pedal action. It is put into the system to give the driver more brake pedal feel.

Check of Internal Binding. Release problems, hard pedal, and dragging (slow releasing) brakes can all be caused by internal binding. To test a vacuum unit for internal binding, place the transmission/transaxle in neutral and start the engine. Increase engine speed to 1,500 rpm, close the throttle, and completely depress the brake pedal. Slowly release the brake pedal and stop the engine. Remove the vacuum check valve and hose from the vacuum-assist unit. Observe for backward movement of the brake pedal. If the brake pedal moves backward, there is internal binding and the unit should be replaced.

Pushrod Adjustment

Proper adjustment of the master cylinder pushrod is necessary to ensure proper operation of the power brake system. A pushrod that is too long causes the master cylinder piston to close off the vent port, preventing hydraulic pressure from being released and resulting in brake drag. A pushrod that is too short causes excessive brake pedal travel and causes groaning noises to come from the booster when the brakes are applied. A properly adjusted pushrod that remains assembled to the booster with which it was matched during production should not require service adjustment. However, if the booster, master cylinder, or pushrod are replaced, the pushrod might require adjustment.

Two methods can be used to check for proper pushrod length and installation: the gauge method and the air method.

Gauge Method

In most vacuum power units, the master cylinder pushrod length is fixed, and length is usually checked only after the unit has been overhauled or replaced. A typical adjustment using the gauge method is shown in **Figure 50–42**.

Air Method

The air-testing method uses compressed air applied to the hydraulic outlet of the master cylinder. Air

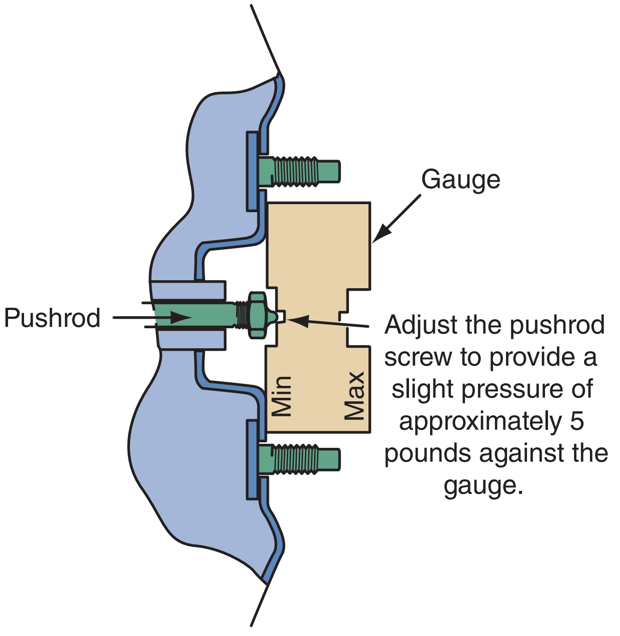


FIGURE 50-42 A gauge for measuring pushrod length.

pressure is regulated to a value of approximately 5 psi (35 kPa) to prevent brake fluid spraying from the master cylinder.

If air passes through the replenishing port, which is the smaller of the two holes in the bottom of the master cylinder reservoir, the adjustment is satisfactory. If air does not flow through the replenishing port, adjust the pushrod as required, either by means of the adjustment screw (if provided) or by adding shims between the master cylinder and power unit shell until the air flows freely.

Hydraulic Brake Boosters

Decreases in engine size, plus the continued use of engine vacuum to operate other engine systems, such as emission control devices, led to the development of hydraulic-assist power brakes. These systems use fluid pressure, not vacuum pressure, to help apply the brakes. They are mostly found on diesel engines and other engines that have low vacuum.

Fluid pressure from the power-steering pump provides the power assist to the brakes. The power brake booster is located between the cowl and the master cylinder. Hoses connect the power-steering pump to the booster assembly.

The power-steering pump provides a continuous flow of fluid to the brake booster whenever the engine is running. Three flexible hoses route the power-steering fluid to the booster. One hose supplies pressurized fluid from the pump. Another hose routes the pressurized fluid from the booster to the power-steering gear assembly. The third hose returns fluid from the booster to the power-steering pump.

The hydraulic pressure in the hydraulic booster should not be confused with the hydraulic pressure in the brake lines. Remember that they are two separate systems and require two different types of fluid: power-steering fluid for the pump and brake fluid for the brake system. Never put power-steering fluid in the brake reservoir. If the brake fluid becomes contaminated by power-steering fluid, the rubber components will be damaged. This may require the replacement of all parts that contain rubber and the steel lines of the brake system will need to be flushed.

Some systems have a nitrogen charged pneumatic accumulator on the booster to provide reserve power-assist pressure. If power-steering pump pressure is not available due to belt failure or similar problems, the accumulator pressure is used to provide brake assist.

The booster assembly **(Figure 50–43)** consists of an open center spool valve and sleeve assembly, a lever assembly, an input rod assembly, a power piston, an output pushrod, and the accumulator. The booster assembly is mounted on the vehicle in much the same manner as a vacuum booster. The pedal rod is connected at the booster input rod end.

Power-steering fluid flow in the booster unit is controlled by a hollow center spool valve. The spool valve has lands, annular grooves, and drilled passages. These mate with grooves and lands in the valve bore. The flow pattern of the fluid depends on the alignment of the valve in the bore.

Operation

When the brake pedal is depressed, the pedal's pushrod moves the master cylinder's primary piston forward. This causes the lever assembly of the booster to move a sleeve forward to close off the holes leading to the open center of the spool valve. A small additional lever movement moves the spool valve into the spool valve bore. The spool valve then diverts some hydraulic fluid into the cavity behind the booster piston building up hydraulic pressure that moves the piston and a pushrod forward. The output pushrod moves the primary and secondary master cylinder pistons that apply pressure to the brake system. When the brake pedal is released, the spool and sleeve assemblies return to

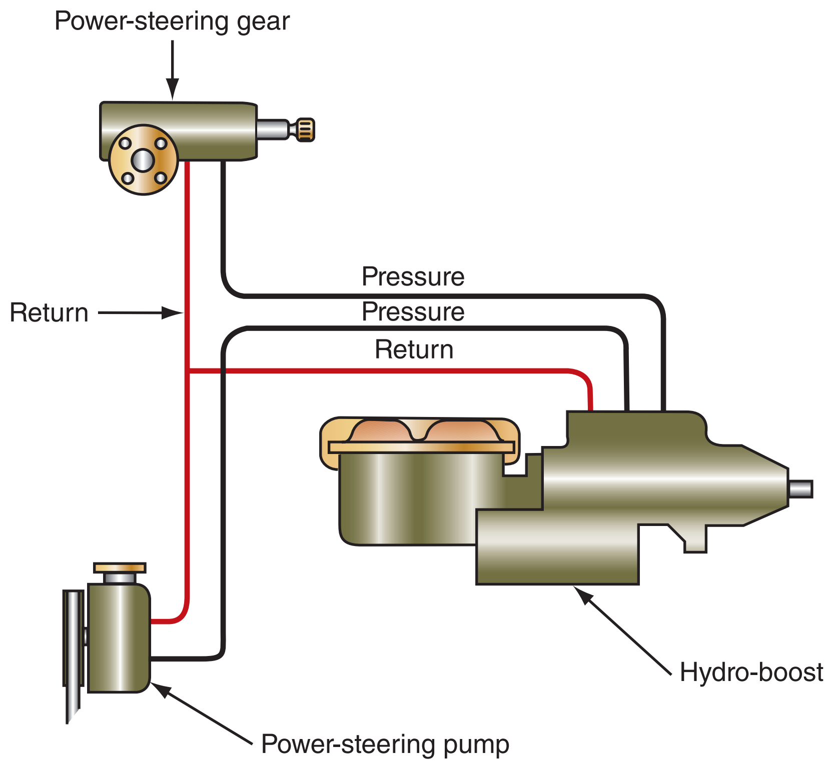


FIGURE 50–43 A hydraulic brake booster.

their normal positions. Excess fluid behind the piston returns to the power-steering pump reservoir through the return line. After the brakes have been released, pressurized fluid from the power-steering pump flows into the booster through the open center of the spool valve and back to the power-steering pump.

There have been many variations of and names given to hydraulic brake booster systems. The most common names are the hydro-boost system produced by Bendix and the Powermaster system produced by General Motors. The Powermaster system is a little different from the rest in that it uses a self-contained hydraulic booster that is built directly onto the master cylinder. Instead of relying on the power-steering pump for hydraulic pressure as is done in the other systems, the Powermaster has its own vane pump and electric motor to provide the hydraulic pressure required for booster operation.

Any investigation of a hydraulic boost complaint should begin with an inspection of the power-steering pump belt, fluid level, and hose condition and connections. Hydraulic boost systems do not work properly if they are not supplied with a continuous supply of clean, bubble-free power-steering fluid at the proper pressure.

Warning! Always depressurize the accumulator of any hydraulic boost system before disconnecting any brake lines or hoses. This is usually done by turning the engine off and depressing and releasing the brake pedal up to ten times.

Basic Operational Test

The basic operational test of these systems is as follows. With the engine off, pump the brake pedal numerous times to bleed off the residual hydraulic pressure that is stored in the accumulator. Hold firm pressure on the brake pedal and start the engine. The brake pedal should move downward, then push up against the foot.

Accumulator Test

To be sure the accumulator is performing properly, rotate the steering wheel with the engine running until it stops and hold it in that position for no more than 5 seconds. Return the steering wheel to the center position and shut off the engine. Pump the

brake pedal. You should feel two to three power-assisted strokes. Now repeat the steps. That pressurizes the accumulator. Wait one hour, then pump the brake pedal. There should be two or three power-assisted strokes. If the system does not perform as just described, the accumulator is leaking and should be replaced.

Noise Troubleshooting

The booster is also part of another major subsystem of the vehicle, the power-steering system. Problems or malfunctions in the steering system may affect brake-assist operation. The following are some common troubleshooting tips.

Moan or low-frequency hum usually accompanied by a vibration in the pedal or steering column might be encountered during parking or other very low-speed maneuvers. This can be caused by a low fluid level in the power-steering pump, or by air in the power-steering fluid due to holding the pump at relief pressure (steering wheel held all the way in one direction) for an excessive amount of time (more than 5 seconds). Check the fluid level and add fluid if necessary. Allow the system to sit for 1 hour with the cap removed to eliminate the air. If the condition persists, it might be a sign of excessive pump wear. Check the pump according to the vehicle manufacturer's recommended procedure.

At or near power runout (brake pedal near fully depressed position), a high-speed fluid noise (like a faucet can make) might occur. This is a normal condition and will not be heard, except in emergency braking conditions.

Whenever the accumulator pressure is used, a slight hiss is noticed. It is the sound of the hydraulic fluid escaping through the accumulator valve and is completely normal.

After the accumulator has been emptied and the engine is started again, another hissing sound might be heard during the first brake application or the first steering maneuver. This sound is caused by the fluid rushing through the accumulator charging orifice. It is normal and will only be heard once after the accumulator is emptied. However, if this sound continues even though no apparent accumulator pressure assist was made, it could indicate that the accumulator is not holding pressure. Check for this possibility using the accumulator test discussed previously.

After bleeding, a gulping sound might be present during brake applications, as noted in the bleeding instructions. This sound is normal and should disappear with normal driving and braking.

Diagnosis and testing of the Powermaster unit requires the use of a special adapter and test gauge or aftermarket equivalents. The Powermaster pressure switch is removed and the adapter and test gauge is installed in its port. The unit can then be energized, and the switch's high-pressure cut-off and low-pressure turn-on points observed and checked against specifications. Follow the instructions given in the service information for the connection and operation of the test gauge and all system test procedures.

Electric Parking Brakes

Electrically operated parking brakes are becoming more common and are replacing mechanical systems. These systems operate as a conventional hydraulic brake for normal braking and as an electric brake for parking. With electric parking brakes, there is no need for a parking brake lever or pedal. This frees up space in the interior.

Electric parking brakes are seen as the first step toward brake-by-wire systems. Two different techniques are currently being used by manufacturers. Some systems have an electric motor mounted on the rear brake calipers and others use an undercar motor to pull on the parking brake cables.

When the caliper is fitted with a motor **(Figure 50–44)**, there is no need for parking brake cables and linkages. The motor is controlled by the PCM. The system interfaces with the vehicle's controller area network (CAN) for continuous monitoring and feedback. This allows the system to do many things besides apply the parking brake, such as:

- Provide some control during emergency braking.
- Help stop the car if the hydraulic system fails.
- Automatically release the parking brakes when the throttle is opened.
- Automatically engage when the ignition is turned off.
- Automatically engage when the driver's door is opened.
- Keep the vehicle from rolling backward when stopped on a hill by applying the rear brakes until the driver operates the clutch or throttle pedals.

(A) (B)

FIGURE 50-44 (A) A switch on the console controls the electric motor (B) that engages and disengages the parking brakes.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2007	**Make:** Chevy	**Model:** Colorado	**Mileage:** 128,787	**RO:** 19028
Concern:	Customer states vehicle lost braking ability—pedal went to the floor several times while towing a trailer on vacation.			
After confirming the fluid level in the master cylinder, the technician performs a complete brake system inspection. No leaks are found but the brake pads and rotors show signs of overheating and glazing. Knowing the truck was under a heavier load than normal, the technician determines the brakes overheated and braking was lost due to fade.				
Cause:	Brakes overheated while towing a trailer causing brake fade.			
Correction:	Replaced brake pads and rotors, flushed and refilled hydraulic system with DOT 3 brake fluid. Advised customer that this particular truck is not equipped to tow heavy trailers through mountainous areas.			

KEY TERMS

Aramid fibers
Brake fade
Caliper
Coefficient of friction (COF)
Combination valve
Cup seal
Metallic linings
Metering valve
Nonasbestos organic linings (NAO)
Proportioning valve
Quick take-up
Replenishing port
Rotor
Semimetallic lining
Static friction
Synthetic lining
Vent port
Ventilated rotor

SUMMARY

- The four factors that determine a vehicle's braking power are pressure, which is provided by the hydraulic system; coefficient of friction, which represents the frictional relationship between pads and rotors or shoes and drums; frictional contact surface, which means bigger brakes stop a car more quickly than smaller brakes; and head dissipation, which is necessary to prevent brake fade.
- Today's brake linings are fully metallic, semimetallic, nonasbestos organic, synthetic, carbon, or ceramic.
- Since 1967, all cars have been required to have two separate brake systems. The dual brake system uses a tandem master cylinder, which is two master cylinders with two separated pistons and fluid reservoirs in one cylinder bore.
- The brake lines transmit brake fluid pressure from the master cylinder to the wheel cylinders and calipers of drum and disc brakes. Brake hoses offer flexible connections to wheel units and must offer high heat resistance.
- A pressure differential valve is used in all dual brake systems to operate a warning light switch that alerts the driver if pressure is lost in either hydraulic system.
- The metering valve, located in the front brake line, provides for better balance of the front and rear brakes while also preventing lockup of the front brakes.
- The proportioning valve controls rear brake pressure, particularly during hard stops.
- Bleeding removes air from the hydraulic system.
- Flushing removes old brake fluid from the system and replaces it with fresh new fluid. This should be done about every 2 years.
- Power brakes can be either vacuum assist or hydraulic assist. Vacuum-assisted units use engine vacuum or vacuum developed by an external pump to help apply the brakes. Hydraulic-assisted units use fluid pressure.

REVIEW QUESTIONS

Short Answer

1. Explain why bleeding air out of a hydraulic system is so important.
2. Explain why modern hydraulic braking systems are dual designs, and why this is important.
3. Describe the functions of the hydraulic system combination valve.
4. When the brakes are applied on a moving car, the frictional parts (brake ___ or ___) are forced against the rotating parts of the car (brake ___ or ___). The friction causes the rotating parts to slow down and stop. Just as the energy of the rotating parts is called kinetic ___, the friction used to stop them is called kinetic ___.
5. What is the purpose of the master cylinder replenishing port?
6. Explain why a height-sensing proportioning valve is used on some vehicles.
7. A three-function combination valve has a brake system failure switch, a ___ valve, and a ___ valve.
8. Explain how vacuum is used to provide a power assist.

True or False

1. *True or False?* Metering and proportioning valves balance the braking characteristics of disc and drum brakes.
2. *True or False?* Semimetallic brake pads still often are made with asbestos.

Multiple Choice

1. The purpose of the master cylinder is to ___.
   a. generate the hydraulic pressure needed to apply the brake mechanisms
   b. automatically pump the brakes during panic stops
   c. apply braking power when wheel slippage occurs
   d. all of the above
2. Which of the following can lead to brake hose failure?
   a. Twisting during installation
   b. Stressing the hose during installations
   c. Deterioration from heat and contaminants
   d. All of the above
3. Which type of brake requires greater application force and is commonly used with power-boost units?
   a. Drum
   b. Disc
   c. Parking
   d. None of the above

4. Which of the following is *not* a factor in determining the effectiveness of a brake system?
   a. Heat dissipation
   b. Lubricant
   c. Pressure
   d. Frictional contact area
5. Which of the following could cause an extremely hard brake pedal?
   a. Air in the system
   b. Excessively worn brake pads
   c. Use of the wrong fluid
   d. A leaking diaphragm in the vacuum power booster

ASE-STYLE REVIEW QUESTIONS

1. A vehicle's power brakes are grabbing: Technician A says that the most likely cause is the power brake booster. Technician B says that the most likely cause is greasy linings or scored drums. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. While discussing what affects the amount of pressure exerted by the brakes: Technician A says that the shorter the line, the more pressure there will be. Technician B says that braking force will increase if the size of the pistons in a master cylinder are increased. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. The metering valve portion of a combination valve fails: Technician A says that this means the entire combination valve must be replaced. Technician B says that the metering part can be repaired. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. While discussing quick take-up master cylinders: Technician A says that this design allows for increased braking power. Technician B says that this design is only used on drum brake systems. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. While bleeding a brake system: Technician A loosens the brake line fitting at the master cylinder to bleed the system if a bleeder screw is seized and cannot be loosened. Technician B uses shop air to push the fluid and air from the wheel units to the master cylinder. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. The basic frictional parts of a brake system are being discussed: Technician A says that the harder the frictional parts are pushed together, the greater the friction. Technician B says that the harder the frictional parts are pushed together, the more heat is developed. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. Vehicle dynamics during braking are being discussed: Technician A says that the rear of the car rises during braking. Technician B says that the front of the car lowers during braking. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. Pressure bleeding is being discussed: Technician A says that metering and combination valves must be held open using a special tool during the bleeding operation to ensure good results. Technician B says that the pressure bleeder requires special adapters to connect it to the master cylinder reservoir. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

9. Technician A says that the master cylinder should be bled before any individual wheel assembly. Technician B says that the bleeder screw should be closed before the brake pedal is released during manual bleeding of the system. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

10. The hydraulic system of the hydro-boost and Powermaster is being discussed: Technician A says that the hydro-boost uses a power-steering pump. Technician B says that the Powermaster uses an electric motor-driven vane pump. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 51

DRUM BRAKES

OBJECTIVES

- Explain how drum brakes operate.
- Identify the major components of a typical drum brake and describe their functions.
- Explain the difference between duo-servo and nonservo drum brakes.
- Perform a cleaning and inspection of a drum brake assembly.
- Recognize conditions that adversely affect the performance of drums, shoes, linings, and related hardware.
- Reassemble a drum brake after servicing.
- Explain how typical drum parking brakes operate.

For many years, drum brakes **(Figure 51–1)** were used on all four wheels on virtually every vehicle on the road. Today, disc brakes have replaced drum brakes on the front wheels of most vehicles and some models are equipped with both front and rear disc brakes. One reason for their continued use is that drum brakes can easily handle the 20 percent to 40 percent of total braking load placed on the rear wheels. Another is that drum brakes can also be built with a simple parking brake mechanism.

Drum Brake Operation

Drum brake operation is fairly simple. The most important feature contributing to the effectiveness of the braking force supplied by the drum brake is the brake shoe pressure or force directed against the drum **(Figure 51–2)**. With the vehicle moving in either the forward or reverse direction with the brakes on, the applied force of the brake shoe pressing against the brake drum increasingly multiplies itself

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2003	**Make:** Ford	**Model:** Windstar	**Mileage:** 138,197	**RO:** 19087
Concern:	Customer says the van nosedives when braking.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

FIGURE 51–1 A drum brake assembly.

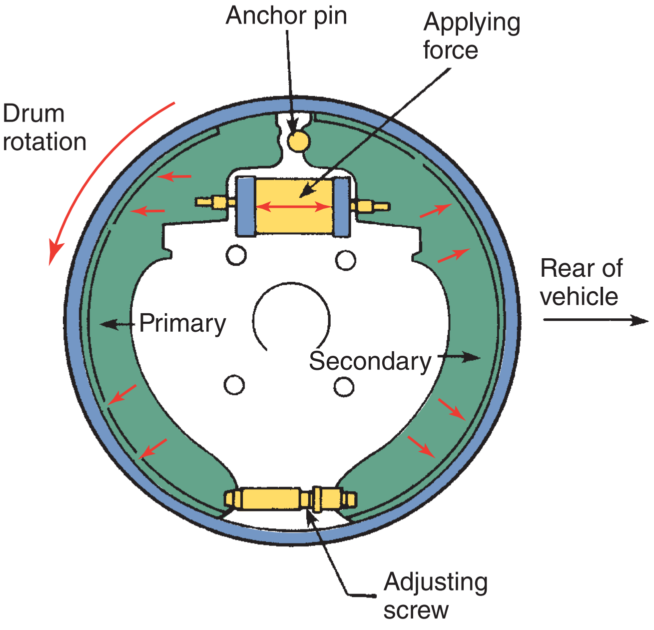


FIGURE 51–2 The wheel cylinder pushes the primary and secondary shoes against the inside surface of the rotating brake drum.

(called self-energizing) because the brake's anchor pin acts as a brake shoe stop and prohibits the brake shoe from its tendency to follow the movement of the rotating drum. The result is a wedging action between the brake shoe and brake drum. The wedging action combined with the applied brake force creates a self-multiplied brake force.

Drum Brake Components

The **backing plate** provides a foundation for the brake shoes and associated hardware **(Figure 51–3)**. The plate is secured and bolted to the axle flange or spindle. The wheel cylinder,

FIGURE 51–3 The backing plate provides a foundation for the brake shoes and associated hardware.

under hydraulic pressure, forces the brake's shoes against the drum. There are also two linked brake shoes attached to the backing plate. Brake shoes are the backbone of a drum brake. They must support the lining and carry it into the drum so the pressure is distributed across the lining surface during brake application. Shoe return springs and shoe holddown parts maintain the correct shoe position and clearance. Some drum brakes are self-adjusting. Others require manual adjustment mechanisms. Brake drums provide the rubbing surface area for the linings. Drums must withstand high pressures without excessive flexing and must also dissipate large quantities of heat generated during brake application. Finally, the rear drum brakes on most vehicles include the parking brakes.

Wheel Cylinders

Wheel cylinders convert hydraulic pressure from the master cylinder into a mechanical force at the brakes **(Figure 51–4)**. The wheel cylinder bore is filled with fluid. When the brake pedal is depressed, additional brake fluid is forced into the cylinder. The additional fluid moves the cups and pistons outward. This piston movement forces the brake shoes outward to the contact drum and thus applies the brakes. Piston stops prevent the fluid leakage or air from getting into the system when the pistons move to the end of their bores.

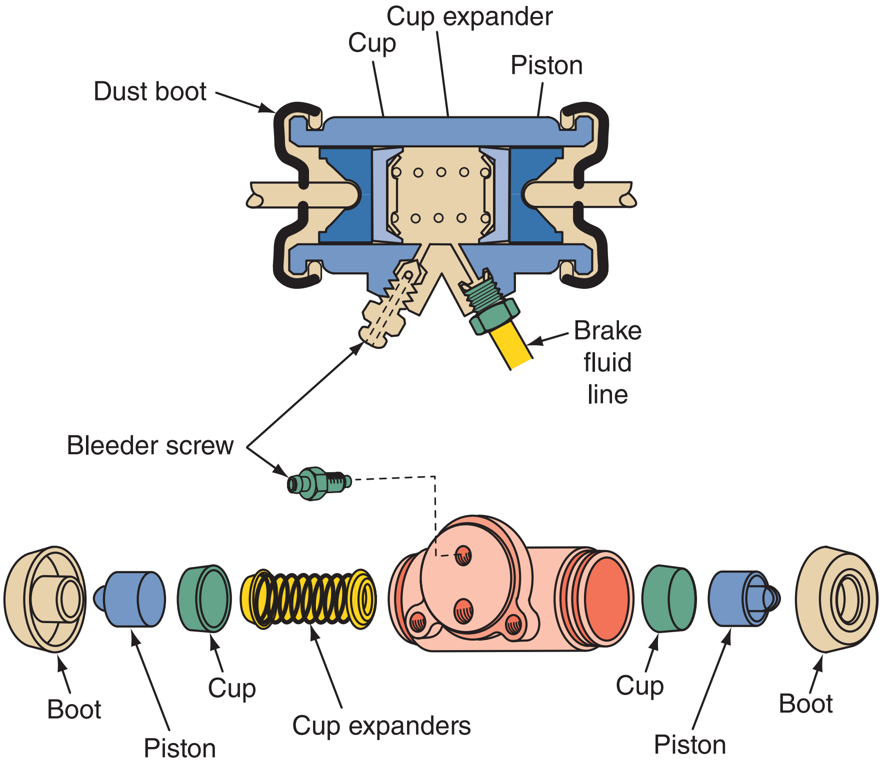


FIGURE 51–4 The exploded view of a typical wheel cylinder.

Brake Shoes and Linings

In the same brake shoe sizes, there can be differences in **web** thickness, shape of web cutouts, and positions of any reinforcements **(Figure 51–5)**.

The shoe rim is welded to the web to provide a stable surface for the lining. The web thickness might differ to provide the stiffness or flexibility needed for a specific application. Many shoes have nibs or indented places along the edge of the rim.

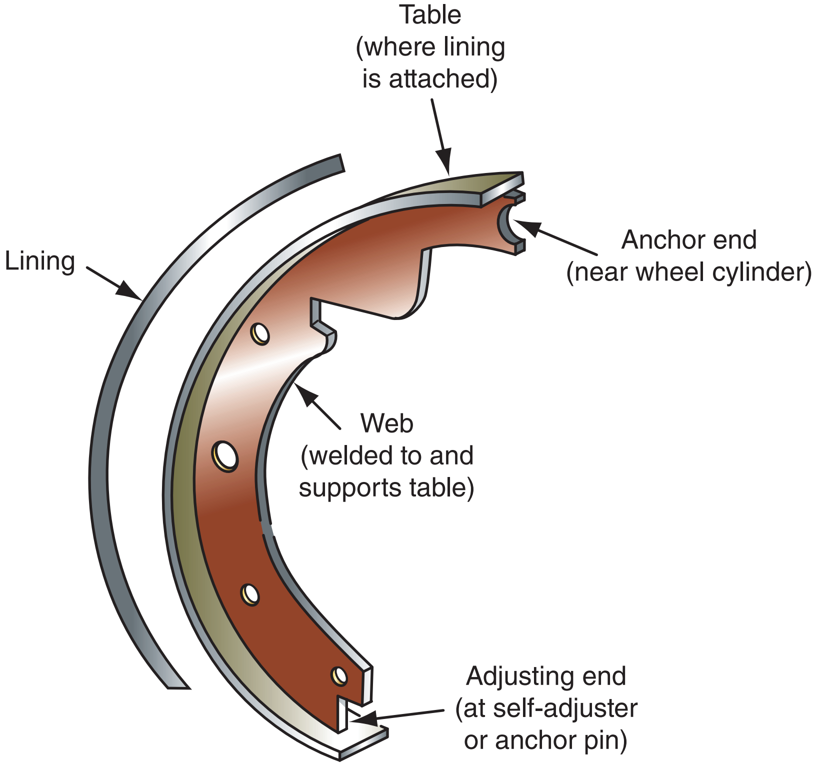


FIGURE 51–5 A typical brake shoe with the lining detached.

These nibs rest against shoe support ledges on the backing plate and keep the shoe from hanging up.

Each drum in the drum braking system contains a set of shoes. In a servo system, the **primary shoe** (or leading shoe) is the one that is toward the front of the vehicle. The friction between the primary shoe and the brake drum forces the primary shoe to shift slightly in the direction that the drum is turning. (An anchor pin permits limited movement.) The shifting of the primary shoe forces it against the bottom of the secondary shoe, which causes the secondary shoe to contact the drum. The **secondary shoe** (or trailing shoe) is the one that is toward the rear of the vehicle. It comes into contact as a result of the movement and pressure from the primary shoe and wheel cylinder piston and increases the braking action **(Figure 51–6)**.

The brake shoe lining provides friction against the drum to stop the car. It contains heat-resistant fibers. The lining is molded with a high-temperature synthetic bonding agent.

The two general methods of attaching the lining to the shoe are riveting and bonding. Regardless of the method of attachment, brake shoes are usually held in a position by spring tension. They are either held against the anchor by the shoe return springs or against the support plate pads by shoe **holddown springs**. The shoe webs are linked together at the end opposite the anchor by an adjuster and a spring. The adjuster holds them apart. The spring holds them against the adjuster ends.

Mechanical Components

In the unapplied position, the shoes are held against the anchor pin by the return springs. The shoes are held to the backing plate by holddown springs or spring clips. Opposite the anchor pin, an adjuster links the shoe webs and provides an adjustment that permits the shoes to be expanded or contracted. The shoes are held against the adjuster by a spring.

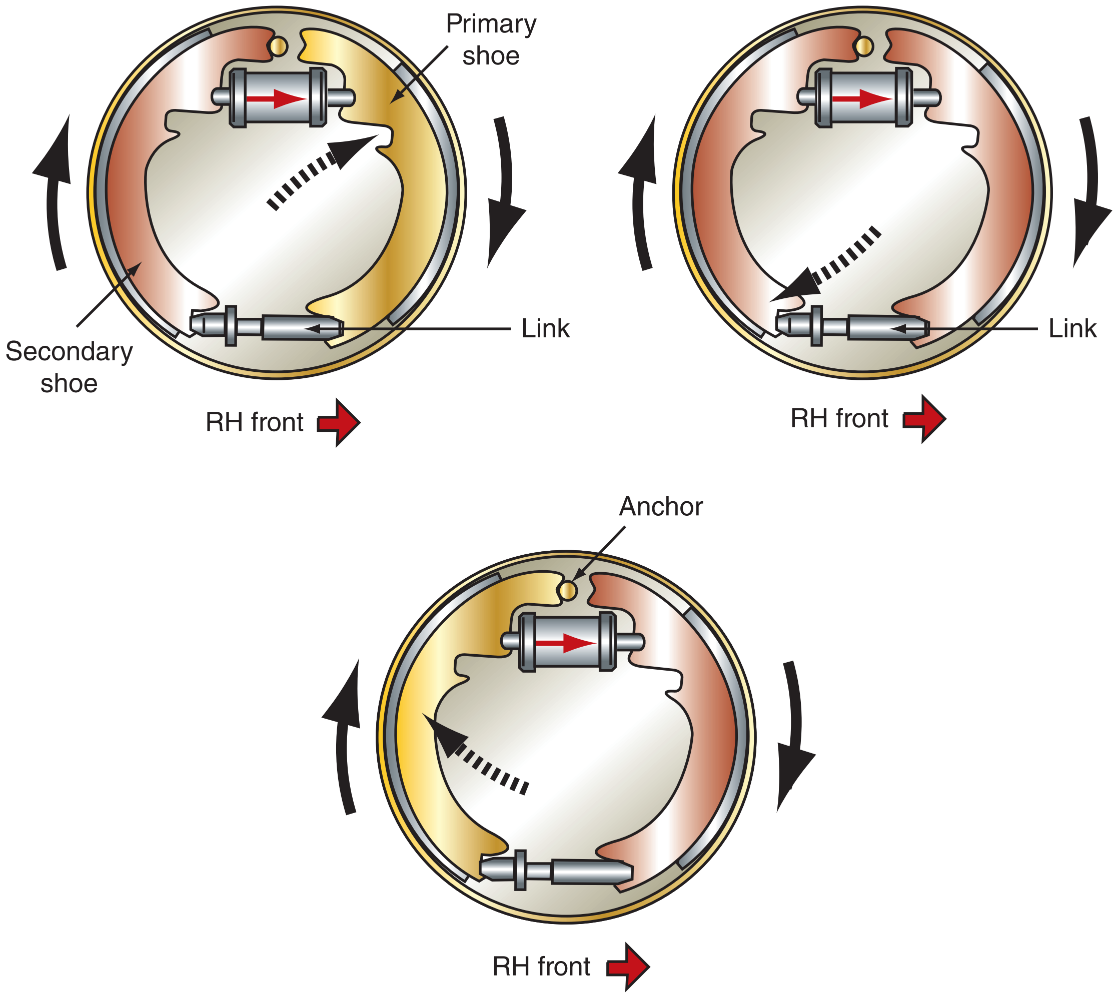


FIGURE 51–6 In a servo brake system, the self-energizing action of the primary shoe applies force to the secondary shoe.

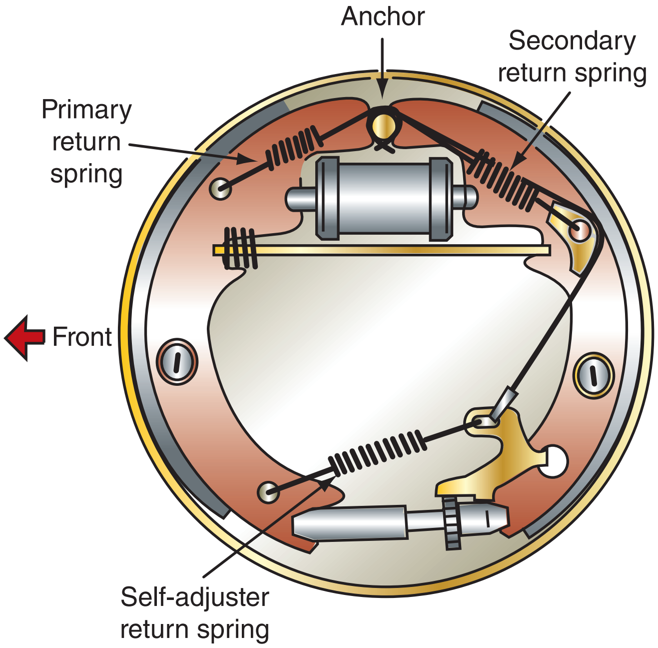


FIGURE 51–7 Typical return spring installation in a duo-servo system.

Shoe Return Springs **Return springs** can be separately hooked into a link or a guide or strung between the shoes. Springs are normally installed on the anchor with servo type brakes as shown in **Figure 51–7**. In nonservo brake assemblies, the return springs typically connect each shoe together as shown in **Figure 51–8**.

While shoe brake springs look the same, they are usually not interchangeable. Sometimes to help distinguish between them, they are color coded. Pay close attention to the colors and the way they are hooked up.

Shoe Holddowns Various shoe holddowns are illustrated in **Figure 51–9**. To unlock or lock the straight pin holddowns, depress the locking cup and coil

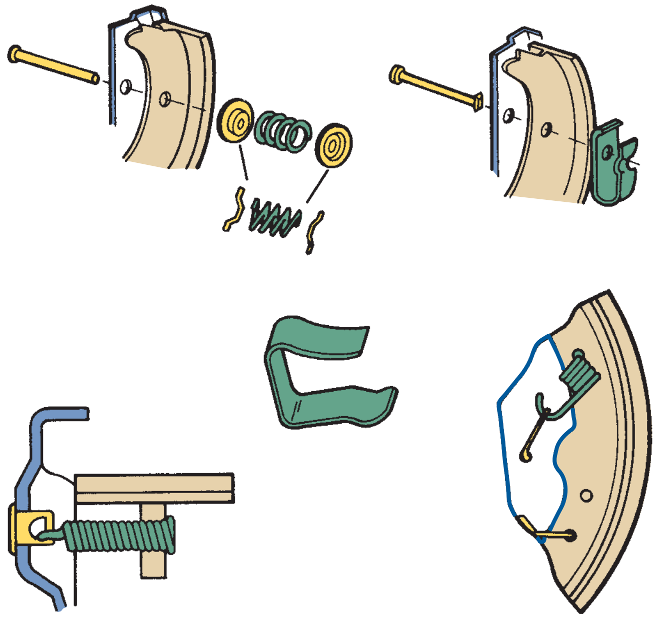


FIGURE 51–9 Types of brake shoe holddowns.

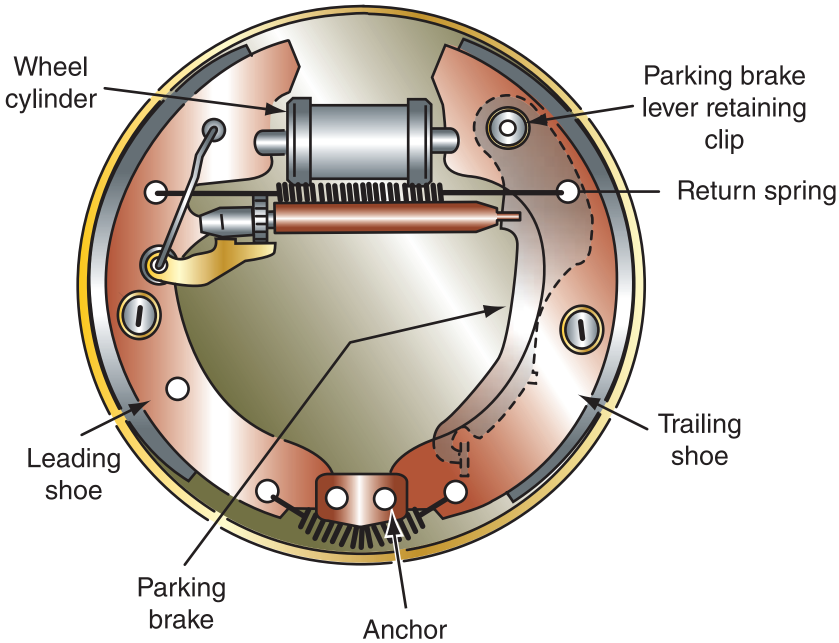


FIGURE 51–8 In nonservo systems, the return springs typically connect each brake shoe together.

spring or the spring clip, and rotate the pin or lock 90 degrees. On General Motors' lever adjusters, the inner (bottom) cup has a sleeve that aligns the adjuster lever.

Shoe Anchors There are various types of **shoe anchors** such as the fixed nonadjustable type, self-centering shoe sliding type, or on some earlier models, adjustable fixed-type providing either an eccentric or a slotted adjustment. On some front brakes, fixed anchors are threaded into or are bolted through the steering knuckle and also support the wheel cylinder.

Drums

Modern automotive brake drums are made of heavy cast iron (some are aluminum with an iron or steel sleeve or liner) with a machined surface inside against which the linings on the brake shoes generate friction when the brakes are applied. This results in the creation of a great deal of heat. The inability of drums to dissipate as much heat as disc brakes is one of the main reasons discs have replaced drums at the front of all late-model cars and light trucks, and at the rear of some sports and luxury cars.

Sometimes the rear drums of FWD cars and larger trucks are integral with the hub and cannot be removed without disassembling the wheel bearing. These are called fixed drums as they are held or fixed in place by other components **(Figure 51–10)**. The rear drums of other FWD and most RWD cars are held in place by the wheel lugs so they can be removed without tampering with the wheel bearings. These are called floating drums.

Drum Brake Designs

There are two brake designs in common use. They are duo-servo (or self-energizing) drum brakes and nonservo (or leading-trailing) drum brakes.

Most large American cars use the duo-servo design of brake. However, the nonservo type has become popular as the size of cars has become smaller. Because the smaller cars are lighter, this type of brake helps reduce rear brake lockup without reducing braking ability.

Duo-Servo Drum Brakes

The name **duo-servo drum brake** is derived from the fact that the **self-energizing force** is transferred from one shoe to the other with the wheel rotating in either direction. Both the primary (front) and secondary (rear) brake shoes are actuated by a double-piston wheel cylinder. The upper end of each shoe is held against a single anchor by a heavy coil return spring. An adjusting screw assembly and spring connect the lower ends of the shoes.

The wheel cylinder is mounted on the backing plate at the top of the brake. When the brakes are applied, hydraulic pressure behind the wheel cylinder cups forces both pistons outward causing the brakes to be applied.

When the brake shoes contact the rotating drum in either direction of rotation, they tend to move with the drum until one shoe contacts the anchor and the other shoe is stopped by the star wheel adjuster link **(Figure 51–11)**. With forward rotation, frictional forces between the lining and the drum of the primary shoe

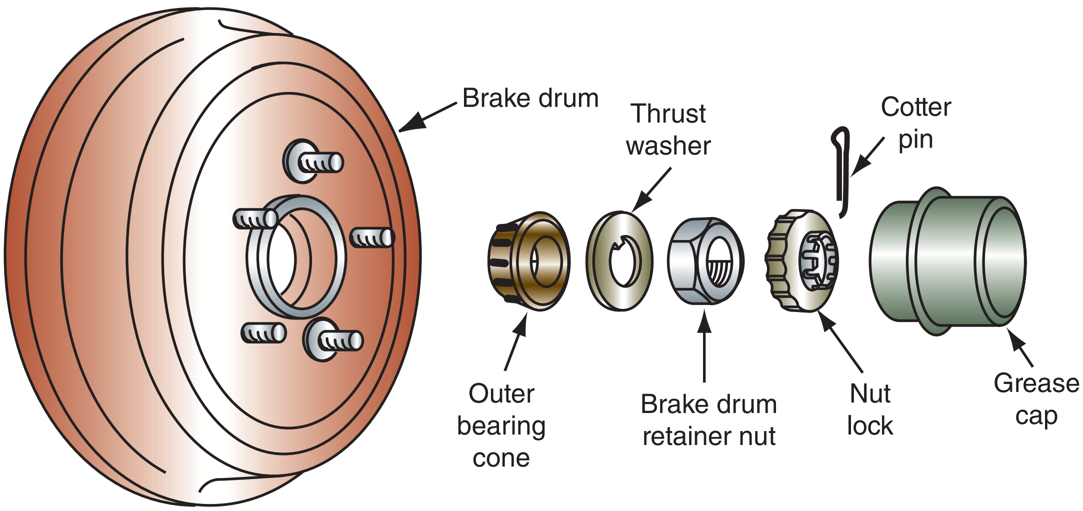


FIGURE 51–10 To remove a fixed drum assembly, remove the retaining nut and slide the assembly off with its bearings.

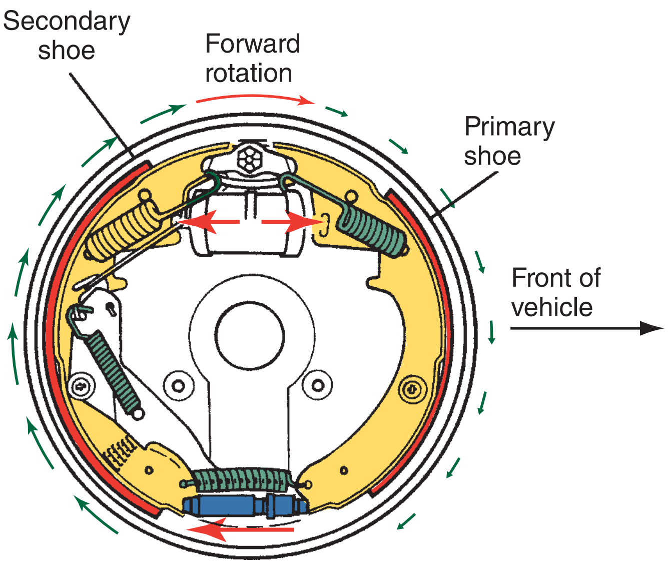


FIGURE 51–11 Duo-servo braking forces.

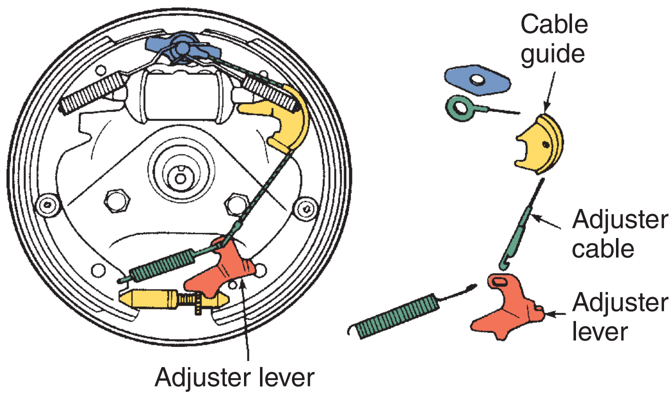


FIGURE 51–12 Cable self-adjusters.

result in a force acting on the adjuster link to apply the secondary shoe. This adjuster link force into the secondary shoe is many times greater than the wheel cylinder input force acting on the primary shoe. The force of the adjuster link into the secondary shoe is again multiplied by the frictional forces between the secondary lining and rotating drum, and all of the resultant force is taken on the anchor pin. In normal forward braking, the friction developed by the secondary lining is greater than the primary lining. Therefore, the secondary brake lining is usually thicker and has more surface area. The roles of the primary and secondary linings are reversed in braking the vehicle when backing up.

Automatically Adjusted Duo-Servo Brakes

Since the early 1960s, automatic drum brake adjusters have been used on all American and most import vehicles. There are several variations of automatic adjusters used with servo brakes. The more common types available follow.

Basic Cable **Figure 51–12** shows a typical automatic adjusting system. Adjusters, whether cable, crank, or lever, are installed on one shoe and operated whenever the shoe moves away from its anchor. The upper link, or cable eye, is attached to the anchor. As the shoe moves, the cable pulls over a guide mounted on the shoe web (the crank or lever pivots on the shoe web) and operates a lever (pawl), which is attached to the shoe so it engages a star wheel tooth. The pawl is located on the outer side of the star wheel and, on different styles, slightly above or below the wheel centerline so it serves as a ratchet lock, which prevents the adjustment from backing off. However, whenever lining wears enough to permit sufficient shoe movement, brake application pulls the pawl high enough to engage the next tooth. As the brake is released, the adjuster spring returns the pawl, thus advancing the star wheel one notch.

On most vehicles, the adjuster system is installed on the secondary shoe and operates when the brakes are applied as the vehicle is backing up. On a few models, it is located on the primary shoe and operates when the brakes are applied as the vehicle is moving forward. Left-hand and right-hand threaded star wheels are used on opposite sides of the car, so parts should be kept separated. If the wrong star wheel thread is installed, the system does not adjust at all or will unadjust with every brake application.

Another system uses a cable and pawl, with the left brake having right-hand threads and the right brake, left-hand threads. The first cable guide is usually retained on the shoe web by the secondary shoe return spring, and the lever-pawl engages a hole in the shoe web. The adjuster operates in either direction of vehicle movement.

Cable with Overtravel Spring **Figure 51–13** shows a system with an upstroke pawl advance. The left brake has left-hand threads, and the right brake has right-hand threads. The lever (pawl) is installed on a web pin with an additional pawl return mousetrap spring. The cable is hooked to the lever (pawl) by means of an overtravel spring installed in the cable hook. The overtravel spring dampens movements and prevents unnecessary adjustment should sudden hard braking cause excessive drum deflection and shoe movement.

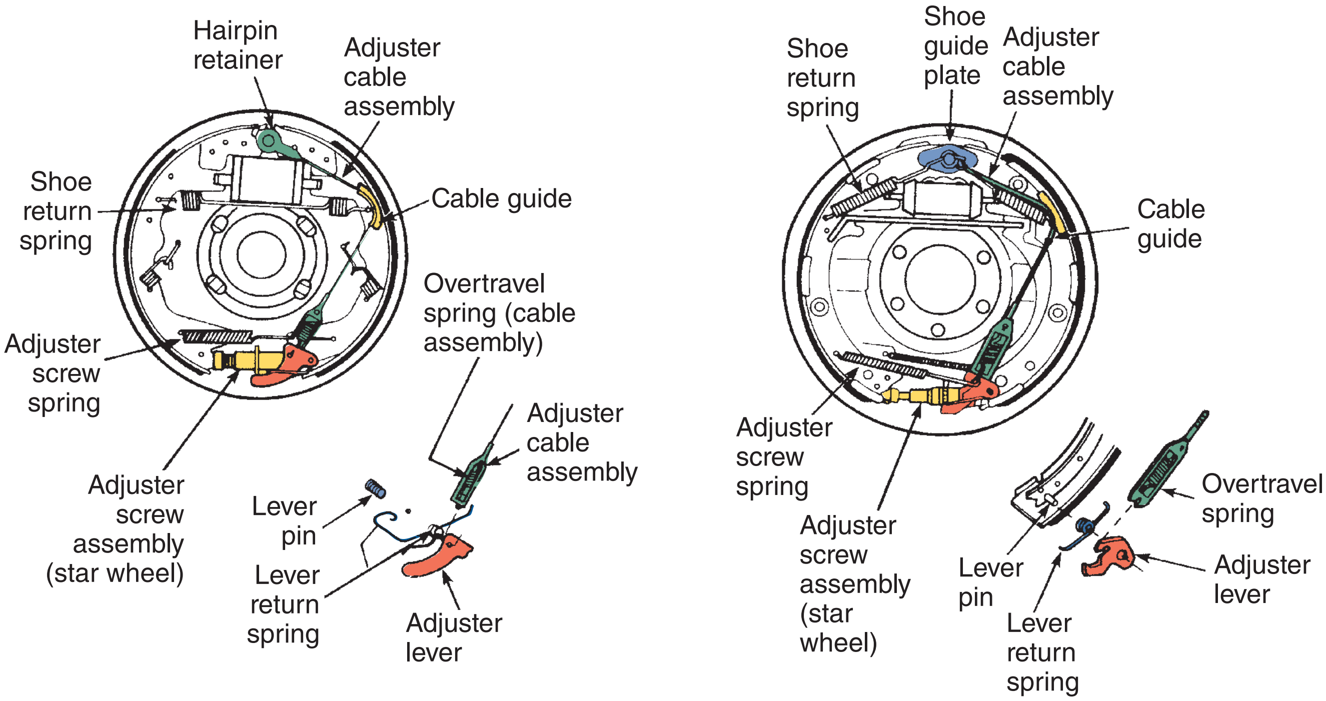


FIGURE 51–13 Cable automatic adjustment with overtravel springs.

Lever with Override The system illustrated in **Figure 51–14** uses a downstroke pawl advance. The left brake has right-hand threads, and the right brake has left-hand threads.

The lever (pawl) is mounted on a shoe holddown, pivoting on a cup sleeve. It has a separate lever-pawl return spring located between the lever and the shoe table. A pivot lever and an override spring assembled to the upper end of the main lever dampen movement, preventing unnecessary adjustment in the event of excessive drum deflection.

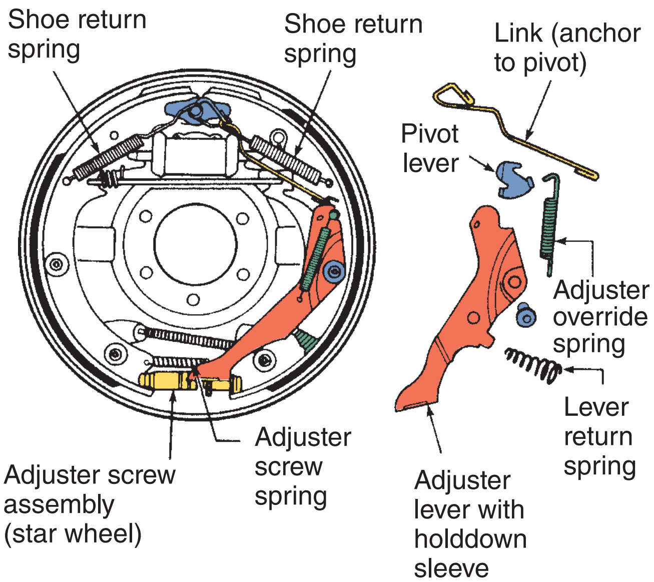
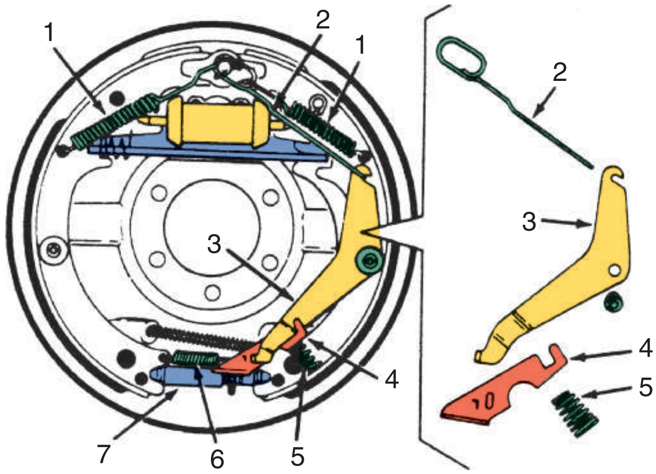


FIGURE 51–14 An adjusting lever with a pivot and override spring.

Lever and Pawl The system illustrated in **Figure 51–15** uses a downstroke pawl advance. The left brake has right-hand threads, and the right brake has left-hand threads. The lever is mounted on a shoe holddown, pivoting on a cup sleeve, and



1. Shoe return springs
2. Link, anchor to lever
3. Adjuster lever (w/holddown sleeve)
4. Adjuster pawl
5. Pawl return spring
6. Adjuster screw spring
7. Adjuster screw assy. (star wheel)

FIGURE 51–15 Lever and pawl automatic adjustment.

SHOP TALK It is important for the technician to remember that on nonservo drum systems the forward shoe is called the leading shoe and the rear one is known as the trailing shoe (when the vehicle is moving in the forward direction). On duo-servo designs, the forward shoe is the primary, and the rear is the secondary.

engages the pawl. A separate pawl return spring is located between the pawl and the shoe.

Nonservo Drum Brakes

The **nonservo drum brake** (or as it is better known today as the *leading-trailing* shoe drum brake) is often used on small cars. The basic difference between this type and the duo-servo brake is that both brake shoes are held against a fixed anchor at the bottom by a retaining spring **(Figure 51–16)**. Nonservo brakes have no servo action.

On a forward brake application, the forward (leading) shoe friction forces are developed by wheel cylinder fluid pressure forcing the lining into contact with the rotating brake drum. The shoe's friction forces work against the anchor pin at the bottom of the shoe. The trailing shoe is also actuated by wheel cylinder pressure but can only support a friction force equal to the wheel cylinder piston forces. The trailing shoe anchor pin supports no friction load. The leading shoe in this brake is energized and does most of the braking in comparison to the nonenergized trailing shoe. In reverse braking, the leading and trailing brake shoes switch functions.

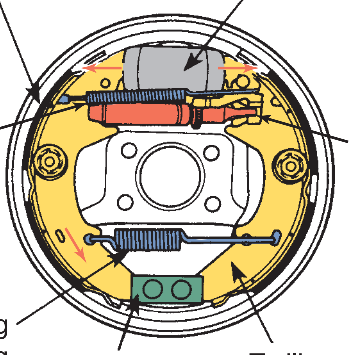


FIGURE 51–16 A typical nonservo drum brake.

Automatically Adjusted Nonservo Brakes

While some standard automatic adjusters similar to the one already discussed are employed on small cars, some of the automatic adjuster mechanisms are unique and varied, using expanding struts between the shoes, or special ratchet adjusting mechanisms. Among the more common of these designs are automatic cam, ratchet automatic, and semiautomatic adjusters.

Automatic Cam Adjusters This rear nonservo drum brake is for use with front disc brakes and has one forward acting (leading) and one reverse acting (trailing) shoe. Shoes rest against the wheel cylinder pistons at the top and are held against the anchor plate by a shoe-to-shoe pull-back spring. The anchor plate and retaining plate are riveted to the backing plate. Adjustment of the brake shoes takes place automatically as needed when the brakes are applied. The automatic cam adjusters are attached to each shoe by a pin through a slot in the shoe webbing. As the shoes move outward during application, the pin in the slot moves the cam adjuster, rotating it outward. Shoes always return enough to provide proper clearance because the pin diameter is smaller than the width of the slot.

Ratchet Automatic Adjuster These brakes are a leading-trailing shoe design with a ratchet self-adjusting mechanism. The shoes are held to the backing plate by spring and pin holddowns, and are held against the anchors at the top by a shoe-to-shoe spring. At the bottom, the shoe webs are held against the wheel cylinder piston ends by a return spring **(Figure 51–17)**.

The self-adjusting mechanism consists of a spacer strut and a pair of toothed ratchets attached to the secondary brake shoe. The parking brake actuating lever is pivoted on the spacer strut.

The self-adjusting mechanism automatically senses the correct lining-to-drum clearance. As the linings wear, the clearance is adjusted by increasing the effective length of the spacer strut. This strut has projections to engage the inner edge of the secondary shoe via the hand brake lever and the inner edge of the large ratchet on the secondary shoe. As wear on the linings increases, the movement of the shoes to bring them in contact with the drums becomes greater than the gap. The spacer strut, bearing on the

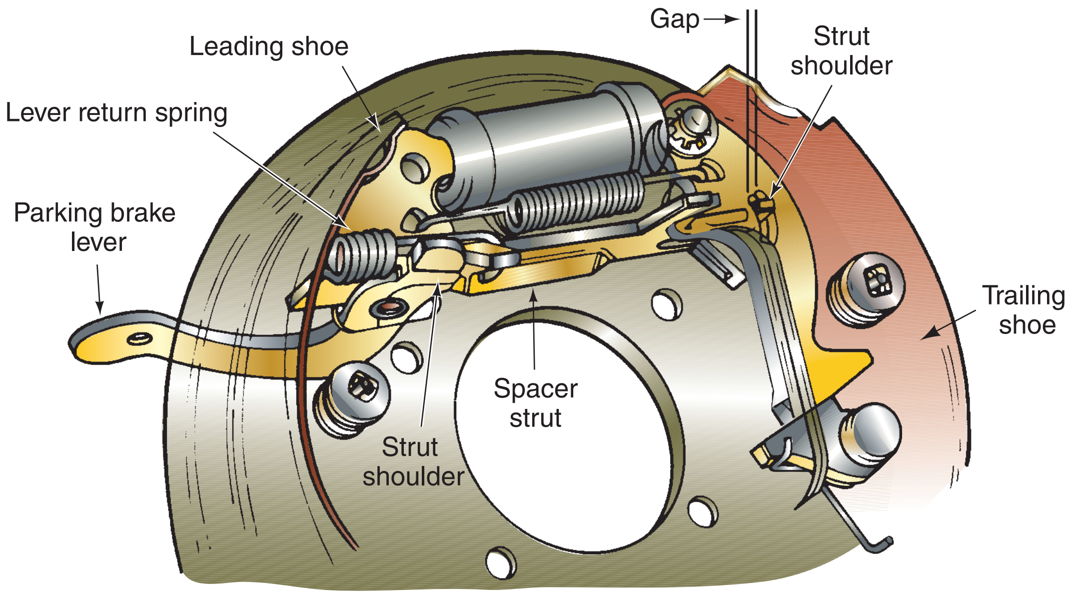


FIGURE 51–17 The ratchet-type self-adjuster for leading-trailing brakes is operated by the parking brake lever.

shoe web, is moved together with the primary shoe to close the gap. Further movement causes the large ratchet behind the secondary shoe to rotate inward against the spring-loaded small ratchet, and the serrations on the mating edges maintain this new setting until further wear on the shoe results in another adjustment. On releasing brake pedal pressure, the return springs cause the shoes to move into contact with the shoulders of the spacer strut/hand brake actuating lever. This restores the clearance between the linings and the drum proportionate to the gap.

Inspection and Service

The first rule of quality brake service is to perform a complete job. For example, perform an inspection of the entire brake system, not just the front or rear brakes. Also, if new linings are installed without regard to the condition of the hydraulic system, the presence of a leaking wheel cylinder quickly ruins the new linings. Braking power and safety are also compromised.

Problems such as spongy pedal, excessive pedal travel, pedal pulsation, poor braking ability, brake drag, lock, or pulling to one side, and braking noises can be caused by trouble in the hydraulic system or the mechanical components of the brake assembly. To aid in doing a complete inspection and diagnosis, a form like the one shown in **Figure 51–18** is very helpful. Working with such a form helps the technician avoid missing any brake test and components that may cause problems.

Brake Noise

All customer complaints related to brake performance must be carefully considered. The number one customer complaint is brake noise. Noise is often the first indication of wear or problems within the braking system, particularly in the mechanical components. Rattles, clicking, grinding, and hammering from the wheels when the brake is in the unapplied position should be carefully investigated. Be sure the noise is not caused by the bearings or various suspension parts. If the noise is coming from the brake assembly, it is most likely caused by worn, damaged, or missing brake hardware, or the poor fastening or mounting of brake components. Grinding noises usually occur when a stone or other object becomes trapped between the lining material and the rotor or drum.

When the brakes are applied, a clicking noise usually indicates play or hardware failure in the attachment of the pad or shoe. On recent systems, the noise could be caused by the lining tracking cutting tool marks on the rotor or drum. A nondirectional finish on rotors eliminates this and so does a less pointed tip on the cutting tool used to refinish drums.

Grinding noises on application can mean metal-to-metal contact, either from badly worn pads or shoes, or from a serious misalignment of the caliper, rotor, wheel cylinder, or backing plate. Wheel cylinders and calipers that are frozen due to internal corrosion can also cause grinding or squealing noises.

Other noise problems and their solutions are covered later in this chapter.

PRE-BRAKE-JOB INSPECTION CHECKLIST

Owner ________________________________ (LAST / FIRST) Phone ______________ Date ___/___/___

Address ________________________________ License No. ______________

Make ________ Model ________ Mileage ________ Serial No. ________ Year ________

Special Key for Hubcaps/Wheels Location ______________ Owner Use Parking Brake Yes ☐ No ☐

4 Drum ☐ 4 Disc ☐ Disc/Drum ☐ P/B No ☐ Yes ☐ Vacuum ☐ Hydro ☐ ABS ☐

Owner Comments ________________________________

1. CHECKS BEFORE ROAD TEST	Safe	Unsafe
Stoplight Operation		
Brake Warning Light Operation		
Master Cylinder Checks		
Fluid Level		
Fluid Contamination		
Under Hood Fluid Leaks		
Under Dash Fluid Leaks (No Power)		
Bypassing		

BRAKE PEDAL HEIGHT AND FEEL

Check One			Check One		
Low			Spongy		
Med			Firm		
High					

Power Brake Unit Checks

VACUUM	Safe	Unsafe	HYDRO	Safe	Unsafe
Vacuum Unit			Hydro Unit		
Engine Vacuum			P/S Fluid		
Vacuum Hose			P/S Belt Tension		
Unit Check Valve			P/S Belt Condition		
Reserve Braking			P/S Fluid Leaks		
			Reserve Braking		

Tire Pressure Specs	Front	Rear
Record Pressure Found		
RF ______ LF ______ RR ______ LR ______		
Tire Condition		
RF ______ LF ______ RR ______ LR ______		

2. ROAD TEST	Yes	No	RF	LF	RR	LR
Brake Pull						
Brake Clunk						
Brake Scraping						
Brake Squeal						
Brake Grabby						
Brakes Lock Prematurely						
Wheel Bearing Noise						
Vehicle Vibrates						

STEERING WHEEL MOVEMENT WHEN STOPPING FROM 2–3 MPH YES/NO/ RGT/LFT

Does ABS Work	YES	NO
Pedal Pulsation when Braking	YES	NO
Steering Wheel Oscillation when Braking	YES	NO
No Stopping Power	YES	NO
Warning Light Comes on when Braking	YES	NO
Difference in Pedal Height after Cornering	YES	NO
Nose Dive	YES	NO

3. In Shop Checks On Hoist	Yes	No	RF	LF	RR	LR
Brake Drag						
Intermittent Brake Drag						
Brake Pedal Linkage Binding						
Wheel Bearing Looseness						
Missing or Broken Wheel Fasteners						
Suspension Looseness						

	Front					Rear				
Mark Wheels and Remove	Right			Left		Right			Left	
Caliper/Piston Stuck RF LF RR LR	Spec	Safe	Unsafe	Safe	Unsafe	Spec	Safe	Unsafe	Safe	Unsafe
Mark Drums and Remove										
Measure Rotor Thickness or Drum Diameter										
Measure Rotor Thickness Variation										
Measure Rotor Runout										
Lining Thickness										
Tubes and Hoses										
Fluid Leaks										
Broken Bleeders										
Leaky Seals										
Self-Adjuster Operation										
									Safe	Unsafe
Parking Brake Cables and Linkage										

FIGURE 51–18 A sample of pre-brake-job inspection checklist.

Road Testing Brakes

Road testing allows the brake technician to evaluate brake performance under actual driving conditions. Whenever practical, perform the road test before beginning any work on the brake system. In every case, road test the vehicle after any brake work to make sure the brake system is working safely and properly.

> **Warning!** Before test driving any car, first check the fluid level in the master cylinder. Depress the brake pedal to be sure there is adequate pedal reserve. Make a series of low-speed stops to be sure the brakes are safe for road testing. Always make a preliminary inspection of the brake system in the shop before taking the vehicle on the road.

Brakes should be road tested on a dry, clean, reasonably smooth, and level roadway. A true test of brake performance cannot be made if the roadway is wet, greasy, or covered with loose dirt. Testing is also adversely affected if the roadway is crowned so as to throw the weight of the vehicle toward the wheels on one side, or if the roadway is so rough that wheels tend to bounce.

Test brakes at different speeds with both light and heavy pedal pressure. Avoid locking the wheels and sliding the tires on the roadway. There are external conditions that affect brake road-test performance. Tires having unequal contact and grip on the road cause unequal braking. Tires must be equally inflated and the tread pattern of right and left tires must be approximately equal. When the vehicle has unequal loading, the most heavily loaded wheels require more braking power than others and a heavily loaded vehicle requires more braking effort. Misalignment of the front end may cause the brakes to pull to one side. Also, a loose front-wheel bearing could permit the drum to tilt and have spotty contact with brake shoe linings, causing pulsations when the brakes are applied. Faulty shock absorbers that do not prevent the car from bouncing on quick stops can give the erroneous impression that the brakes are too severe.

Drum Brake Inspection

Place the vehicle in neutral, release the parking brake, and raise the vehicle on the hoist. Once the wheels are removed, mark the wheel-to-drum and drum-to-axle positions so the components can be correctly reassembled.

Drum Removal

Drum removal procedures are different for fixed and floating drums. In all cases, however, you may need to manually retract the self-adjusters **(Figure 51–19)** to have enough shoe-to-drum clearance to remove the drum. Wear on the friction surface of the drum creates

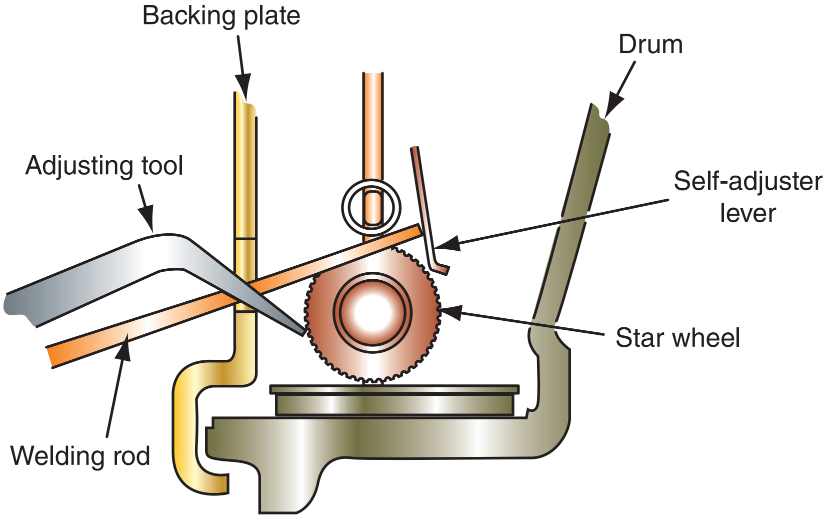


FIGURE 51–19 Use a heavy piece of wire to move the adjusting lever away from the star wheel, then rotate the star wheel to move the brake shoe away from the drum before removing the drum.

a ridge at the edge of the drum's rim. As the self-adjusters move the shoes outward to take up clearance, the shoe diameter becomes larger than the ridge diameter. If the adjuster is not retracted, the drum's ridge may jam on the shoes and prevent drum removal. Trying to force the drum over the shoes may damage brake parts. To retract the shoes, reach through the adjusting slot with a thin screwdriver (or similar tool) and carefully push the self-adjusting lever away from the star wheel a maximum of $^{1}/_{16}$ inch. While holding the lever back, insert a brake adjusting tool into the slot and turn the star wheel in the proper direction until the brake drum can be removed. On vehicles that have the adjusting slot in the drum rather than in the backing plate, reach through the slot with a thin wire hook and pull the adjuster lever away from the star wheel.

Before you remove a drum, mark it "L" or "R" for left or right so that it gets reinstalled on the same side of the vehicle from which it was removed.

Warning! Do not step on the brake pedal while a brake drum is off. This will cause the pistons in the wheel cylinder to overextend or pop apart.

Brake drums that are made as a one-piece unit with the wheel hub were common on FWD cars and on the front wheels of older vehicles with four-wheel drum brakes. The hub contains the wheel bearings and is held onto the spindle by a single large nut. This nut also is used to adjust the wheel bearings. To remove this type of drum, remove the dust cap from the center of the hub. Then remove the cotter pin from the castellated nut or nut lock on the spindle. Next, remove the spindle nut and washer. Pull the drum outward to slide it off the spindle.

On older 4WD trucks, the rear drums are held in place by the rear axle and wheel bearings. First, remove the bolts securing the axle to the hub and then remove the axle. In most cases, a special socket is required to remove the retaining nut and remove the bearings. Once the bearings are removed, the drum can be removed.

Floating drums do not have a built-in hub. In most cases, the drums are held in place by studs on the axle flange and the wheel and lug nuts. On many floating drums, push nuts or speed nuts are used during vehicle assembly to hold the drum onto two or three studs. Typically the push nuts do not need to be reinstalled after service. However, on some vehicles, the push nuts are used to hold the drum squarely against the axle or hub flange.

FIGURE 51–20 Pull the drum away from the axle flange or hub, being careful not to drop it.

Floating drums are pulled off the hub or axle flange **(Figure 51–20)**. If the brake drum is rusted or corroded to the axle flange and cannot be removed, lightly tap the axle flange to the drum mounting surface with a ball-peen hammer. Many drums have threaded holes in the face to help remove the drum. Thread two bolts into the holes **(Figure 51–21)** and tighten evenly. The bolts will thread against the axle flange and push the drum off the hub. Penetrating oil may help in loosening a stuck drum. If the drum is

FIGURE 51–21 Threaded holes allow for easier drum removal.

stuck to its flange, use a large scribe or center punch to score around the joint at the drum and flange and break the surface tension. Remember that if the drum is worn, the brake shoe adjustment has to be backed off for the drums to clear the brake shoes. Do not force the drum or distort it. Do not pry against the drum using the backing plate, this will damage or possibly bend the backing plate. Once loose, do not allow the drum to drop.

Once the drum is removed, inspect the brake assembly for signs of fluid leakage from the wheel cylinder and, on RWD vehicles, from the rear axle seals. Faulty axle seals, shown in **(Figure 51–22)**, allow differential lubricant to leak out and contaminate the rear brake components. When this occurs, the shoes must be replaced because the fluid cannot be cleaned from the lining material.

Fixed Drums After the drum is removed, inspect the grease in the hub and on the bearings. If the grease is dirty or dried out and hard, it is a clue to possible bearing damage. Also inspect the rear axle gaskets and wheel seals for leaks. Replace worn components as needed. Set the drum and all bearing parts aside for cleaning and close inspection. If the grease seems to be in good condition, place the drum on a bench with the open side down. Cover the outer bearing opening with a shop cloth to keep dirt out.

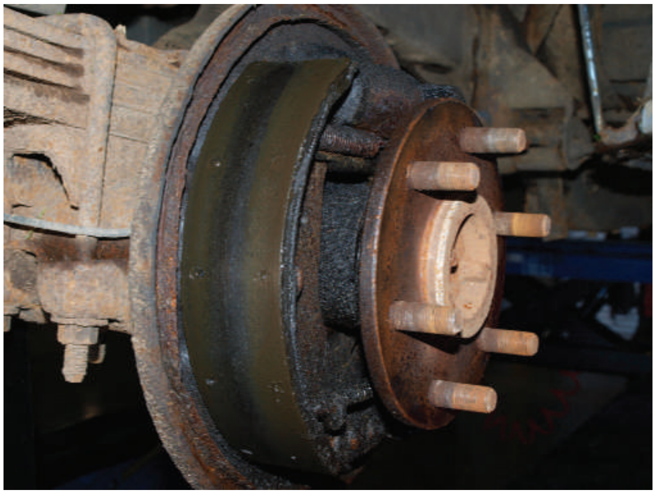


FIGURE 51–22 Faulty axle seals allow axle fluid to leak and contaminate the brake linings.

FIGURE 51–23 Before disassembling the brakes, use an OSHA-approved washer to make sure all asbestos dust is removed from the parts.

> **Caution!** When servicing wheel brake parts, do not create dust by cleaning with a dry brush or with compressed air. Asbestos fibers can become airborne if dust is created during servicing. Breathing dust containing asbestos fibers can cause serious bodily harm. To clean away asbestos from brake surfaces, use an OSHA-approved washer **(Figure 51–23)**. Follow the manufacturer's instructions when using the washer.

Drum Inspection

One of the most important parts that need to be inspected is the brake drum **(Figure 51–24)**. Thoroughly clean the drums with a water-dampened cloth or a water-based solution. If the drums have been exposed to leaking oil or grease, thoroughly clean them with a non-oil base solvent after washing to remove dust and dirt. It is important to determine the source of the oil or grease leak and correct the problem before reinstalling the drums.

Brake drums act as a heat sink. They absorb heat and dissipate it into the air. As drums wear from normal use or are machined, their cooling surface area is reduced and their operating temperatures increase. Their structural strength is also reduced. This leads to distortion, which causes some of the drum conditions shown in **(Figure 51–25)**.

Also take a look at the brake shoes while they are still mounted. Their condition can often reveal defects in the drums. If the linings on one wheel are worn more than the others, it might indicate a rough drum. Uneven wear from side to side on any one set of shoes can be caused by a tapered drum. If some linings are worn badly at the toe or heel, it might indicate an out-of-round drum.

FIGURE 51–24 Carefully check the inside surface of the brake drum.

Scored Drum Surface The most common cause of this condition is buildup of brake dust and dirt between the brake lining and drum. A glazed brake lining, hardened by high heat or in some cases by very hard inferior grade brake lining, can also groove the drum surface. Excessive lining wear that exposes the rivet head or shoe steel will score the drum surface. If the grooves are not too deep, the drum can be turned.

Bell-Mouthed Drum This distortion is due to extreme heat and braking pressure. It occurs mostly on wide drums and is caused by poor support at the outside of the drum. Full drum-to-lining contact cannot be achieved and fading can be expected. Drums must be turned.

Concave Drum This is an excessive wear pattern in the center area of the drum brake surface. Extreme braking pressure can distort the shoe platform so braking pressure is concentrated at the center of the drum.

Convex Drum This wear pattern is greater at the closed end of the drum. It is the result of excessive heat or an oversized drum, which allows the open end of the drum to distort.

Hard Spots on the Drum This condition in the cast-iron surface, sometimes called chisel spots or islands of steel, results from a change in metallurgy caused by braking heat. Chatter, pulling, rapid wear, hard pedal, and noise can occur. These spots can be removed by grinding. However, only the raised surfaces are removed, and they can reappear when heat is applied. If this condition reappears, the drum must be replaced.

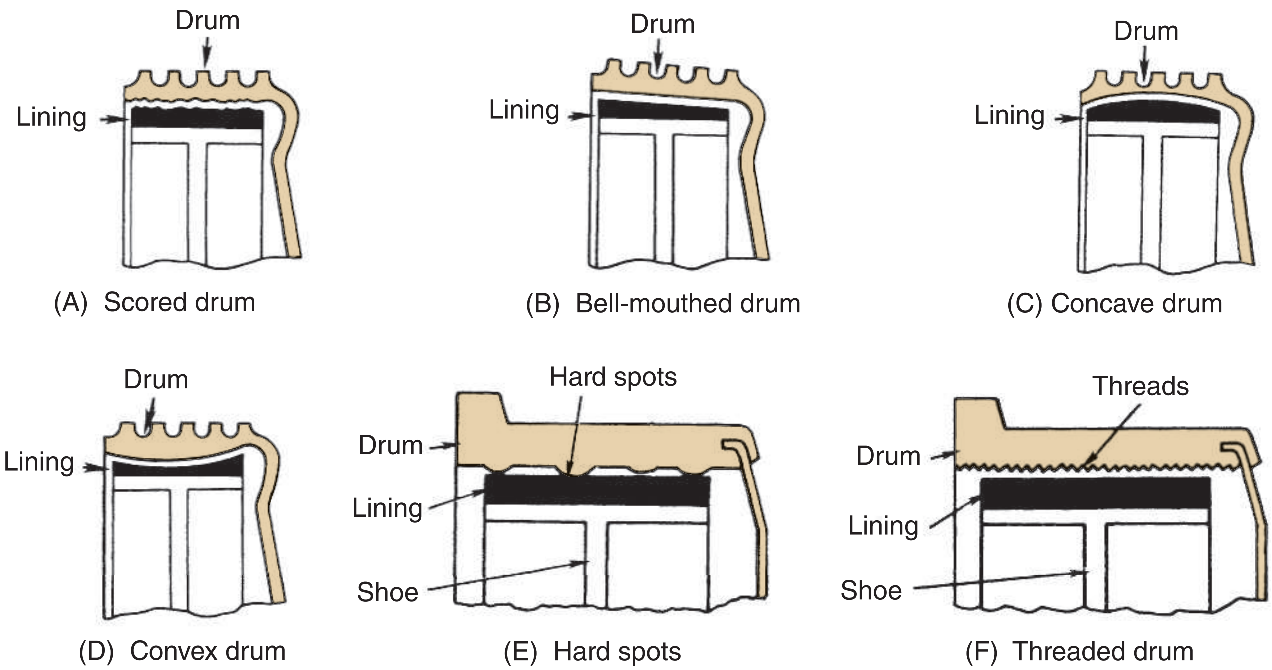


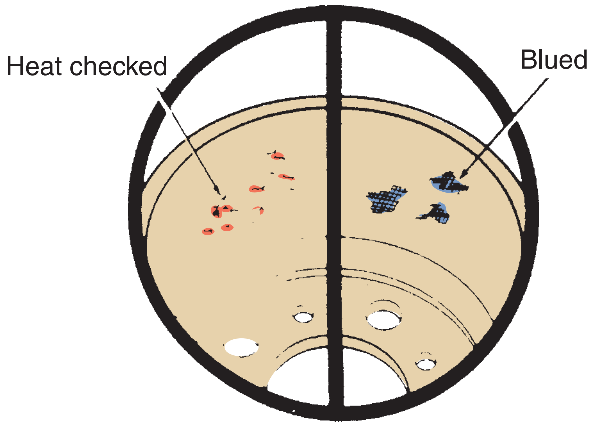
FIGURE 51–25 Drum wear conditions.

Threaded Drum Surface An extremely sharp or chipped tool bit or a lathe that turns too fast can result in a threaded drum surface. This condition can cause a snapping sound during brake application as the shoes ride outward on the thread, then snap back. To avoid this, recondition drums using a rounded tool and proper lathe speed. Check the edge of the drum surface around the mounting flange side for tool marks indicating a previous machining. If the drum has been machined, it might have worn too thin for use. Check the diameter.

Heat Checks **Heat checks** are visible, unlike hard spots that do not appear until the machining of the drum **(Figure 51–26)**. Extreme operating temperatures are the major cause. The drum might also show a bluish/gold tint, which is a sign of high temperatures. Hardened carbide lathe bits or special grinding attachments are available through lathe manufacturers to service these conditions. Excessive damage by heat checks or hard spots requires drum replacement.

Cracked Drum Cracks in the cast-iron drum are caused by excessive stress. They can be anywhere but usually are in the vicinity of the bolt circle or at the outside of the flange. Fine cracks in the drums are often hard to see and, unfortunately, often do not show up until after machining. Nevertheless, should any cracks appear, no matter how small, the drum must be replaced.

Out-of-Round Drums Drums with eccentric distortion might appear fine to the eye but can cause pulling, grabbing, and pedal vibration or pulsation. An out-of-round or egg-shaped condition is often caused by heating and cooling during normal brake operation. Out-of-round drums can be detected before the drum is removed by adjusting the brake to a light drag and feeling the rotation of the drum by hand. After removing the drum, gauge it to determine the amount of eccentric distortion. Drums with this defect should be machined or replaced.



Courtesy of Federal-Mogul Corporation.

FIGURE 51-26 An example of a heat-checked and overheated brake drum.

FIGURE 51-27 Measuring the inside diameter with a drum micrometer.

Drum Measurements

Measure every drum with a drum micrometer **(Figure 51–27)**, even if the drum passed a visual inspection, to make sure that it is within the safe oversize limits. If the drum is within safe limits, even though the surface appears smooth, it should be turned to ensure a true drum surface and to remove any possible contamination in the surface from previous brake linings, road dust, and so forth. Remember that if too much metal is removed from a drum, unsafe conditions can result.

Take measurements at the open and closed edges of the friction surface and at right angles to each other. Drums with taper or out-of-roundness exceeding 0.006 inch (0.152 mm) are unfit for service and should be turned or replaced. If the maximum diameter reading (measured from the bottom of any grooves that might be present) exceeds the new drum diameter by more than 0.060 inch (1.5 mm), the drum cannot be reworked. If the drums are smooth and true but exceed the new diameter by 0.090 inch (2.2 mm) or more, they must be replaced.

Drum Refinishing

Brake drums can be refinished by either turning or grinding on a brake lathe **(Figure 51–28)**.

Only enough metal should be removed to obtain a true, smooth friction surface. When one drum must be machined to remove defects, the other drum on the same axle set must also be machined in the same manner and to the same diameter (±0.010 inches) so braking is equal.

FIGURE 51–28 Brake drums can be resurfaced by grinding or turning them on a brake lathe.

USING SERVICE INFORMATION

Service information lists the standard brake drum inside diameter along with the discard dimension. They also state the standard and minimum lining thickness. Manual illustrations should be used to accurately identify all components plus the disassemble/reassembly procedure. Tightening specifications for backing plate nuts and other components should always be followed.

SHOP TALK

Keep the adjusting screws and automatic adjuster parts for left and right brakes separate. These parts usually are different. For example, on some automatic adjusters, the adjusting screws on the right brakes have left-hand threads and the adjusting screws on the left brakes have right-hand threads.

Brake drums are stamped with a discard dimension **(Figure 51–29)**. This is the allowable wear dimension and not the allowable machining dimension. There must be 0.030 inch (0.762 mm) left for wear after turning the drums. Some states have laws about measuring the limits of a brake drum.

Machining or grinding brake drums increases the inside diameter of the drum and changes the lining-to-drum fit. When remachining a drum, follow the equipment instructions for the specific tool you are using.

FIGURE 51–29 The drum's discard diameter is stamped on the drum.

Cleaning Newly Refaced Drums

The friction surface of a newly refaced drum contains millions of tiny metal particles. These particles not only remain free on the surface, they also lodge themselves in the open pores of the newly machined surface. If the metal particles are allowed to remain in the drum, they become embedded in the brake lining. Once the brake lining gets contaminated in this manner, it acts as a fine grinding stone and scores the drum.

SHOP TALK

Mark the shoe positions if shoes and linings are to be reused. When disassembling an unfamiliar brake assembly, work on one wheel at a time and use the other wheel as a reference.

PROCEDURE

Mechanical Component Service of Duo-Servo Drum Brakes

STEP 1 Clean the brake dust from the brake assembly using the appropriate cleaning equipment.

STEP 2 If required, install wheel cylinder clamps on the wheel cylinders to prevent fluid leakage or air from getting into the system while the shoes are removed. Some brakes have wheel cylinder stops; therefore, wheel cylinder clamps are not required. Regardless of whether the clamps are needed, do not press down on the brake pedal after shoe return springs have been removed. To prevent this, block up the brake pedal so it cannot be depressed.

STEP 3 Remove the brake shoe return springs. Use a brake spring removal and installation tool to unhook the springs from the anchor pin or anchor plate **(Figure 51–30)**.

STEP 4 Remove the shoe retaining or holddown cups and springs. Special tools are available **(Figure 51–31)**, but the holddown springs can be removed by using pliers to compress the spring and rotating the cup with relation to the pin.

STEP 5 Self-adjuster parts can now be removed. Lift off the actuating link, lever and pivot assembly, sleeve (through lever), and return spring. No advantage is gained by disassembling the lever and pivot assembly unless one of the parts is damaged.

STEP 6 Spread the shoes slightly to free the parking brake strut and remove the strut with its spring. Disconnect the parking brake lever from the secondary shoe. It can be attached with a retaining clip, bolt, or simply hooked into the shoe.

STEP 7 Slip the anchor plate off the pin. No advantage is gained by removing the plate if it is bolted on or riveted. Spread the anchor ends of the shoes and disengage them from the wheel cylinder links, if used. Remove the shoes connected at the bottom by the adjusting screw and spring, as an assembly.

STEP 9 Overlap the anchor end of the shoes to relieve spring tension. Unhook the adjusting screw spring and remove the adjusting screw assembly.

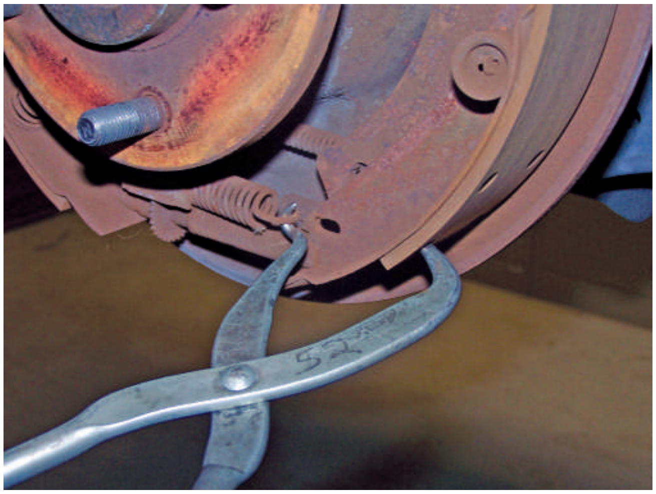


FIGURE 51–30 A brake spring tool.

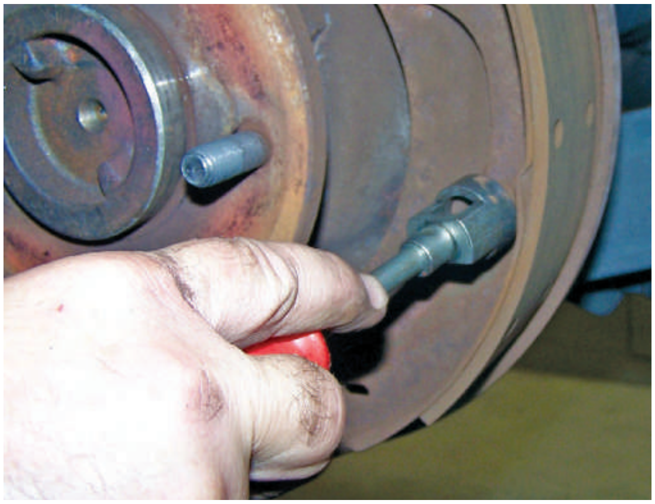


FIGURE 51–31 A holddown spring tool.

PROCEDURE

Disassembling Nonservo or Leading-Trailing Brakes

STEP 1 Install the wheel cylinder clamp. Then unhook the adjuster spring from the parking brake strut and reverse shoe.

STEP 2 Unhook the upper shoe-to-shoe spring from the shoes and unhook the antinoise spring from the spring bracket.

STEP 3 Remove the parking brake strut and disengage the shoe webs from the flat, clamp shoe holddown clips.

STEP 4 Unhook the lower shoe-to-shoe spring and remove the forward shoe. Disconnect the parking brake cable, then remove the reserve shoe.

STEP 5 Remove the shoe holddown clips from the backing plate.

STEP 6 Press off the C-shaped retainers from the pins and remove the parking brake lever, automatic adjuster lever, and adjuster latch.

STEP 7 Remove the parking brake lever.

PROCEDURE

Cleaning and Inspecting Brake Parts

STEP 1 Clean the backing plates, struts, levers, and other metal parts to be reused using a water-dampened cloth or a water-based solution. Equipment is commercially available to perform washing functions of brake parts. Wet cleaning methods must be used to prevent asbestos fibers from becoming airborne.

STEP 2 Carefully examine the raised shoe support pads on the backing plate to make sure they are free from corrosion or other surface defects that might prevent the shoes from sliding freely **(Figure 51–32)**. Use fine emery cloth to remove surface defects, if necessary. Clean them thoroughly.

STEP 3 Check to make sure that the backing plates are not cracked or bent. If so, they must be replaced. Make sure backing plate bolts and bolted-on anchor pins are torqued to specifications.

STEP 4 If replacement of the wheel cylinder is needed, it should be done at this time. To determine wheel cylinder condition, carefully inspect the boots. If they are cut, torn, heat-cracked, or show evidence of leakage, the wheel cylinders should be replaced. If more than a drop of fluid spills out, leakage is excessive and indicates that replacement is necessary.

STEP 5 Disassemble the adjusting screw assembly **(Figure 51–33)** and clean the parts in a suitable solvent. Make sure the adjusting screw threads into the pivot nut over its complete length without sticking or binding. Check that none of the adjusting screw teeth are damaged. Lubricate the adjusting screw threads with brake lubricant.

STEP 6 Examine the shoe anchor, support plate, and small parts for signs of looseness, wear, or damage that could cause faulty shoe alignment. Check springs for spread or collapsed coils, twisted or nicked shanks, and severe discoloration **(Figure 51–34)**. Operate star wheel automatic adjusters by prying the shoe lightly away from its anchor or by pulling the cable to make sure the adjuster advances easily, one notch at a time. Adjuster cables tend to stretch, and star wheels and pawls become blunted after a long period of use. For rear-axle parking brakes, pull on the cable and shoe linkage to make sure no binding condition is present that could cause the shoes to drag when the parking brake is released.

FIGURE 51-32 Carefully examine the raised shoe support pads on the backing plate.

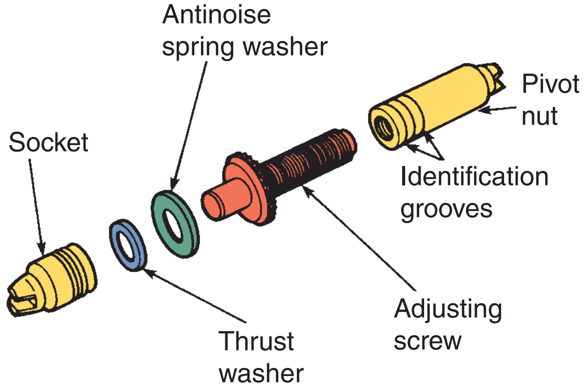


FIGURE 51-33 An exploded view of a brake adjuster assembly.

These metal particles must be removed by washing or cleaning the drum. Do not blow out the drum with air pressure. Either of the following methods is recommended to clean a newly refaced brake drum.

The first method involves washing the brake drum thoroughly with hot soapy water and wiping with a lint-free rag. Then use the air pressure to thoroughly dry it. If the front hub and drums are being cleaned, be very careful to avoid contaminating the wheel bearing grease. Or, completely remove all the old grease, then regrease and repack the wheel bearing after the drum has been cleaned and dried. The wheel bearings and the grease seals must be removed from the drum before cleaning.

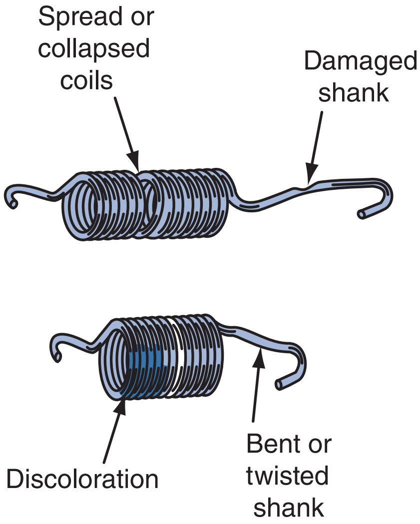


FIGURE 51-34 All springs should be checked for distortion and damage.

The second method involves wiping the inside of the brake drum (especially the newly machined surface) with a lint-free white cloth dipped in one of the many available brake cleaning solvents that do not leave a residue. This operation should be repeated until dirt is no longer apparent on the wiping cloth. Allow the drum to dry before reinstalling it on the vehicle.

Both of these procedures are also good for cleaning disc brake rotors.

Brake Shoes and Linings

Lining materials influence braking operation. The use of a lining with a friction value that is too high can result in a severe grabbing condition. A friction value that is too low can make stopping difficult because of a hard pedal.

Overheating a lining accelerates wear and can result in dangerous lining heat fade—a friction-reducing condition that hardens the pedal and lengthens the stopping distance. Continual overheating eventually pushes the lining beyond the point of recovery into a permanent fade condition. In addition to fade, overheating can cause squeal.

Overheating is indicated by a lining that is charred or has a glass-hard glazed surface, or if severe, random cracking of the surface is present.

Inspect the linings for uneven wear, embedded foreign material, loose rivets, and to see if they are oil soaked. If linings are oil soaked, replace them.

Caution! Automotive friction materials may contain substantial amounts of asbestos. Studies indicate that exposure to excessive amounts of asbestos dust can be a potential health hazard. It is important that anyone handling brake linings understands this and takes the necessary precautions to avoid injury.

If linings at any wheel show a spotty wear pattern or an uneven contact with the brake drum, it is an indication that the linings are not centered in the drums. Linings should be circle ground to provide better contact with the drum.

Brake Shoe Replacement

Brake linings that are worn to within $^1/_{32}$ inch (0.79 mm) of a rivet head or that have been contaminated with brake fluid, grease, or oil must be replaced **(Figure 51–35)**. Failure to replace worn linings results in a scored drum. When it is necessary to replace brake shoes, they must also be replaced on the wheel on the opposite side of the vehicle. Inspect brake shoes for distortion, cracks, or looseness. If these conditions exist, the shoe must be discarded.

Do not let brake fluid, oil, or grease touch the brake lining.

Selecting Replacement Linings

Identification codes, called the automotive friction material edge codes, are printed on the edges of drum brake linings **(Figure 51–36)** and disc brake pads. The letters and numbers identify the manufacturer of the

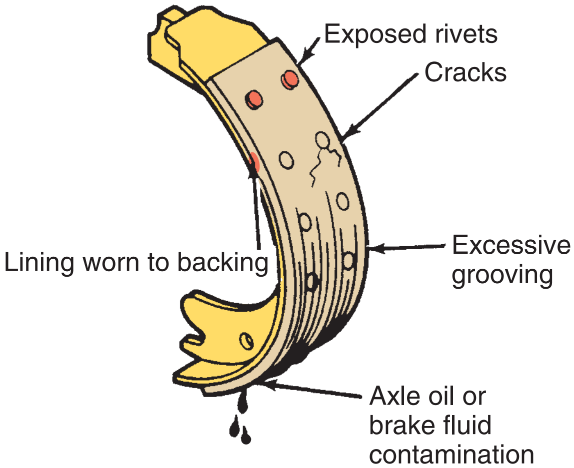


FIGURE 51–35 Potential brake shoe problems.

FIGURE 51–36 Identification codes, called the automotive friction material edge codes, are printed on the edges of drum brake linings.

lining material and the material used, and the last two letters identify the cold and hot coefficients of friction (COF).

These codes do not address lining quality or its hardness. From a service standpoint, the hot and cold COF codes are the most important and are coded as follows:

C = not over 0.15

D = over 0.15 but not over 0.25

E = over 0.25 but not over 0.35

F = over 0.35 but not over 0.45

G = over 0.45 but not over 0.55

H = over 0.55

It is also important to use the recommended friction material when replacing brake shoes. The incorrect type of friction material can affect the stopping characteristics of the car.

Hard and *soft* are terms applied to linings within a general category of material. Thus, any particular organic lining may be considered as a hard or a soft organic material. Overall, organic linings are considered softer than semimetallic linings, and semimetallic linings are considered softer than fully metallic linings. A hard lining usually has a low COF but resists fade better and lasts longer than a soft lining. A soft lining has a higher COF but fades sooner and wears faster than a hard lining. A soft lining is less abrasive on drum surfaces and operates more quietly than a hard lining. It also is common to use linings with a lower COF on the rear brakes than on the front to minimize rear brake lockup.

SHOP TALK

On duo-servo shoe designs, the forward shoe is the primary and the rear, the secondary. The secondary shoe lining is longer.

Sizing New Linings

Modern brake shoes are usually supplied with what is known as cam, offset, contour, or eccentric shape, which is ground in at the factory. That is, the full thickness of the lining is only present at the heel and toe of the shoe, and is ground down slightly at the center. The diameter of the circle the shoes make is slightly smaller than that of the drum. This compensates for the minor tolerance variations of drums and brake mountings and promotes proper wearing-in of the linings to match the drum.

Lining Adjustment

New eccentric-ground linings tolerate a closer new lining clearance adjustment than concentric ground linings. With manual adjusters, the shoes should be expanded into the drums until the linings are at the point of drag but not dragging heavily against the drum. With star wheel automatic adjusters, a drum/shoe gauge **(Figure 51–37)** provides a convenient means of making the preliminary adjustment. This type of gauge, when set at actual drum diameter, automatically provides the working clearance of the shoes **(Figure 51–38)**. If new linings have been concentrically ground, the initial clearance adjustment must be backed off an amount that provides sufficient working clearance.

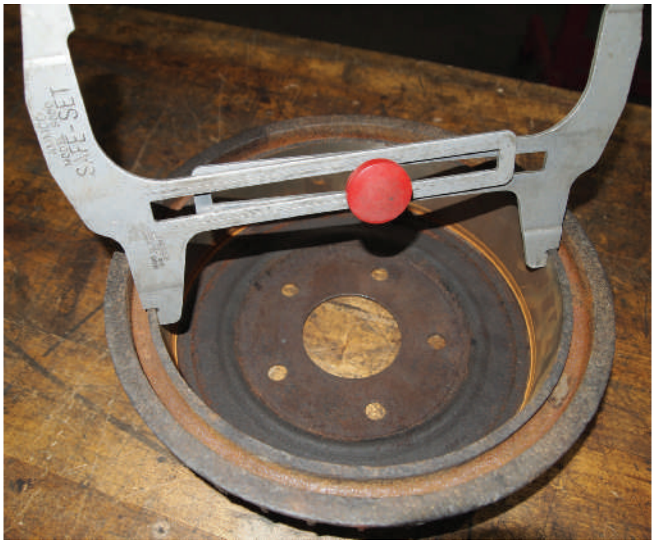


FIGURE 51–37 Using a brake shoe set gauge to match the diameter of the drum to the brake shoes so further shoe adjustment is limited.

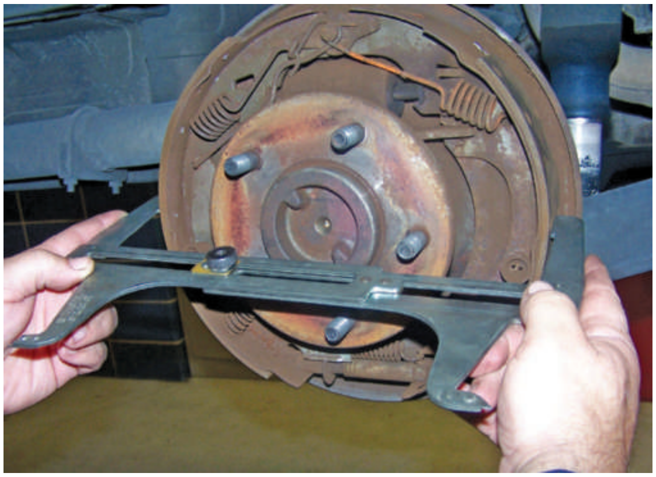


FIGURE 51–38 Using the other side of the brake gauge to set the brake shoes.

Drum Shoe and Brake Installation

Before installing the shoes, sand the inner edge of the shoe to smoothen any metal nicks and burrs that could interfere with the sliding on the support pads.

A support (backing) plate must be tight on its mount and not bent. Remove any burrs or grooves on the shoe support pads that could cause the shoes to bind or hang up.

Using an approved lubricant, lightly coat the support pads **(Figure 51–39)** and the threads of servo star wheel adjusters. On rear axle parking brakes, lubricate any point of potential binding in the linkage and the cable.

SHOP TALK

Some brake technicians check brake spring tension by the drop method. This method is not overly scientific and the results are not always correct. Drop the brake spring on a clean concrete floor. If it bounces with a chunky sound, it is good. If the bounced spring gives off a tinny sound, it is tired and should be replaced. Many technicians simply replace the springs as part of the brake service. This ensures the brake hardware will be in good condition.

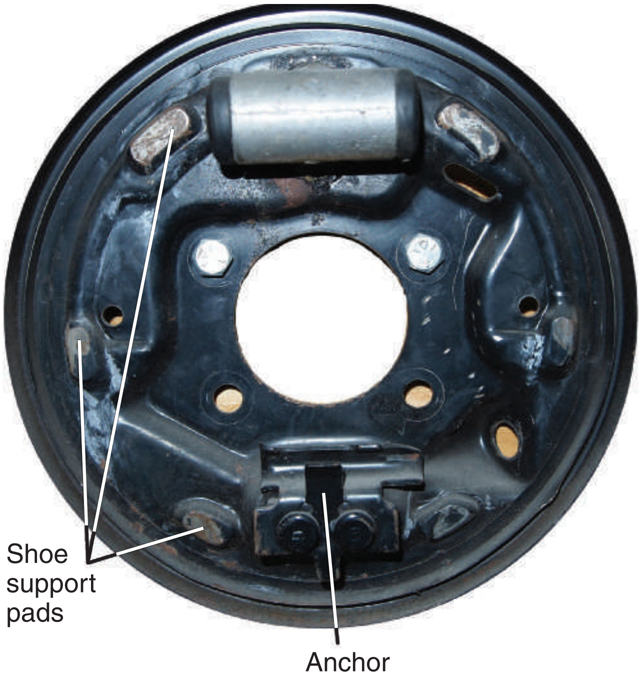


FIGURE 51-39 The areas or pads where the brake shoe will rub or contact the backing plate.

Prior to installing the new shoes, some technicians cover the linings with masking tape to prevent lubricant, dirt, and other contaminates from getting on the linings. Reassemble the brakes in the reverse order of disassembly. Make sure all parts are in their proper locations and that both brake shoes are properly positioned in both ends of the adjuster. Also, both brake shoes should correctly engage the wheel cylinder pushrods and parking brake links. They should be centered on the backing plate. Parking brake links and levers should be in place on the rear brakes. With all of the parts in place, try the fit of the brake drum over the new shoes. If not slightly snug, pull it off and turn the star wheel until a slight drag is felt when sliding on the drum. A brake preset gauge makes this job easy and final brake adjustment simple. Then install the brake drum and wheel/tire assemblies, and make the final brake adjustments as specified in individual instructions in the vehicle's service information. Torque the spindle and lug nuts to specifications.

Wheel Cylinder Inspection and Servicing

Wheel cylinders might need replacement when the brake shoes are replaced or when they begin to leak.

Inspecting and Replacing Wheel Cylinders

Wheel cylinder leaks reveal themselves in several ways: (1) fluid can be found when the dust boot is peeled back **(Figure 51–40)**; (2) the cylinder, linings, and backing plate, or the inside of a tire might be wet; or (3) there might be a drop in the level of fluid in the master cylinder reservoir.

Such leaks can cause the brakes to grab or fail and should be immediately corrected. Note the amount of fluid present when the dust boot is pulled back. A small amount of fluid seepage dampening the interior of the boot is normal. A dripping boot is not.

Warning! Hydraulic system parts should not be allowed to come in contact with oil or grease. They should not be handled with greasy hands. Even a trace of any petroleum-based product is sufficient to cause damage to the rubber parts.

Cylinder binding can be caused by rust deposits, swollen cups due to fluid contamination, or by a cup wedged into an excessive piston clearance. If the clearance between the pistons and the bore wall exceeds allowable values, a condition called heel drag might exist. It can result in rapid cup wear and can cause the piston to retract very slowly when the brakes are released.

Care must be taken when installing new or reconditioned wheel cylinders on cars equipped with

FIGURE 51-40 Pull back the wheel cylinder's dust boot to check for internal wheel cylinder leaks.

SHOP TALK

Wheel cylinders are seldom rebuilt; rather, they are replaced as a unit. The time and risk involved with rebuilding them is not worth it. However, if it is necessary to rebuild one, refer to the service information first.

wheel cylinder piston stops. The rubber dust boots and the pistons must be squeezed into the cylinder before it is tightened to the backing plate. If this is not done, the pistons jam against the stops causing hydraulic fluid leaks and erratic brake performance.

Drum Parking Brakes

The parking brake keeps a vehicle from rolling while it is parked. It is important to remember that the parking brake is not part of the vehicle's hydraulic braking system. It works mechanically, using a lever assembly connected through a cable system to the rear drum service brakes.

Types of Parking Brake Systems

Parking brakes can be either hand or foot operated. In general, downsized cars and light trucks use hand-operated self-adjusting lever systems **(Figure 51–41)**. Full-size vehicles normally use a foot-operated parking brake pedal **(Figure 51–42A)**.

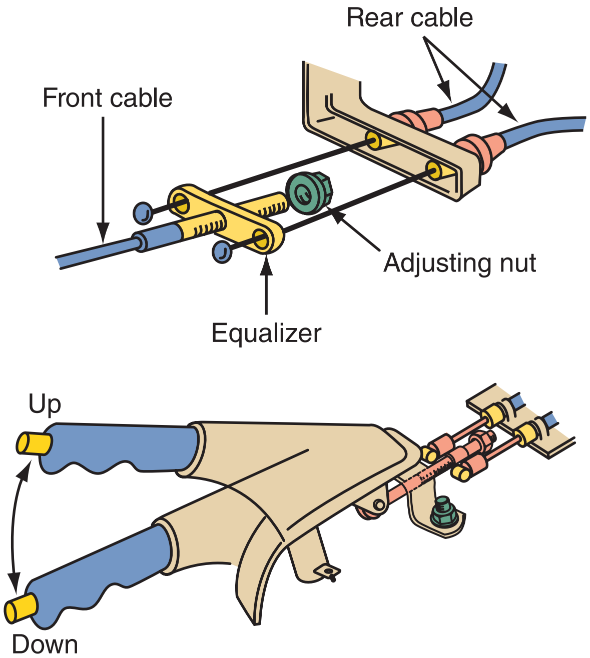


FIGURE 51–41 A typical setup for a center-mounted hand-operated parking brake.

PROCEDURE

Replacing a Wheel Cylinder

STEP 1 Because brake hoses are an important link in the hydraulic system, it is recommended that they be replaced when a new cylinder is to be installed or when the old cylinder is to be reconditioned. Remove the brake shoe assemblies from the backing plate before proceeding. The smallest amount of brake fluid contaminates the friction surface of the brake lining.

STEP 2 Use the appropriate tubing wrench and disconnect the hydraulic line where it enters the wheel cylinder. Care must be taken while removing this steel line. It might break or bend and be difficult to reinstall.

STEP 3 Remove the plates, shims, and bolts that hold the wheel cylinder to the backing plate. Some later design wheel cylinders are held to the backing plate with a retaining ring that can be removed with two small picks.

STEP 4 Remove the wheel cylinder from the backing plate and clean the area with a proper cleaning solvent.

STEP 5 Install the new wheel cylinder. Care must be taken when installing wheel cylinders on cars equipped with wheel cylinder piston stops. The rubber dust boots and pistons must be squeezed into the cylinder before it is tightened to the backing plate. If this is not done, the pistons will jam against the stops, causing fluid leaks and erratic brake performance.

STEP 6 Thread the brake line into the cylinder before attaching the wheel cylinder to the backing plate. Once the cylinder's mounting bolts are tightened to specifications, tighten the brake line. Then reassemble the brake unit and bleed the system.

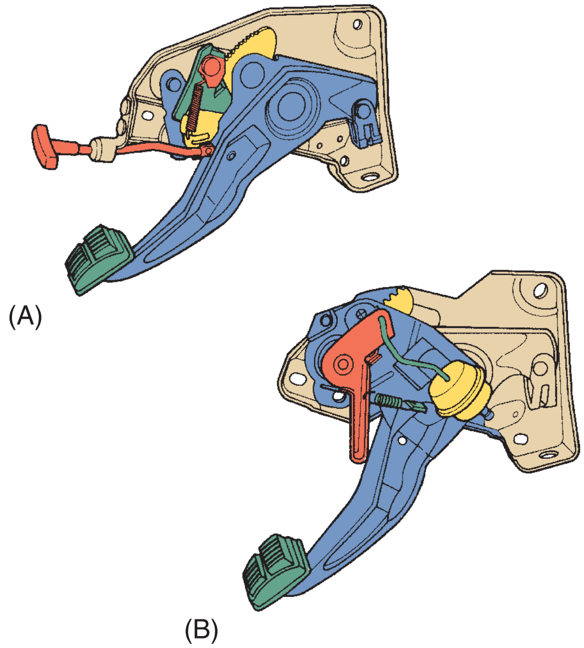


FIGURE 51–42 Typical pedal-operated parking brakes: (A) mechanical release and (B) vacuum release.

The pedal or lever assembly is designed to latch into an applied position and is released by pulling a brake release handle or pushing a release button.

On some vehicles, a vacuum power unit **(Figure 51–42B)** is connected by a rod to the upper end of the release lever. The vacuum motor is actuated to release the parking brake whenever the engine is running and the transmission is in forward driving gear. The lower end of the release lever extends down for alternate manual release in the event of vacuum power failure or for optional manual release at any time. Hoses connect the power unit and the engine manifold to a vacuum release valve on the steering column.

The starting point of a typical parking brake cable and lever system is the foot pedal or hand lever. This assembly is a variable ratio lever mechanism that converts input effort of the operator and pedal/lever travel into output force with less travel. Tensile force from the front cable is transmitted through the car's brake cable system to the rear brakes. This tension pulls the flexible steel cables attached to each of the rear brakes. It operates the internal lever and strut mechanism of each rear brake, expanding the brake shoes against the drum. Springs return the shoes to the unapplied position when the parking brake pedal is released and tensile forces in the cable system are relaxed.

An electronic switch, triggered when the brake pedal is applied, lights the brake indicator in the instrument panel when the ignition is turned on. The light goes out when either the pedal or control is released or the ignition is turned off.

The cable/lever routing system in a typical parking brake arrangement uses a three-lever setup to multiply the physical effort of the operator. First is the pedal assembly or hand grip. When moved, it multiplies the operator's effect and pulls the front cable. The front cable, in turn, pulls the equalizer lever.

The **equalizer lever** multiplies the effort of the pedal assembly, or hand grip, and pulls the rear cables. This pulling effort passes through an equalizer, which ensures equal pull on both rear cables. The equalizer functions by allowing the rear brake cables to slip slightly to balance out small differences in cable length or adjustment.

Figure 51–43 shows a typical parking brake system. When the parking brake pedal is applied, the cables and equalizer exert a balanced pull on the parking brake levers of both rear brakes. The levers and the parking brake struts move the shoes outward against the brake drums. The shoes are held in this position until the parking brake pedal is released.

The rear cable enters each rear brake through a conduit **(Figure 51–44)**. The cable end engages the

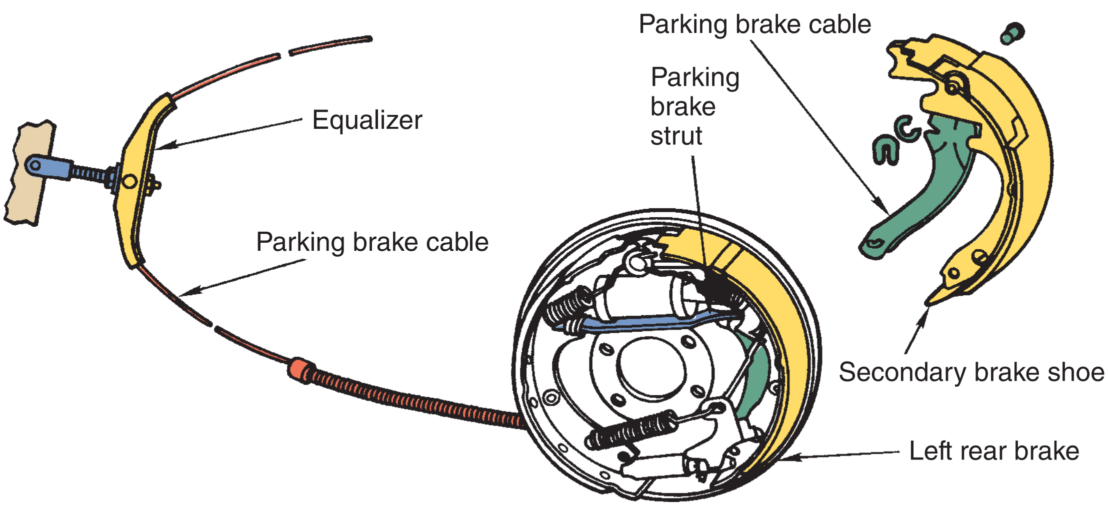


FIGURE 51–43 Parking brake components.

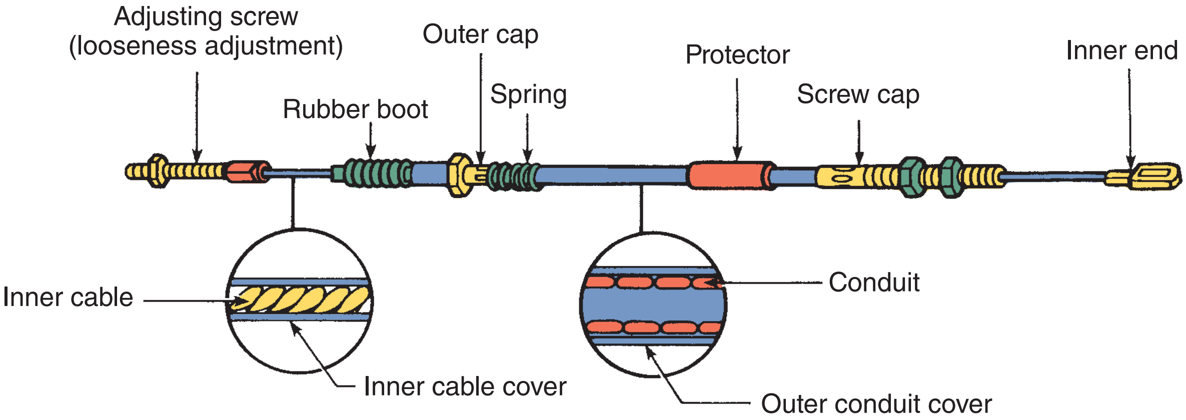


FIGURE 51-44 Rear cable and conduit details.

lower end of the parking brake lever. This lever is hinged to the web of the secondary shoe and linked with the primary shoe by means of a strut. The lever and strut expand both shoes away from the anchor and wheel cylinder and into contact with the drum as the cable and lever are drawn forward. The shoe return springs reposition the shoes when the cable is slacked.

To remove and replace the brake shoes, it might be necessary to relieve the parking brake cable tension by backing off the adjusting nuts at the equalizer.

Adjusting and Replacing Parking Brakes

Regular wheel brake service should be completed before adjusting the parking brake. Then check the parking brake for free movement of the parking brake cables in the conduits. If the cables drag, replace them. Check for worn equalizer and linkage parts. Replace any defective parts. Finally, check for broken strands in the cables. Replace any cable that has broken strands or shows signs of wear.

Testing Parking brake testing and adjustment procedures vary with the vehicle manufacturer. A common test is to raise the vehicle off the ground and apply the brake a specific number of "clicks." Once the brake is set, attempt to spin the rear wheels. If the wheels spin, release the parking brake and check the rear shoe-to-drum clearance and adjust if necessary. Recheck the parking brake. If the wheels still spin, adjust the parking brake until the brake holds. Release the brake and make sure the wheels spin and the brakes are not dragging.

Some technicians test the parking brake by parking the vehicle facing up on an incline of 30 degrees or less. Set the parking brake fully and place the transmission in neutral. The vehicle should hold steady. Reverse the vehicle position so it is facing down the incline and repeat the test. If the vehicle creeps or rolls in either case, the parking brake requires adjustment.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2003	**Make:** Ford	**Model:** Windstar	**Mileage:** 138,197	**RO:** 19087
Concern:	Customer says the van nosedives when braking.			
After driving the vehicle and confirming the complaint, the technician inspects the brake system. The brake fluid level is good and the fluid is in good condition. With the wheels removed, he finds the brake pads half worn and shoes in good condition, with little signs of wear. He finds no signs of fluid leaks. Unable to determine the cause of the complaint, he checks each wheel brake to make sure applies and releases. He finds the brake shoes are not applying against the drums when the pedal is pressed.				
Cause:	Found wheel cylinder pistons rusted and frozen in cylinder bores.			
Correction:	Replaced wheel cylinders, flushed brake system to remove moisture. Rear brakes now apply properly and vehicle no longer nosedives when stopping.			

KEY TERMS

Backing plate
Duo-servo drum brake
Equalizer lever
Floating drum
Heat checks
Holddown spring
Nonservo drum brake
Primary shoe
Return spring
Secondary shoe
Self-energizing force
Shoe anchor
Web

SUMMARY

- Drum brakes are still used on the rear wheels of many cars and light trucks.
- The drum is mounted to the wheel hub. When the brakes are applied, a wheel cylinder uses hydraulic power to press two brake shoes against the inside surface of the drum. The resulting friction between the shoe's lining and drum slows the drum and wheel.
- The brake's anchor pin acts as a brake shoe stop, keeping the shoes from following the rotating drum. This creates a wedging action that multiplies braking force.
- The shoes and wheel cylinder are mounted on a backing plate. Hardware, such as shoe return springs, holddown parts, and linkages are also mounted on the backing plate.
- The primary or leading shoe is toward the front of the vehicle while the secondary or trailing shoe is toward the rear of the vehicle.
- Brake lining can be attached to the shoes by riveting or a special adhesive bonding process.
- Brake drums act as a heat sink to dissipate the heat of braking friction. Drums can be refinished on a brake lathe provided the inside diameter is not increased above a safe limit (discard dimension).
- Servicing brakes requires performing a complete system inspection. Partial replacement of worn or damaged parts does not solve the braking problems and may ruin the new parts installed.
- When servicing brakes, extreme care must be taken to avoid generating asbestos dust.
- Wheel cylinders should be replaced if they show any signs of hydraulic fluid leakage or component wear.
- Drum brakes allow for the use of a simple parking brake mechanism that can be activated with a hand lever or foot pedal. This is a mechanical system, completely separate from the service brake hydraulic system.

REVIEW QUESTIONS

Short Answer

1. Name the two methods of attaching brake lining materials to the brake shoes.
2. Explain how drum brakes create a self-multiplying brake force.
3. List at least five separate types of wear and distortion to look for when inspecting brake drums.
4. What is the job of wheel cylinder stops?
5. Explain the operation of an integral drum brake parking brake.
6. Explain how a duo-servo brake assembly works to provide great braking ability.

True or False

1. *True or False?* Backing plates, struts, levers, and other metal brake parts should be cleaned with a wet-cleaned using water or a water-based solution.
2. *True or False?* The name *duo-servo drum brake* is derived from the fact that the self-energizing force is transferred from one shoe to another with the wheel rotating forward.

Multiple Choice

1. In a typical drum brake, which component provides a foundation for the brake shoes and associated hardware?
   a. Wheel cylinder
   b. Drum
   c. Backing plate
   d. Lining
2. Which of the following statements about drum brake shoes is *not* true?
   a. Linings may be riveted or bonded to the shoes.
   b. Shoe indentions hold the shoe in place against the backing plate.
   c. The shoe rim supports the shoe lining.
   d. The primary/leading shoe is typically the one that is positioned toward the front of the vehicle.

3. Brake linings should be replaced when ___.
   a. linings are worn to within $^{1}/_{32}$ inch of a rivet head
   b. linings are contaminated with oil or grease
   c. linings are contaminated with brake fluid
   d. all of the above
4. In the unapplied position, drum brake shoes are held against the anchor pin by the ___.
   a. holddown springs
   b. star wheel adjuster
   c. shoe holddown
   d. return springs
5. Duo-servo drum brakes are also known as what type of brake assembly?
   a. Leading-trailing brakes
   b. Self-energizing brakes
   c. Nonservo brakes
   d. None of the above
6. On most vehicles, the automatic adjuster cables or levers are ___.
   a. installed on the secondary shoe
   b. set up to operate when the brakes are applied as the vehicle moves forward
   c. installed on the primary shoe
   d. set up to operate when the brakes are not applied
7. A buildup of brake dust and dirt between the lining and the drum is the most common cause of a ___.
   a. concave/barrel-shaped drum
   b. convex/tapered drum
   c. threaded drum surface
   d. scored drum surface

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that an out-of-round drum can cause a pulsating brake pedal. Technician B says that an out-of-round drum can cause the brakes to grab. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Technician A says that a grinding noise from a drum brake when it is not applied can be caused by a bad wheel bearing. Technician B says that a grinding noise from a drum brake when it is not applied can be caused by worn brake hardware. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. It has been determined that chatter and brake pull are being caused by hard spots on the brake drum: Technician A says that the problem can be solved by grinding off the hard spots. Technician B says that the drum must be replaced. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. Technician A says that the discard dimension of a brake drum is the drum's allowable machining dimension. Technician B says that the discard dimension is the allowable wear dimension. There must be 0.030 inch left for wear after machining. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. After resurfacing a brake drum: Technician A cleans it using hot soapy water and a lint-free cloth. He then uses compressed air to thoroughly dry it. Technician B cleans the drum using a lint-free cloth dipped in a special brake cleaning solvent. She then allows the drum to dry before reinstallation. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. Drum linings are badly worn at their heel and toe: Technician A says that the problem is an out-of-round drum. Technician B says that the problem is a tapered drum. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. When machining brake drums: Technician A tries to remove only enough metal to obtain a true, smooth surface. Technician B cuts the drum on the other side of the axle to the same diameter as the one that was cut first. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. While discussing what would happen if too much metal is removed from a drum by machining: Technician A says that noise can result from the thin drum vibrating when the brakes are applied. Technician B says that the brakes could fade because the thin drum is unable to absorb heat during braking. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. Technician A checks the surface of the drum for scoring by running a fingernail across the surface. Technician B replaces any drum that is scored. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. While discussing pull during braking: Technician A says that this can be caused by one tire being underinflated. Technician B says that a frozen wheel cylinder on one side of the car can cause this. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER

52

DISC BRAKES

OBJECTIVES

- List disc brake components and describe their functions.
- Explain the difference between the three types of calipers commonly used on disc brakes.
- Describe the two types of parking brake systems used with disc brakes.
- Describe the causes of common disc brake problems.
- Explain what precautions should be taken when servicing disc brake systems.
- Describe the general procedure involved in replacing disc brake pads.
- List and describe five typical disc brake rotor problems.

Disc brakes resemble the brakes on a bicycle. The friction elements are in the form of pads, which are squeezed or clamped about the edge of a rotating wheel. With automotive disc brakes, this wheel is a separate unit mounted inboard of the wheel and tire, called the rotor **(Figure 52–1)**. The rotor is typically made of cast iron. Because the pads clamp against both sides of a rotor, both sides are machined smooth. The pads are attached to metal backings, which are actuated by pistons. The pistons are contained within a caliper assembly, which is a housing that wraps around the edge of the rotor. The caliper is mounted to the steering knuckle to stop it from rotating. The caliper contains the pistons and related seals, springs, bleeder screws, and boots as well as the cylinder(s) and fluid passages necessary to force the pads against the rotor.

Disc brakes offer four major advantages over drum brakes. Disc brakes are more resistant to

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE			REPAIR ORDER	
Year: 2010	**Make:** Ford	**Model:** Fusion	**Mileage:** 61,052	**RO:** 19145
Concern:	Customer states brakes smell and feel like they are dragging at the rear.			
History:	Customer installed new brake pads on rear of vehicle recently.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

FIGURE 52–1 A disc brake assembly.

heat fade during high-speed brake stops or repeated stops. The design of the disc brake rotor exposes more surface to the air and thus dissipates heat more efficiently. They are also resistant to water fade because the rotation of the rotor tends to throw off moisture. The squeeze of the sharp edges of the pads clears the surface of water. Disc brakes perform more straight-line stops. Due to their clamping action, disc brakes are less apt to pull. Finally, disc brakes automatically adjust as pads wear.

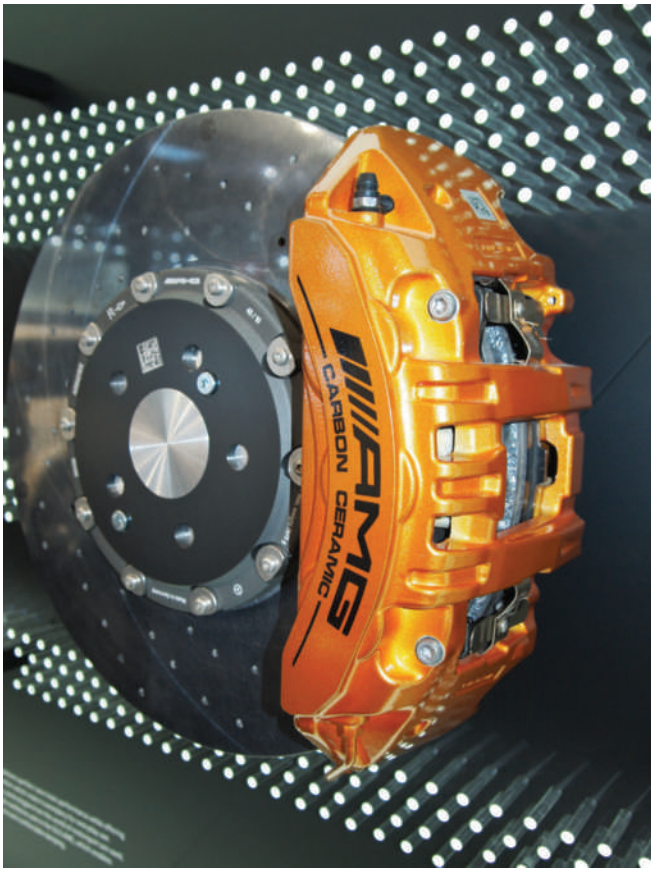


FIGURE 52–2 A fixed caliper assembly.

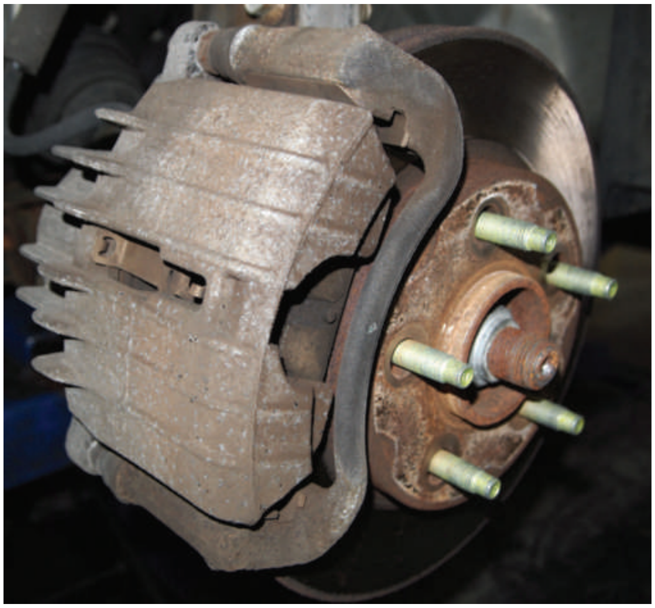


FIGURE 52–3 A floating caliper.

Disc Brake Components and their Functions

The disc brakes used today are typically of two basic designs: fixed caliper **(Figure 52–2)** or floating caliper. There is also a sliding caliper, but its design is very similar to the floating caliper **(Figure 52–3)**. The only difference is that sliding calipers slide on surfaces that have been machined smooth for this purpose, and floating calipers slide on special pins or bolts. The disc brake, regardless of its design,

consists of a hub and rotor assembly, a caliper assembly, and the brake pads.

Rotors

The disc brake rotor has two main parts: the hub and the braking surface. The hub is where the wheel is mounted and may contain the wheel bearings. The braking surface is the machined surface on both sides of the rotor. It is carefully machined to provide a friction surface for the brake pads. The entire rotor is usually made of cast iron, which provides an excellent friction surface.

The size of the rotor braking surface is determined by the diameter of the rotor. Large and high performance cars, which require more braking energy, have large rotors. Smaller, lighter cars can use smaller rotors. Generally, manufacturers want to keep parts as small and light as possible while maintaining efficient braking ability.

The rotor is protected from water and dirt due to road splash by a splash shield bolted to the steering knuckle **(Figure 52–4)**. The outboard side is shielded by the vehicle's wheel. The splash shield and wheel also are important in directing air over the rotor to aid cooling.

Fixed and Floating Rotors Rotors are classified by their hub design. A **fixed rotor** may have the hub and the rotor cast as a single unit. The rotor illustrated in Figure 52–4 is an example of a fixed rotor. Another fixed design has the rotor bolted to the hub assembly. Removal requires taking off the hub, bearing, and rotor as a unit. The rotor is then unbolted from the hub and bearing. **Floating rotors** and hubs are made as two separate parts. The hub is a conventional casting and is mounted on wheel bearings or on the axle. The wheel studs are mounted in the hub and pass through the rotor center section **(Figure 52–5)**. One advantage of this design is that the rotor is less expensive and can be replaced easily and economically.

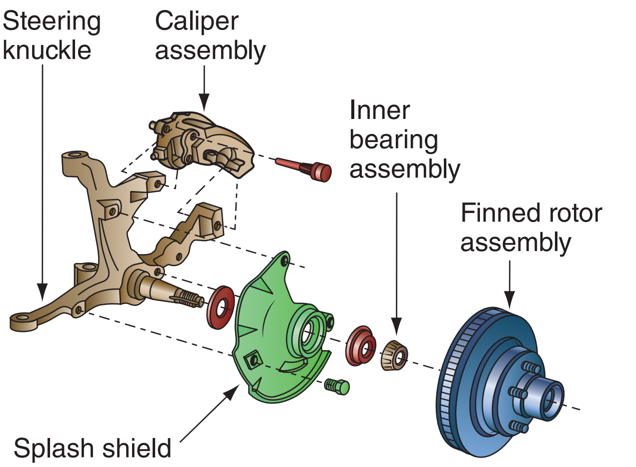


FIGURE 52–4 A splash shield protects the inboard side of the rotor.

Composite Rotors The need to reduce vehicle weight led to the development of composite rotors. Composite rotors are made of different materials,

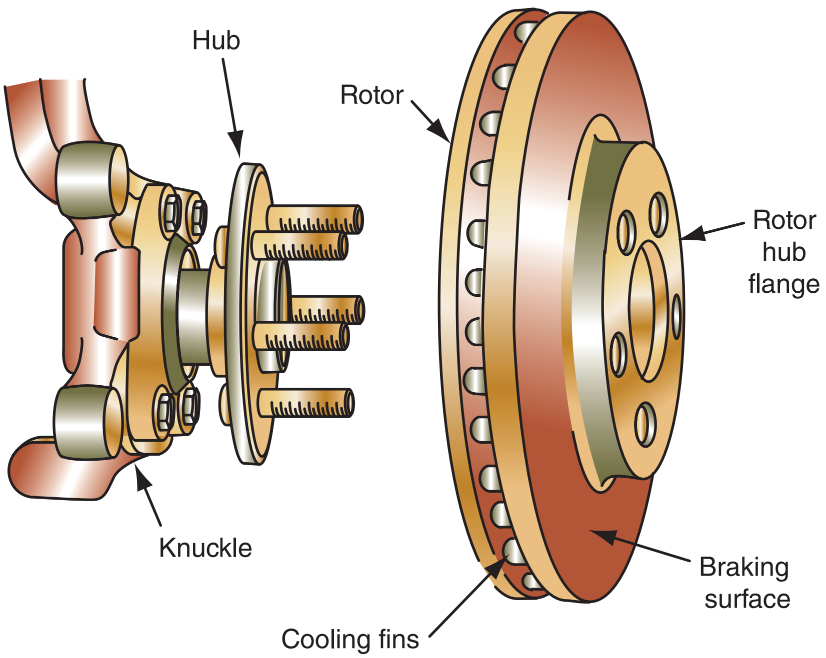


FIGURE 52–5 A rotor that is cast as a separate part and fastened to the hub is called a floating rotor.

usually cast iron and steel, to reduce weight. The friction surfaces and the hubs are cast iron, but the supporting parts of the rotor are made of lighter steel stampings **(Figure 52–6)**. The steel and iron sections are bonded to each other under heat and high pressure to form a one-piece finished assembly. Composite rotors may be fixed or floating rotors. Because the friction surfaces of composite rotors are cast iron, the wear standards are generally the same as they are for other rotors.

Ceramic Rotors In the late 1990s, Porsche first offered a carbon-ceramic brake option on the 911 GT2 and then on its 911 Turbo in 2000. Today, ceramic brakes are standard on many Ferraris and Lamborghinis and are available on Porsches, Bentleys, and some Corvettes **(Figure 52–7)**.

Ceramic brakes are costly, costing up to $15,000 on some vehicles, but weigh about one-half of a conventional rotor. This means they allow for lower unsprung weight that helps ride quality and handling and improves fuel economy. They also last four times longer than steel discs. Brake pads also last about three times longer. The brake pads designed to be used with ceramic discs contain a ceramic powder mixed with metal wires or particles. The pads have heat shields to prevent the heat from traveling through the system.

Ceramic brakes have excellent fade resistance and stopping power. Also, the vehicle's wheels stay cleaner because no black brake dust is released.

The disc assembly is a two-piece unit: a ceramic ring and a steel center piece or hub. The ring is bolted to the hub. The ring of the rotor is made of

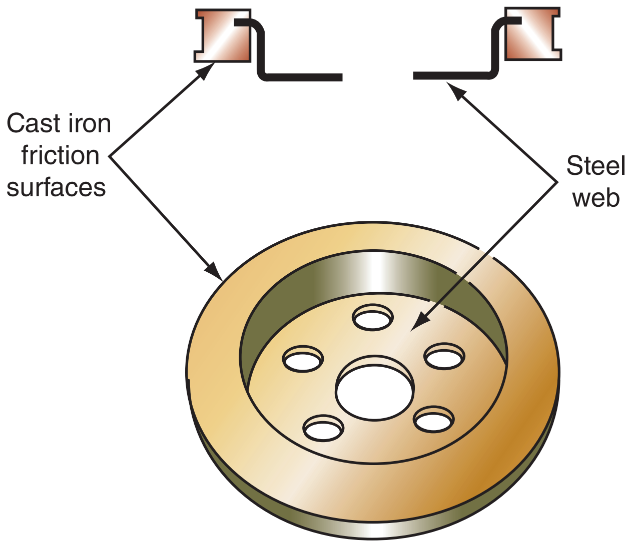


FIGURE 52–6 Composite rotors are made of different materials, usually cast iron and steel.

FIGURE 52–7 A carbon-ceramic brake assembly.

ceramic with carbon fibers arranged to strengthen the disc and conduct heat away from the surface. The ceramic material is based on silicon carbide, which is an extremely hard material with a crystal structure similar to that of diamond. The finished surface of the rotor looks like stone.

Solid and Ventilated Rotors A rotor may be solid or it may be ventilated. A solid rotor is simply a solid piece of metal with a friction surface on each side. A solid rotor is light, simple, cheap, and easy to manufacture. Because they do not have the cooling

capacity of a ventilated rotor, solid rotors usually are used on the rear of small to medium size cars of moderate performance. The rear brakes of performance-oriented vehicles—larger cars, trucks, and many SUVs-use vented rear rotors.

A ventilated rotor has cooling fins cast between the braking surfaces to increase the cooling area of the rotor. When the wheel is in motion, the rotation of these fins in the rotor also increases air circulation and brake cooling **(Figure 52–8)**. Although ventilated rotors are larger and heavier than solid rotors, these disadvantages are more than offset by their better cooling ability and heat dissipation.

Some ventilated rotors have cooling fins that are curved or formed at an angle to the hub center **(Figure 52–9)**. These fins increase the centrifugal force on the rotor airflow and increase the air volume that removes heat. Such rotors are called unidirectional rotors because the fins only work properly when the rotor rotates in one direction. Therefore, unidirectional rotors cannot be interchanged from the right side to the left side on the car.

Drilled vs. Slotted Rotors Many high-performance vehicles are fitted with cross-drilled rotors **(Figure 52–10)**. The idea behind having holes through the rotor is simply to allow heat, gases, and dirt to escape. In addition, the edges of the holes give a place for the pads to grab. They, however, also decrease the overall surface area of the rotor, which reduces the thermal capacity of the discs and the discs have a poor service life. The latest trend is to cut a series of tangential slots or channels into the surface. These slots do the same thing as the holes without the disadvantages.

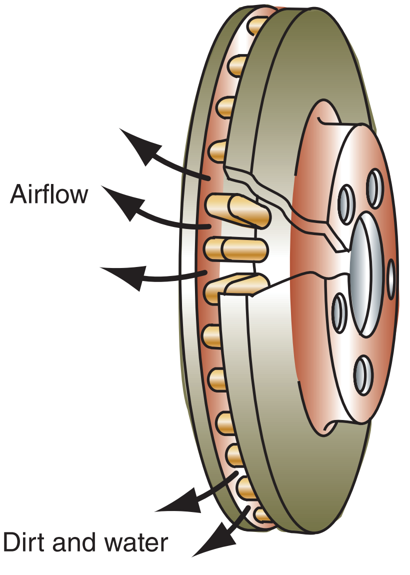


FIGURE 52–8 A ventilated rotor has cooling fins cast between the braking surfaces to increase the cooling area of the rotor.

FIGURE 52–9 The internal cooling fins on a directional rotor.

FIGURE 52–10 A cross-drilled brake rotor.

Rotor Hubs and Wheel Bearings

Tapered roller bearings, which are installed in the wheel hubs, were common on the front wheels of RWD and the rear wheels of FWD vehicles. Normally late-model vehicles do not use tapered roller bearings, however, there are many vehicles still on the

road that have them. The tapered roller bearing has two main parts: the inner bearing cone and the outer bearing cup. The bearing cone is an assembly that contains steel tapered rollers. The rollers ride on an inner cone-shaped race and are held together by a bearing cage. The bearing fits into the outer cup, or race, which is pressed into the hub. This provides two surfaces, an inner cone and outer cup, for the rollers to ride on. The bearings are held in place with a thrust washer, nut, locknut, and cotter pin. A dust cap fits over the assembly to keep dirt out and lubricant in. A seal on the inboard side prevents lubricant from escaping at this end.

Caliper Assembly

A brake caliper converts hydraulic pressure into mechanical force. The caliper housing is usually a one-piece construction of cast iron or aluminum and has an inspection hole in the top to allow for lining wear inspection. The housing contains the cylinder bore(s). In the cylinder bore is a groove that seats a square-cut seal. This groove is tapered toward the bottom of the bore to increase the compression on the edge of the seal that is nearest hydraulic pressure. The top of the cylinder bore is also grooved as a seat for the dust boot. A fluid inlet hole is machined into the cylinder bore and a bleeder valve is located near the top of the casting **(Figure 52–11)**.

A caliper can contain one, two, four, or six cylinder bores and pistons that provide uniform pressure distribution against the brake's friction pads. The pistons are relatively large in diameter and short in stroke to provide high pressure on the friction pad assemblies with a minimum of fluid displacement.

Basically, the hydraulics of disc brakes are the same as for drum brakes, in that the master cylinder piston forces the brake fluid into the wheel cylinders and against the wheel pistons.

The disc brake piston is made of steel, aluminum, or fiberglass-reinforced phenolic resin (a polymer plastic). Steel pistons are usually nickel-chrome plated for improved durability and smoothness. The top of the pistons is grooved to accept the dust boot that seats in a groove at the top of the cylinder bore and also in a groove in the piston. The dust boot prevents moisture and road contamination from entering the bore.

A piston hydraulic (square-cut) seal prevents fluid leakage between the cylinder bore wall and the piston. This rubber sealing ring also acts as a retracting mechanism for the piston when hydraulic pressure is released, causing the piston to return in its bore **(Figure 52–12)**. When hydraulic pressure is diminished, the seal functions as a return spring to retract the piston.

In addition, as the disc brake pads wear, the seal allows the piston to move farther out to adjust automatically for the wear without allowing fluid to leak. Since the brake pads need to retract only slightly after they have been applied, the piston moves back only slightly into its bore. The additional brake fluid

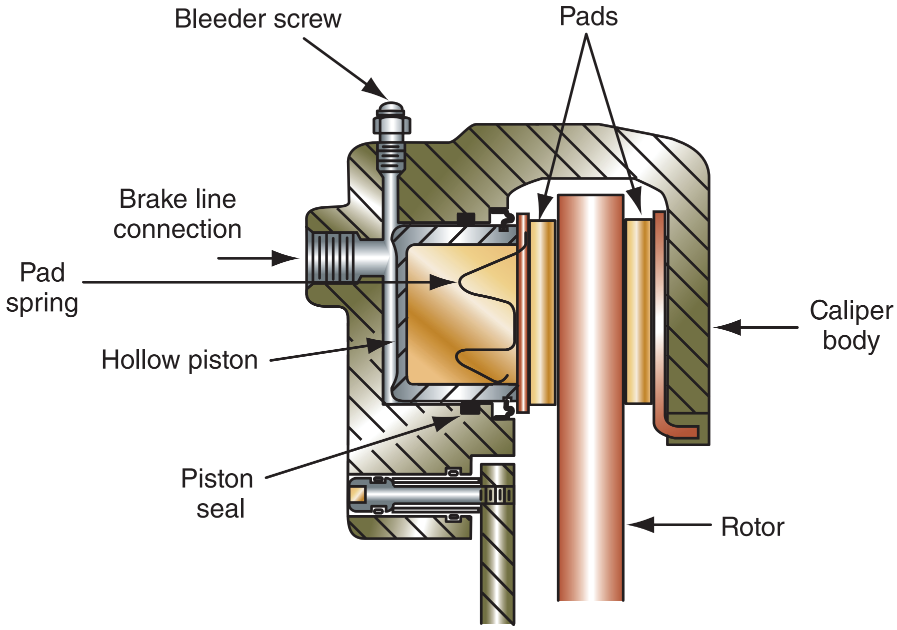


FIGURE 52–11 Cross section of a typical caliper.

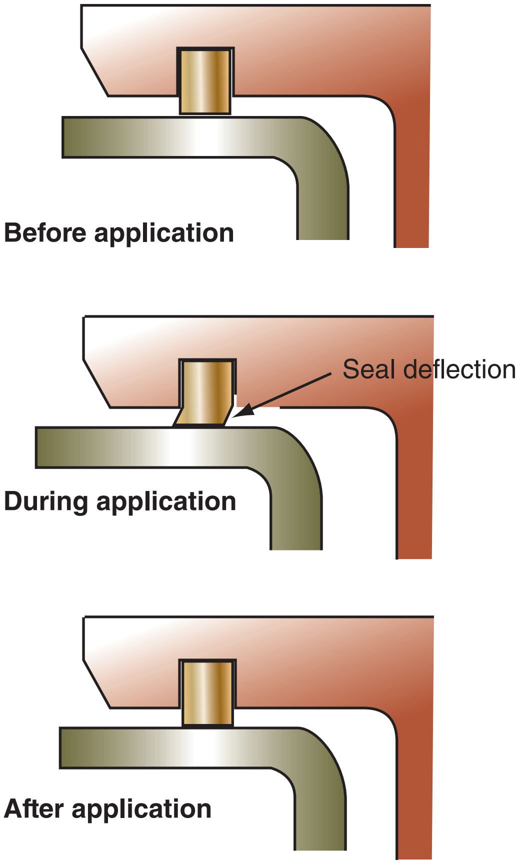


FIGURE 52–12 The deflection of a square-cut seal during brake application and brake release.

in the caliper bore keeps the piston out and ready to clamp the surface of the rotor.

Fixed Caliper Disc Brakes **Fixed caliper** disc brakes have a caliper assembly that is bolted in a fixed position and does not move when the brakes are applied. The pistons in both sides of the caliper come inward to force the pads against the rotor **(Figure 52–13)**. Fixed calipers typically have two to six pistons based on the size of the brake and the performance of the vehicle.

Fixed calipers may be one or a two-piece design. Also called a monobloc caliper, one-piece designs are made from a single piece of aluminum to reduce weight. Two-piece calipers are bolted together and are less expensive than one-piece calipers. Fluid passages may be machined into the caliper body or external transfer tubes (steel brake lines) route fluid to both sets of pistons.

Floating Caliper Disc Brakes A typical **floating caliper** disc brake is a one-piece casting that has one hydraulic cylinder and a single piston. The caliper is attached to the spindle anchor plate with two threaded locating pins **(Figure 52–14)**. A Teflon sleeve separates the caliper housing from each pin and the caliper slides back and forth on the pins as

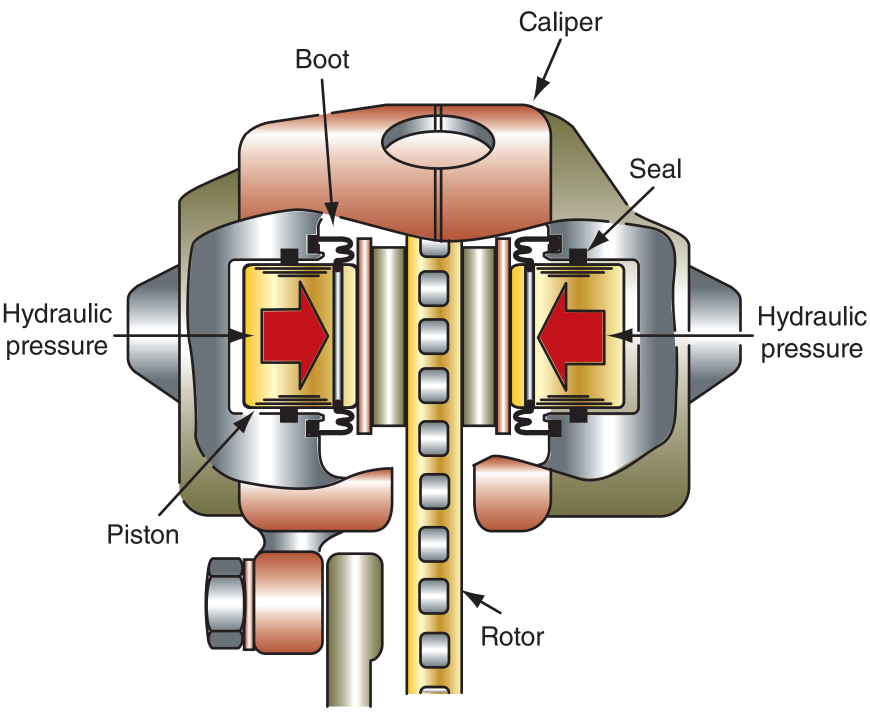


FIGURE 52–13 The caliper of a fixed caliper assembly is bolted in a fixed position and does not move when the brakes are applied.

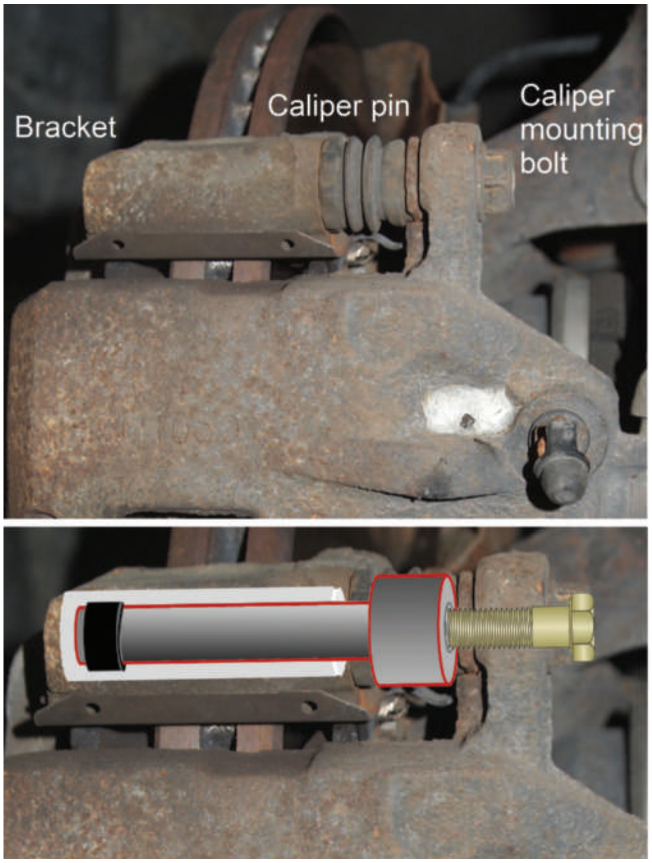


FIGURE 52–14 The caliper bolt attaches the caliper to the pin inside the bracket.

the brakes are actuated. When the brakes are applied, hydraulic pressure builds in the cylinder behind the piston and seal. Because hydraulic pressure exerts equal force in all directions, the piston moves evenly out of its bore.

The piston presses the inboard pad against the rotor. As the pad contacts the revolving rotor, greater resistance to outward movement is increased, forcing pressure to push the caliper away from the piston. This action forces the outboard pad against the rotor **(Figure 52–15)**. However, both pads are applied with equal pressure.

Sliding Caliper Disc Brakes With a **sliding caliper** assembly, the caliper slides or moves sideways when the brakes are applied. As mentioned previously, in operation, these brakes are almost identical to the floating type. But unlike the floating caliper, the sliding caliper does not float on pins or bolts attached to the anchor plate. It has angular machined surfaces at each end that slide in mating machined surfaces on the anchor plate. This is where the caliper slides back and forth.

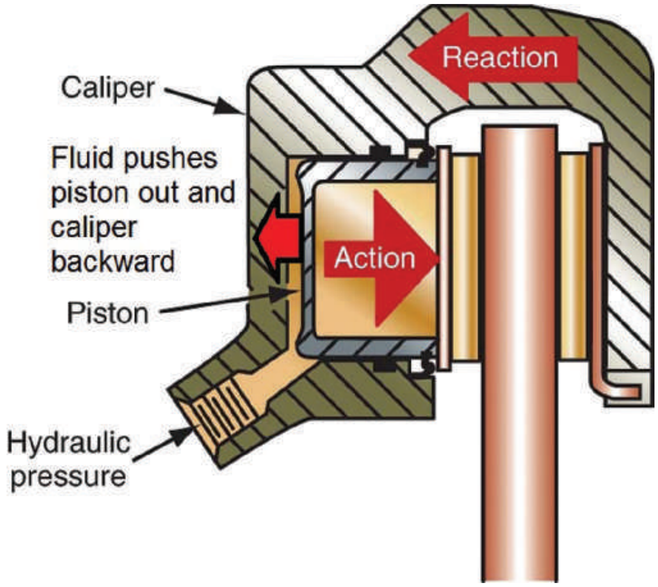


FIGURE 52–15 Operation of a floating caliper.

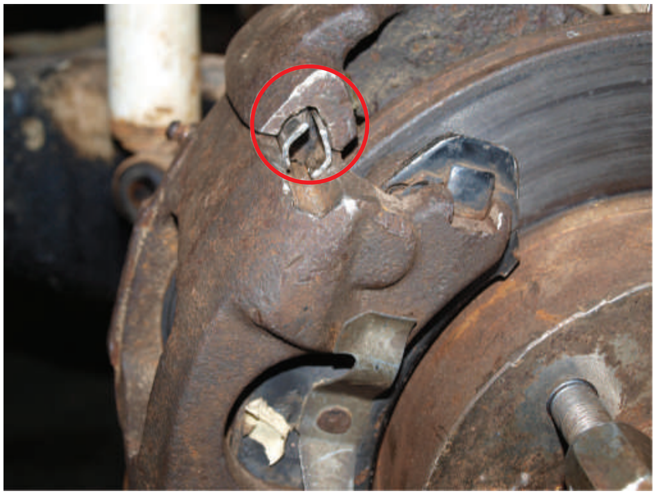


FIGURE 52–16 Some sliding calipers use a support key to locate and support the caliper in the anchor plate.

Some sliding calipers use a support key to locate and support the caliper in the anchor plate **(Figure 52–16)**. The caliper support key is inserted between the caliper and the anchor plate. A worn support key may cause tapered brake pad wear. Always inspect the support keys when replacing brake pads. Also make sure they are lubricated when reassembling the unit.

Brake Pad Assembly

Brake pads are metal plates with the linings either riveted or bonded to them. Pads are placed at each side of the caliper and straddle the rotor. The

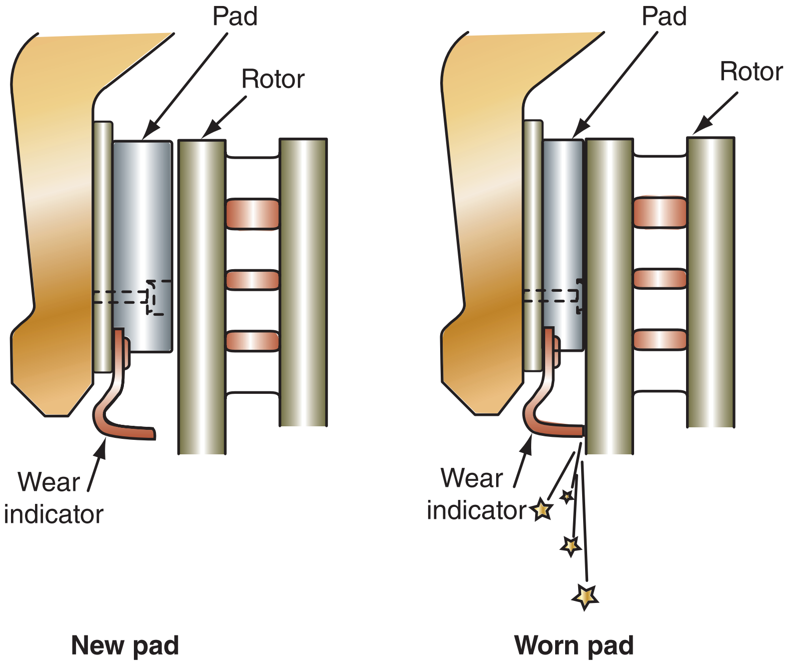


FIGURE 52–17 Operation of the wear indicator.

linings are made of semimetallic or other non-asbestos material.

Disc Pad Wear Sensors Some brake pads have wear indicators. The three most common design wear sensors are audible, visual, and tactile.

Audible sensors are thin, spring steel tabs that are riveted to or installed onto the edge of the pad's backing plate and are bent to contact the rotor when the lining wears down to a point that replacement is necessary. At that point, the sensor causes a high-pitched squeal whenever the wheel is rotating, except when the brakes are applied. Then the noise goes away. The noise gives a warning to the driver that brake service is needed and perhaps saves the rotor from destruction **(Figure 52–17)**.

Pads often have grooves cut into the lining **(Figure 52–18)**. These not only help with venting dust and pad cooling but also can be used to indicate when the pads need to be replaced. The grooves typically do not completely bisect the pad, instead, they leave 1 to 2 millimeters of the lining uncut. Once the pad wears to the bottom of the groove, the pad is due for replacement.

Some vehicles have systems with an electronic wear indicator in the disc brake pads. As the pad wears to a predetermined point, a warning light in the instrument panel is illuminated by the wear sensors. In some systems, a small pellet is contained in the brake pad's friction material. The pellets are wired in series or in parallel to the red brake warning lamp circuit **(Figure 52–19)** and complete the lamp circuit when the pellets contact the rotor.

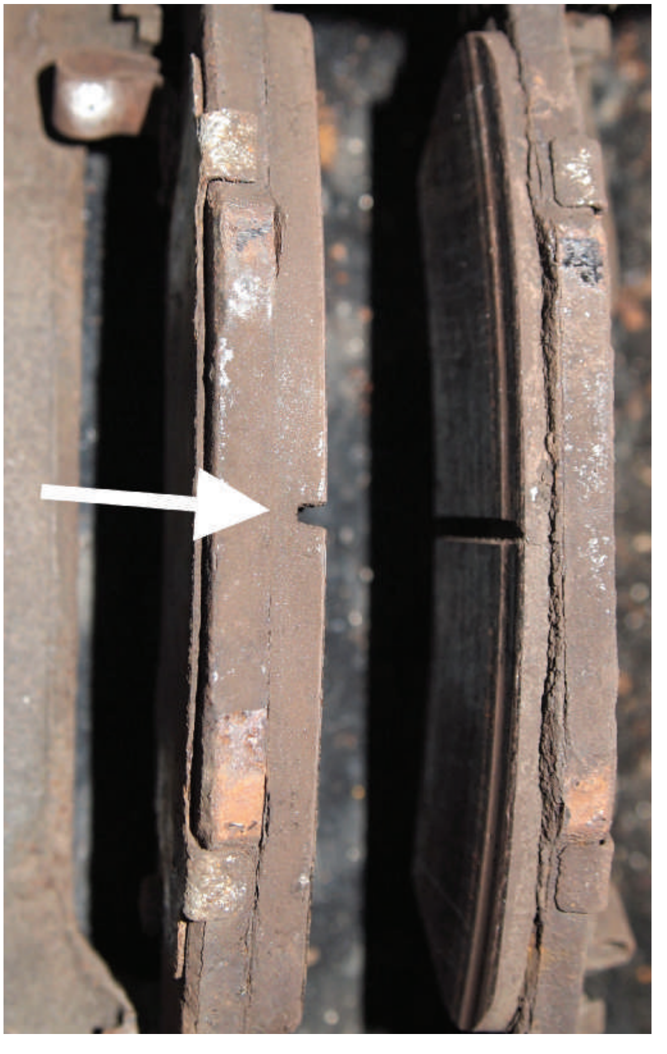


FIGURE 52–18 The groove cut into the lining serves several purposes.

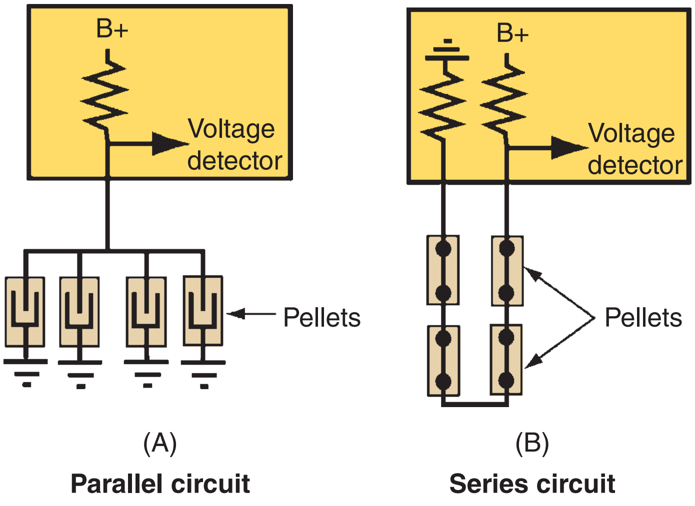


FIGURE 52–19 Electronic pad wear sensors can be wired in parallel or in series with the warning lamp. The pellets are embedded in the brake pads.

Rear-Wheel Disc Brakes

Rear-wheel disc brake calipers may be fixed, floating, or sliding, and all of these designs work in the same way as when they are used at the front wheels. The only difference between a front and rear disc brake caliper is that the rear disc brake caliper needs a parking brake. Four-wheel disc brake installations must have some way to apply the rear brakes when the parking brake is set.

Rear Disc/Drum (Auxiliary Drum) Parking Brake

The rear disc/drum or auxiliary drum parking brake arrangement is found on many cars, light-duty trucks, and SUVs. On these brakes, the inside of each rear wheel hub and rotor assembly is used as the parking brake drum **(Figure 52–20)**. A pair of small brake shoes is mounted on a backing plate that is bolted to the axle housing or the hub carrier. These parking brake shoes operate independently of the service brakes. They are applied by linkage and cables from the control pedal or lever. The cable at each wheel operates a lever and strut that apply the shoes in the same way that rear drum parking brakes work.

The assembly (often called the drum-in-hat system) is a smaller version of a drum brake and is serviced much like any other drum brake. However, they do not have self-adjusters. The parking brakes must be adjusted manually with star wheels that are accessible through the backing plate or through the outboard surface of the drum **(Figure 52–21)**.

CUSTOMER CARE

Excessive heat liquefies the resin binder that holds the brake pad material together. Once liquefied, the binder rises to the surface of the pad to form a glaze. A glazed pad may cause squealing because more heat is needed to achieve an amount of friction equal to a pad in good condition. One common cause of pad glazing is the improper break-in of the pads. Remember to inform customers that unnecessary hard braking during the first 200 miles (320 km) of a pad's life can generate enough heat to glaze the pads and ruin the quality of the work just performed. There are pads now available that require no break-in time.

FIGURE 52–20 On some rear disc brakes, the inside of the rear wheel hub and rotor assembly is used as the parking brake drum.

Late-model GM trucks use an expandable, single metal band covered with friction material inside the parking brake drum that is machined on the inside of the rear brake disc.

Caliper-Actuated Parking Brakes

Some floating or sliding caliper rear disc brakes mechanically apply the calipers' pistons to lock the pads against the rotors for parking. All caliper-actuated

FIGURE 52–21 The auxiliary drum parking brakes are adjusted through a window in the backing plate.

parking brakes have a lever that protrudes from the inboard side of the caliper. These levers are operated by linkage and cables from the parking brake control pedal or lever.

The two most common types of caliper-actuated parking brakes are the screw-and-nut type and the ball-and-ramp type. A few imported cars have a third type that uses an eccentric shaft and a rod to apply the caliper piston. An eccentric acts like a cam. One portion of the shaft is oval-shaped. As the shaft rotates, the high part of the oval pushes the operating rod out to apply the brakes.

General Motors' floating caliper rear disc brakes are the most common example of the screw-and-nut parking brake mechanism **(Figure 52–22)**. The caliper lever is attached to an actuator screw inside the caliper that is threaded into a large nut. The nut, in turn, is splined to the inside of a large cone that fits inside the caliper piston. When the parking brake is applied, the caliper lever rotates the actuator screw. Because the nut is splined to the inside of the cone, it cannot rotate, so it forces the cone outward against the inside of the piston, forcing it outward. Similarly, the piston cannot rotate because it is keyed to the brake pad, which is fixed in the caliper. The piston then applies the inboard brake pad, and the caliper slides as it does for service brake operation and forces the outboard pad against the rotor. An adjuster spring inside the nut and cone rotates the nut outward when the parking brakes are released to provide self-adjustment. Rotation of the nut takes up clearance as the brake pads wear.

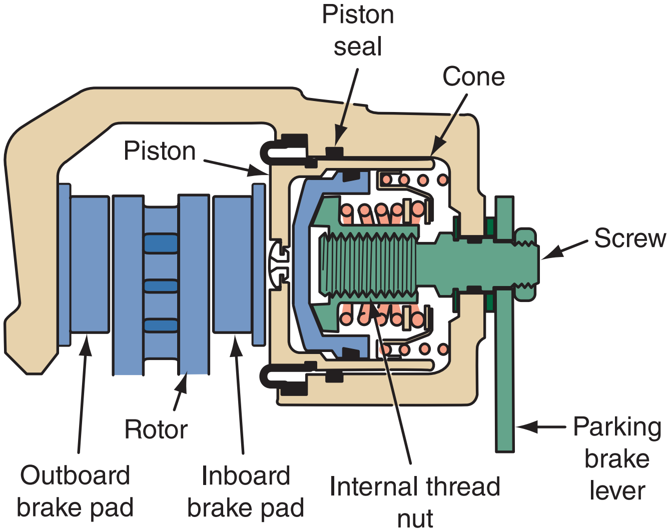


FIGURE 52–22 A GM screw-and-nut parking brake mechanism for a disc brake.

Ford's floating caliper rear disc brakes are the most common example of the ball-and-ramp parking brake mechanism **(Figure 52–23)**. The caliper lever is attached to a shaft inside the caliper that has a small plate on the other end. Another plate is attached to a thrust screw inside the caliper piston. The two plates face each other, and three steel balls separate them. When the parking brake is applied, the caliper lever rotates the shaft and plate. Ramps in the surface of the plate force the balls outward against similar ramps in the other plate. As the plates move farther apart, the thrust screw forces the piston outward. The thrust screw cannot rotate because

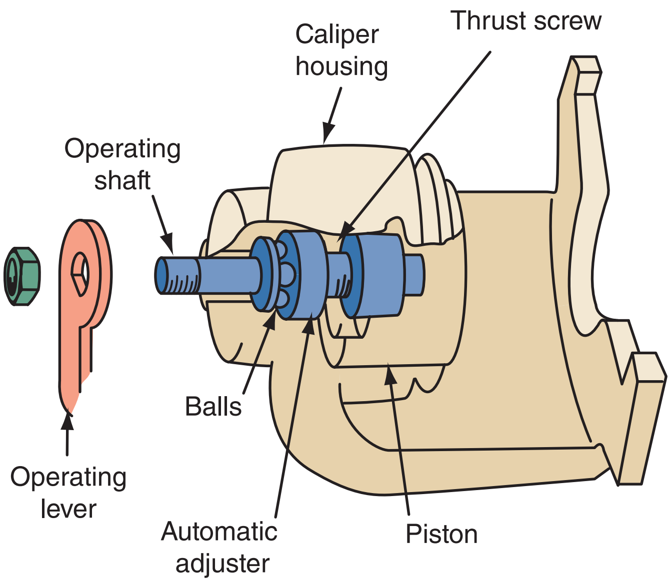


FIGURE 52–23 A Ford ball-and-ramp parking mechanism for a disc brake.

it is keyed to the caliper. The piston then applies the inboard brake pad, and the caliper slides as it does for service brake operation and forces the outboard pad against the rotor. When the piston moves away from the thrust screw, an adjuster nut inside the piston rotates on the screw to take up clearance and provide self-adjustment. A drive ring on the nut keeps it from rotating backward.

Another way to tighten the pads against the rotor when the parking brake is applied is to use a threaded, spring-loaded pushrod. As the parking brakes are applied, a mechanism rotates or unscrews the pushrod, which in turn pushes the piston out.

Electrically Operated Parking Brake

Many new vehicles use electronic parking brakes. To set or release the brake, the driver holds the brake pedal down and presses or pulls the Parking Brake button **(Figure 52–24)**. The brake control module commands the electric motor(s) to apply the parking brake. Application can be direct, meaning the motor is attached to the back of the rear caliper **(Figure 52–25)** or the motor may pull a parking brake cable attached to a traditional parking brake caliper. To release, press and hold the brake pedal and then the Parking Brake button.

These systems also have an automatic release function. If the driver puts the vehicle into gear and starts to drive off without pressing the button, the computer will automatically release the brake to prevent damage. In both designs, the motors are not designed to be used to stop the vehicle in the event the service brakes fail; instead, the system is used only for holding the vehicle in place when it is parked.

Servicing these systems, even installing rear brake pads often requires the use of a scan tool.

FIGURE 52–24 The button to set and release an electronic parking brake.

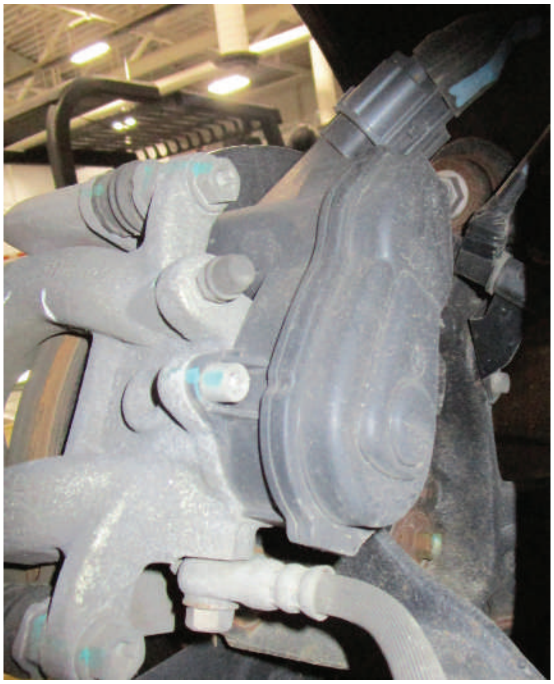


FIGURE 52–25 A rear caliper with an electric parking brake motor.

Disc Brake Diagnosis

Many problems experienced on vehicles with disc brakes are the same as those evident with drum brake systems. Some problems occur only with disc brakes. Before covering the typical complaints, it is important to remind you to get as much information as possible about the complaint from the customer. Then road test the vehicle to verify the complaint. A complete inspection of the rotor, caliper, and pads should be done any time you are working on the brakes.

What follows is a brief discussion of common complaints and their typical causes.

Warning Lights

Today's vehicles are normally equipped with more than one brake warning light on the instrument panel. Regardless of what warning light is lit, it is an indication of warning to the driver. You need to understand what would cause the different lights to illuminate in order to take care of the problem. Keep in mind, a vehicle may have one, two, or all of these lights **(Figure 52–26)**.

FIGURE 52–26 Typical brake warning lamps.

The red warning light indicates there is a problem in the regular brake system, such as low brake fluid levels or that the parking brake is on. A low fluid light may be present in addition to the red brake warning light. Whenever the fluid is low, you should suspect a leak or very worn brake pads.

The yellow or amber brake warning light is tied into the antilock brake system (ABS). This light turns on for two reasons: the ABS is performing a self-test or there is a fault in the ABS.

A blue or yellow warning light lets the driver know the wheels are slipping because of poor road conditions.

Pulsating Pedal

Customers will feel a vibration or pulsation in the brake pedal when the brakes are applied if a brake rotor is warped. A warped brake rotor is one that no longer has parallel friction surfaces or has side-to-side movement, called lateral runout. If this symptom exists, check the rotors for runout and parallelism, described later in this chapter. A warped rotor may need to be replaced and can be caused by improper tightening of the wheel lug nuts. In fact, uneven lug nut torque can cause a pulsating brake pedal. You should be aware that pedal pulsation is normal on vehicles with ABS when the ABS is working.

Spongy Pedal

With a spongy pedal, the customer will probably feel the need to pump the brake pedal to get good stopping ability. The complaint may also be described as a soft pedal. This problem is typically caused by air in the hydraulic system. Although bleeding the system may remove the air, you should always question how the air got in there. Check for leaks and for proper master cylinder operation.

A spongy brake pedal can be caused by excessive flexing in the pads or caliper and bracket. If the caliper is able to flex or move too much during braking, the pedal will travel further and be less firm.

Hard Pedal

The driver's complaint of a hard pedal normally indicates a problem with the power brake booster. However, it can also be caused by a restricted brake line or hose. Carefully check the lines and hoses for damage. Feel the brake hoses. If they seem to have lost their rigidity, the hose may have collapsed on the inside, and this is causing the restriction. Make sure the brake hoses have not been twisted. Incorrect caliper installation can twist and restrict the hose. A hard pedal can also be caused by frozen caliper or wheel cylinder pistons.

Dragging Brakes

Dragging brakes make the vehicle feel as if it has lost or is losing power as it drives down the road. The problem also wastes a lot of fuel and generates destructive amounts of heat that can cause serious brake damage and brake failure. While trying to find the cause of this problem, check the parking brake first. Make sure it is off. Check the rear wheels to make sure the parking brakes are released when they should be. If the problem is not in the parking brakes, check for restricted brake hoses keeping pressure applied to the calipers. Inspect the calipers and wheel cylinders for sticky or seized pistons.

Seized caliper pistons can be freed by using a pry bar or C-clamp to push the pistons back into the calipers, as shown in **Figure 52–27**. Position the pry bar to pull the caliper outward, forcing the piston backward into its bore. If the piston does not retract, loosen the bleeder valve and retry. If the caliper still does not move, the piston is likely seized. If the piston retracts, the brake hose is likely the cause of the problem.

Grabbing Brakes

When the brakes seem to be overly sensitive to pedal pressure, they are grabbing. Normally this problem is caused by contaminated brake linings. If the linings are covered or saturated with oil, find the source of the oil and repair it. Then replace the pads and refinish or replace the rotor.

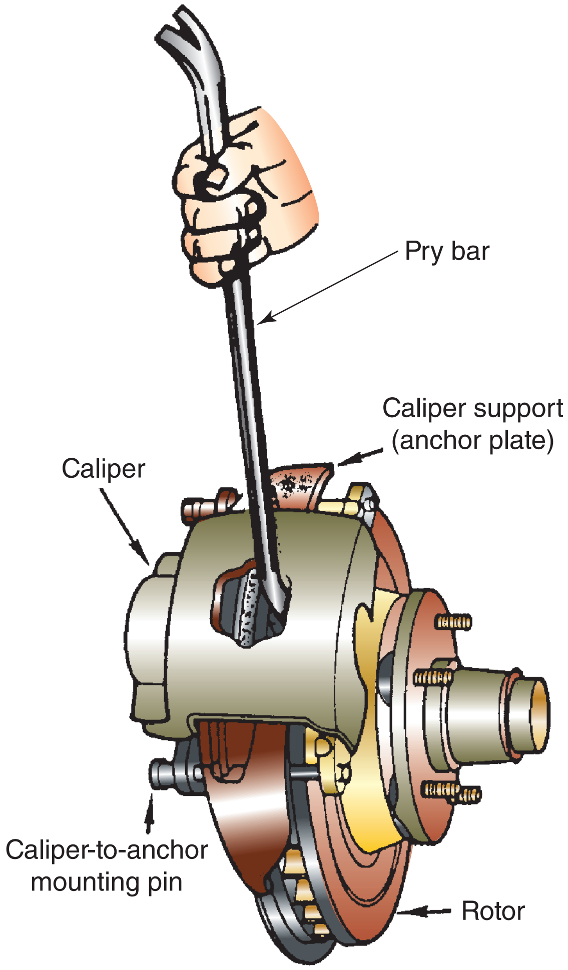


FIGURE 52–27 A large screwdriver or pry bar can be used to move a piston back into its bore in the caliper.

Noise

If the customer's complaint is noisy brakes, verify during the road test that the problem is in the brakes. If the noise is caused by the brakes, pay attention to the type of noise and let that lead you to the source of the problem. Remember, some brake pads have wear sensors that are designed to make a high-pitched squeal when the pads are worn. Other causes could be the rotor rubbing against the splash shield or that something has become wedged between the rotor and another part of the vehicle. Noise may also be caused by failure to install all of the hardware when replacing a caliper or brake pads.

Other sources of noise include the pads themselves. Depending on the lining materials, some pads are more prone to make noise. These noises can be like a light wire brush against metal sound, grinding, or high-pitched squeal depending on the pad.

Pulling

When a vehicle drifts or pulls to one side while cruising or when braking, the cause could be in the brake system or in the steering and suspension system. Check the inflation of the tires, the tires' tread condition, and verify that the tires on each axle are the same size. Check the operation of the brakes. If only one front wheel is actually doing the braking, the vehicle will seem to stumble or pivot on that one wheel. If no problems are found in the brake system, suspect an alignment or suspension problem such as worn control arm bushings.

Service Guidelines

The following general service guidelines apply to all disc brake systems and should always be followed:

- Be sure the vehicle is properly centered and secured on stands or a hoist.
- If the vehicle has antilock brakes, depressurize the system according to the procedures given in the service information.
- Before any service is performed, check the following:
  - Tires for excessive wear or improper inflation
  - Wheels for bent or warped rims
  - Wheel bearings for looseness or wear
  - Suspension components to see if they are worn or broken
  - Brake fluid level and condition
  - Master cylinder, brake lines or hoses, and each wheel for leaks
  - Parking brake operation
- Before you remove a brake hydraulic part, use a pedal depressor to slightly depress the brake pedal. This closes the master cylinder's ports and prevents fluid from draining. It also makes the bleeding process easier after the system is reassembled.
- Before beginning brake work, remove about two-thirds of the brake fluid from the master cylinder's reservoir. If this is not done, the fluid could overflow and spill when the pistons are forced back into the caliper bore. Many technicians open the caliper bleeder screw and run a hose to a container to catch the fluid that is expelled **(Figure 52–28)**. This prevents dirty brake fluid from being forced back into the ABS control unit.

FIGURE 52–28 When you open the caliper bleeder screw, attach a hose inserted into a container to catch the fluid that is expelled.

- If the bleeder screws are frozen tight with corrosion, it is sometimes possible to free them by tapping on the caliper body at the bleeder with a hammer. If the bleeder screws cannot be loosened, the entire caliper is probably in bad shape so it is best to replace the entire unit.
- During servicing, grease, oil, brake fluid, or any other foreign material must be kept off the brake linings, caliper, surfaces of the disc, and external surfaces of the hub. Handle the brake disc and caliper in such a way to avoid damage to the disc.
- When a hydraulic hose is disconnected, plug it to prevent foreign material from entering.
- Never permit the caliper assembly to hang with its weight on the brake hose. Support it on the suspension or hang it by away from the assembly **(Figure 52–29)**.
- When using compressed air to remove the caliper pistons, avoid high pressures. A safe pressure to use is 30 psi (207 kPa).
- Clean the hydraulic brake components in either denatured alcohol or clean brake fluid. Do not use mineral-based cleaning solvent such as gasoline, kerosene, carbon tetrachloride, acetone, or paint thinner to clean the caliper. It causes rubber parts to become soft and swollen in an extremely short time.
- With the recommended lubricant, lubricate all moving parts, such as the caliper housing or mounting bracket to ensure a free-moving action.
- Obtain a firm brake pedal after servicing the brakes and before moving the vehicle. Be sure to road test the vehicle.

FIGURE 52–29 Never permit the caliper assembly to hang with its weight on the brake hose. Support it on the suspension or hang it away from the assembly.

- Before installing the lug nuts to fasten the wheels, check the studs for signs of damage or stretching. If any defects are found, replace the stud.

GO TO Chapter 40 for information on replacing the wheel studs.

- Always torque all brake fasteners to specifications. Torque the lug nuts when installing a wheel onto the vehicle. Never use an impact gun to tighten the lug nuts. Warpage of the rotor could result if an impact gun is used.

Warning! Do not use a torch to heat a frozen bleeder screw. This can damage the seals inside the caliper and possibly cause the brake hose to rupture.

General Caliper Inspection and Servicing

Frequently, caliper service involves only the removal and installation of the brake pads. However, since the new pads are thicker than the worn-out set they replace, they locate the piston farther back in the bore where dirt and corrosion might cause the seals to leak. For this reason, it is often good practice to carefully inspect the calipers whenever installing new pads. Of course, it is also good practice to true-up or replace the rotors when replacing brake pads.

When bench testing or servicing a caliper assembly, use a vise that is equipped with protector jaws. Excessive vise pressure causes bore and piston distortion.

Caliper Removal

To be able to replace brake pads, service the rotor, or to replace the caliper, the caliper must be removed. The procedure for doing this varies according to caliper design. Always follow the specific procedures given in the service information. Use the following as an example of these procedures:

Brake Pad Removal

Sliding or floating calipers typically must be lifted off the rotor for pad replacement. However, some designs allow the caliper to be tilted out of the way, allowing the pads to be removed and replaced without removing the caliper **(Figure 52–33)**. Even if caliper removal is not necessary, it is a good practice to remove it to allow for closer inspection and cleaning of the components.

Fixed calipers might have pads that can be replaced by removing the retaining pins or clips instead of having to lift the entire caliper off. Brake pads may be held in position by retaining pins, guide pins, or a support key. Note the position of the shims, antirattle clips, keys, bushings, or pins during disassembly. A typical procedure for replacing brake pads is outlined in Photo Sequence 49.

If you are only replacing the pads, lift the caliper off the rotor and hang it up by a wire. Remove the pads. Remove the old sleeves and bushings and install new ones. Replace the rusty pins to ensure free movement.

Brake Pad Inspection

Disc brake pads should be checked periodically. Some calipers have inspection holes in the caliper body. If they do not, the pads can be inspected from the outer ends of the caliper.

PROCEDURE

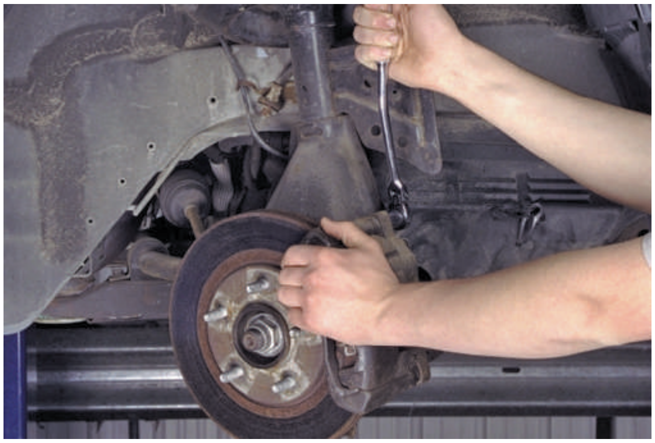
1. Remove about two-thirds of the brake fluid from the master cylinder.
2. Raise the vehicle and remove the wheel and tire assembly.
3. On a sliding or floating caliper, install a C-clamp with the solid end of the clamp on the caliper housing and the screw end on the metal portion of the outboard brake pad. Tighten the clamp until the piston bottoms in the caliper bore **(Figure 52–30)**, then remove the clamp. Bottoming the piston allows room for the brake pad to slide over the ridge of rust that accumulates on the edge of the rotor.
4. On threaded-type rear calipers, the piston must be rotated to depress it, which requires a special tool. This is discussed later in this chapter.
5. If only the brake pads are to be replaced, do not disconnect the brake hose. If rebuilding or replacing the caliper, disconnect the brake hose from the caliper and remove the copper gaskets or washer and cap the end of the brake hose. Remove the two mounting brackets to the steering knuckle bolts. Support the caliper when removing the second bolt to prevent the caliper from falling.
6. On a sliding caliper, remove the top bolts, retainer clip, and antirattle springs **(Figure 52–31)**. On a floating caliper, remove the two special pins that hold the caliper to the anchor plate **(Figure 52–32)**. On a fixed caliper, remove the bolts holding it to the steering knuckle. On all three types, get the caliper off by prying it straight up and lifting it clear of the rotor.

Removing and Replacing Brake Pads

P49-1 Front brake pad replacement begins with removing brake fluid from the master cylinder reservoir.

P49-2 Raise the car. Make sure it is safely positioned on the lift. Remove its wheel assemblies.

P49-3 Inspect the brake assembly. Look for signs of fluid leaks, broken or cracked lines, or a damaged brake rotor. If any problem is found, correct it before installing the new brake pads.



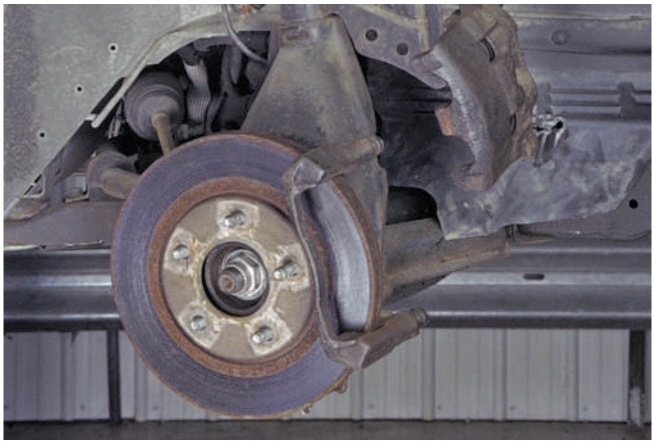
P49-4 Loosen the bolts and remove the pad locator pins.

P49-5 Lift and rotate the caliper assembly from the rotor.

P49-6 Remove the brake pads from the caliper assembly.

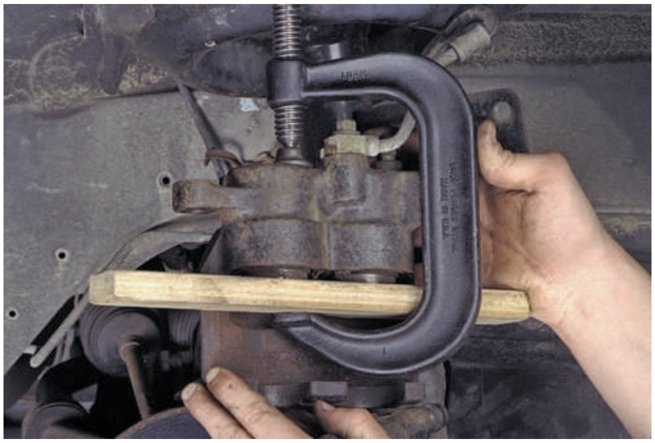
PHOTO SEQUENCE 49

Removing and Replacing Brake Pads *(continued)*

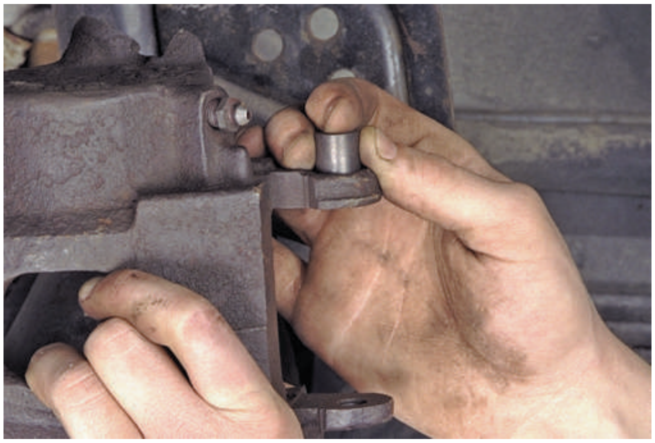


P49-7 Fasten a piece of wire to the car's frame and support the caliper with the wire.

P49-8 Check the condition of the locating pin insulators and sleeves.



P49-9 Place a piece of wood over the caliper's piston and install a C-clamp over the wood and caliper. Tighten the clamp to force the piston back into its bore.



P49-10 Remove the clamp and install new locating pin insulators and sleeves, if necessary.

P49-11 Install the new pads into the caliper.

P49-12 Set caliper with pads over the rotor and install the locating pins. After the assembly is in the proper position, torque the pins according to specifications.

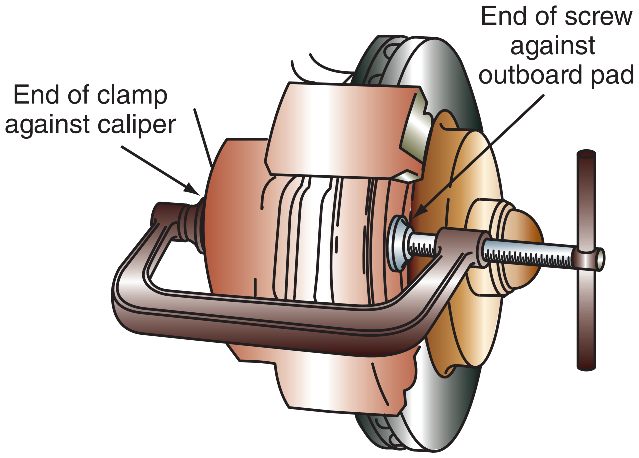


FIGURE 52–30 Use a C-clamp to retract the piston into the bore of the caliper.

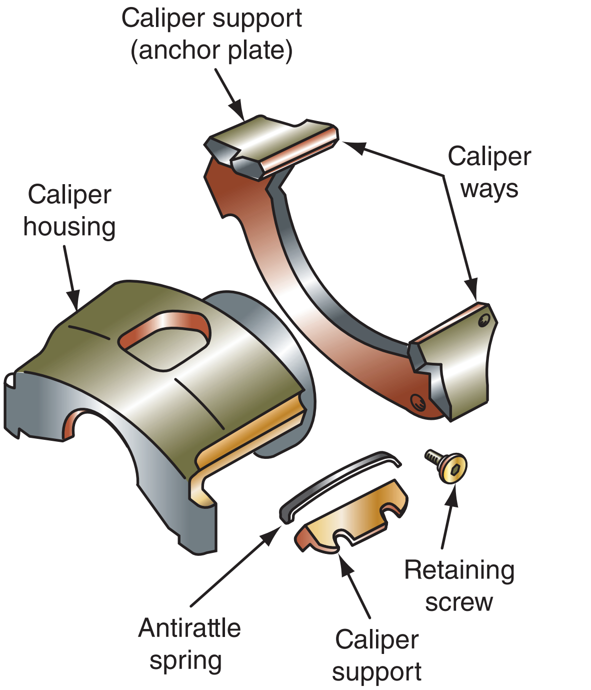


FIGURE 52–31 To remove a sliding caliper, remove the support retaining screws, antirattle springs and then the supports.

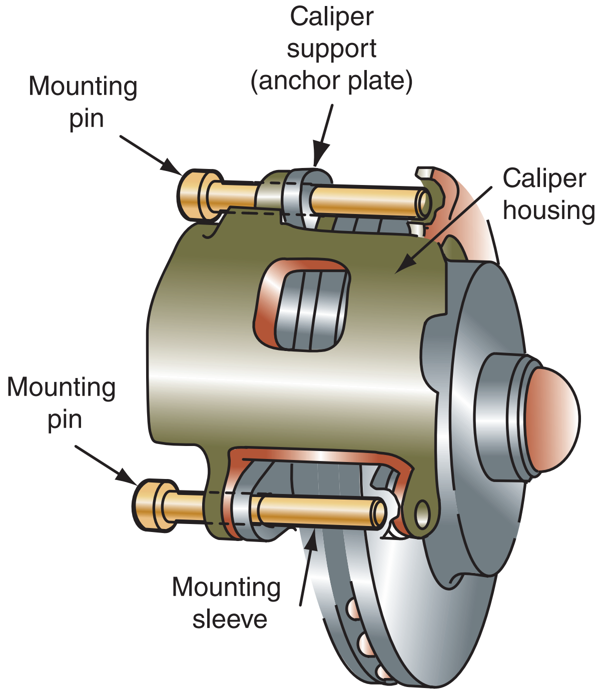


FIGURE 52–32 To remove a floating caliper, remove the pins holding it to the steering knuckle or bracket.

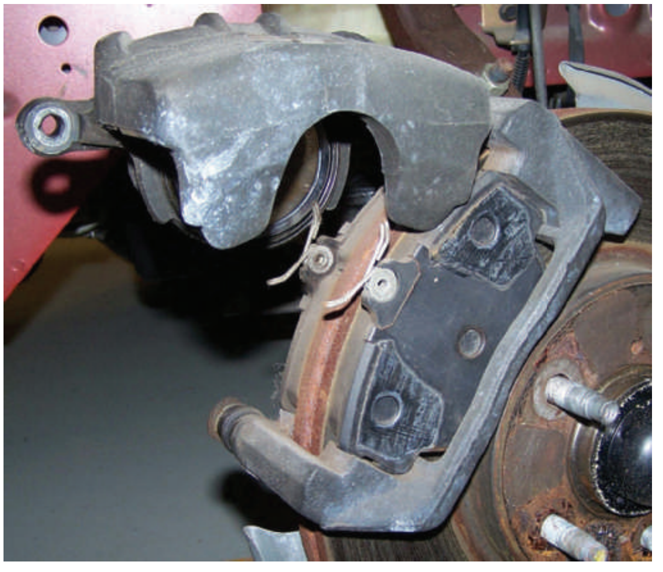


FIGURE 52–33 Some calipers can be rotated up on its upper mounting pin to replace the brake pads.

If you are not sure the pads are worn enough to warrant replacement, measure them at the thinnest part of the pad. Compare this measurement to the minimum brake pad lining thickness listed in the service information **(Figure 52–34)**, and replace the pads if needed. Typically, if the friction material remaining on the backing plate is less than ⅛-inch (3.175 mm), the pads should be replaced.

When a pad on one side of the rotor has worn more than the other side, there is uneven wear. Uneven pad wear often means the caliper is sticking and not giving equal pressure to both pads. On a sliding caliper, the problem could be caused by poor lubrication or deformation of the machined sliding areas on the caliper and/or anchor plate. Rust buildup on the pad guides is a common cause of the pads not sliding properly.

Caliper Disassembly

If the caliper must be rebuilt, it should be taken to the workbench for servicing. Drain any brake fluid

Year	Model		Brake Disc			Brake Drum Diameter			Minimum Lining Thickness	Brake Caliper	
			Original Thickness	Minimum Thickness	Maximum Runout	Original Inside Diameter	Maximum Wear Limit	Maximum Machine Diameter		Bracket Bolts (ft. lbs.)	Mounting Bolts (ft. lbs.)
2006	Accent	F	0.870	0.790	0.001				0.079	62-69	16-23
		R				8.000	①	①	0.039		
	Azera	F	1.100	1.040	0.002				0.079	58-72	16-23
		R	0.390	0.310	0.002				0.080	58-72	16-23
	Elantra	F	1.020	0.940	0.002				0.079	58-72	16-23
		R	0.390	0.330	0.002				0.079	36-43	16-23
	Elantra	F	1.020	0.940	0.002				0.079	58-72	16-23
		R				8.000	①	①	0.039		
	Sonata (2.4L)	F	1.024	0.961	0.002				0.120–0.160	59-74	18-22
		R	0.390	0.330	0.002				0.120	59-74	18-22
	Sonata (3.3L)	F	1.100	1.040	0.002				0.120–0.160	59-74	18-22
		R	0.390	0.330	0.002				0.120	59-74	18-22
	Tiburon	F	1.024	0.961	0.003				0.079	48-55	16-24
		R	0.400	0.330	0.002				0.080	48-55	16-24

① Drum roundness Service Limit: 0.00236 inch

FIGURE 52–34 Brake service specifications.

SHOP TALK

Most often, calipers are replaced rather than rebuilt. The old caliper is sent back to the manufacturer as a core. The following overview for rebuilding is intended only to give you an understanding of what may be done. Always refer to the appropriate service information when rebuilding a caliper.

from the caliper by way of bleeder screws. Remove the bleeder valve protector, if so equipped.

On a floating caliper, examine the mounting pins for rust that could limit travel. Most manufacturers recommend that these pins and their bushings be replaced each time the caliper is removed. This is a good idea because the pins are inexpensive and a good insurance against costly comebacks. On a fixed caliper, check the pistons for sticking and rebuild the caliper if this problem is found.

To disassemble the caliper, the piston and dust boot must first be removed. Place the caliper face down on a workbench **(Figure 52–35)**. Insert the used outer pad or a block of wood into the caliper. Place a folded shop towel on the face of the lining to cushion the piston. Apply low air pressure (NEVER MORE THAN 30 PSI) to the fluid inlet port of the caliper to force the piston from the caliper housing.

Caution! Wear safety glasses while disassembling the caliper to protect your eyes from spraying brake fluid.

Warning! Be careful to apply air pressure very gradually. Be sure there are enough shop rags to catch the piston when it comes out of the bore. Never place your fingers in front of the piston for any reason when applying compressed air. Personal injury could occur if the piston is popped out of the bore.

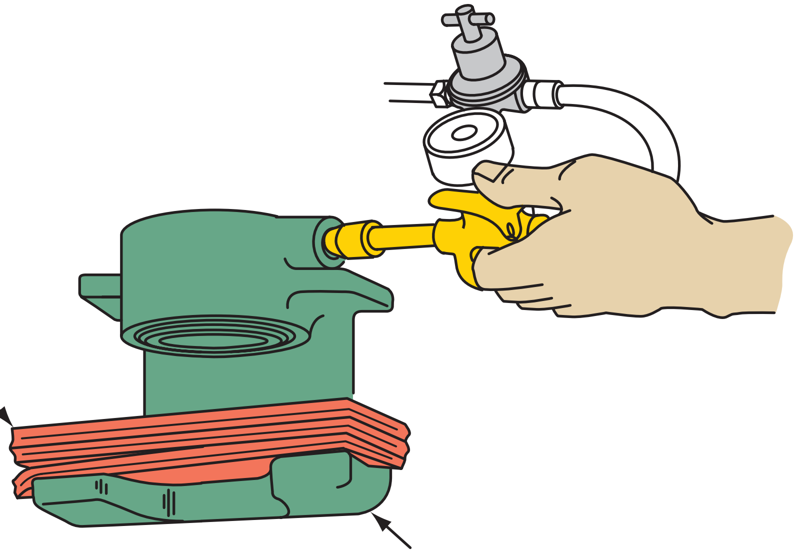


FIGURE 52-35 Using air to remove a piston.

If a piston is frozen, release air pressure and tap the piston into its bore with a soft-headed hammer or mallet. Reapply air pressure. Frozen phenolic (plastic) pistons can be broken into pieces with a chisel and hammer. Be careful not to damage the cylinder bore while doing this. Internal expanding pliers are sometimes used to remove pistons from caliper bores.

Inspect phenolic pistons for cracks, chips, or gouges. Replace the piston if any of these conditions are evident. If the plated surface of a steel piston is worn, pitted, scored, or corroded, it also should be replaced.

Dust boots vary in design depending on the type of piston and seal, but they all fit into one groove in the piston and another groove in the cylinder. One type comes out with the piston and peels off. Another type stays in place and the piston comes out through the boot, and then is removed from the cylinder **(Figure 52–36)**. In either case, peel the boot from its groove. In some cases it might be necessary to pry it out, but be careful not to scratch the cylinder bore while doing so. The old boot can be discarded since it must be replaced along with the seal.

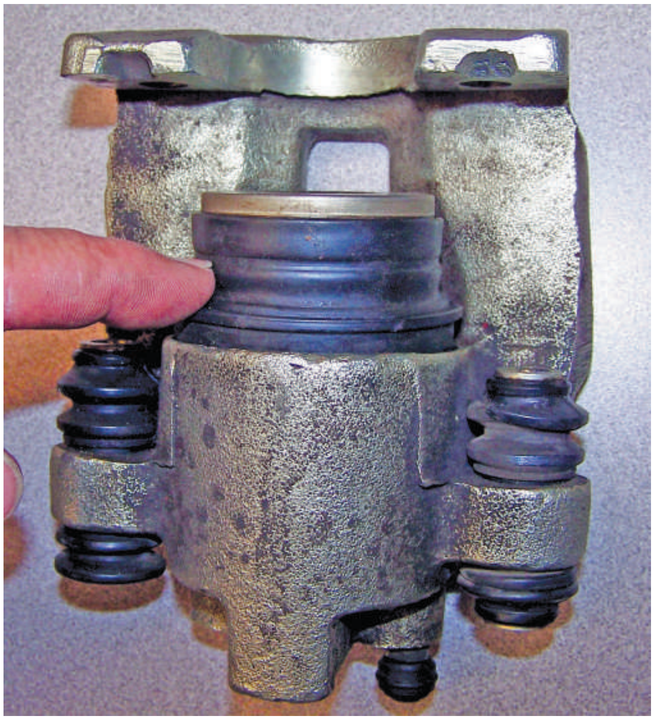


FIGURE 52-36 The dust boot is peeled away from the piston and caliper.

Remove the piston's and the cylinder's seal by prying them out with a wooden or plastic tool **(Figure 52–37)**. Do not use a screwdriver or other metal tool. Any of these could nick the metal in the caliper bore and cause a leak. Inspect the bore for pitting or scoring. A bore that shows light scratches or corrosion can usually be cleaned with crocus cloth. However, a bore that has deep scratches or scoring normally indicates that the caliper should be replaced. In some cases, the cylinder can be honed. Check the service information before doing this. If there is no mention of honing the bore, the manufacturer probably does not recommend it. Black stains on the bore walls are caused by piston seals. They do no harm.

When using a hone, be sure to install the hone baffle before honing the bore. The baffle protects the

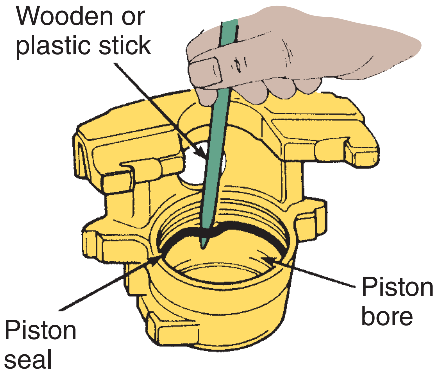


FIGURE 52-37 Removing a piston seal with a wooden or plastic stick.

hone stones from damage. Use extreme care in cleaning the caliper after honing. Remove all dust and grit by flushing the caliper with alcohol. Wipe it dry with a clean lint-free cloth and then clean the caliper a second time in the same manner.

Loaded Calipers

Rather than overhaul a caliper, many shops install loaded calipers. Loaded calipers are complete units with friction pads and mounting hardware included. Besides the convenience and the savings of installation time, preassembled calipers also reduce the odds of errors during caliper overhaul.

Mistakes that are frequently made when replacing calipers include forgetting to bend the pad locating tabs that prevent pad vibration and noise, leaving off antirattle clips and pad insulators, and reusing corroded caliper mounting hardware that can cause a floating caliper to bind up and wear the pads unevenly.

Caliper Reassembly

Before assembling the caliper, clean the phenolic piston (if so equipped) and all metal parts to be reused in clean denatured alcohol or brake fluid. Then, clean out and dry the grooves and passageways with compressed air. Make sure that the caliper bore and component parts are thoroughly clean.

To replace a typical piston seal, dust boot, and piston, first lubricate the new piston seal with clean brake fluid or assembly lubricant (usually supplied with the caliper rebuild kit). Make sure the seal is not distorted. Insert it into the groove in the cylinder bore so it does not become twisted or rolled. Install a new dust boot by setting the flange squarely in the outer groove of the caliper bore. Next, coat the piston with brake fluid or assembly lubricant and install it in the cylinder bore. Be sure to use a wood block or other flat stock when installing the piston back into the piston bore. Never apply a C-clamp directly to a phenolic piston, and be sure the pistons are not cocked. Spread the dust boot over the piston as it is installed. Seat the dust boot in the piston groove.

SHOP TALK

Avoid mismatching friction materials from side to side. When one caliper is bad, both calipers should be replaced using the same friction material.

With some types of boot/piston arrangements, the procedure for installation is slightly different from that already described. That is, the new dust boot is pulled over the end of the piston **(Figure 52–38)**. Lubricate the piston with brake fluid before installing it in the caliper. Then by hand, slip the piston carefully into the cylinder bore, pushing it straight, so the piston seal is not damaged during installation. Use an installation tool or wooden block to seat the new dust boot **(Figure 52–39)**.

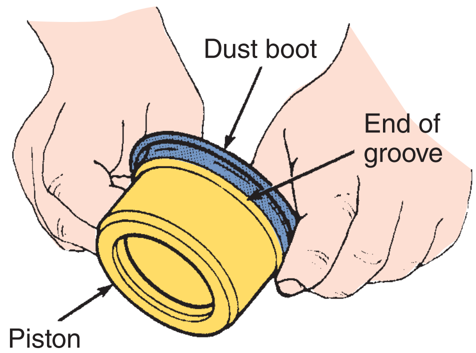


FIGURE 52-38 Some installation procedures require the dust boot to be pulled over the end of the piston.

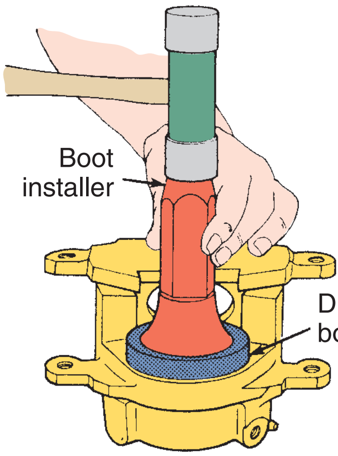


FIGURE 52-39 Seating a dust boot with a boot installer.

Caution! On fixed calipers, bridge bolts are used to hold the two caliper halves together. These are high-tensile bolts ordered only by specific part number. They require accurate torque tightness to prevent leakage. Do not attempt to use standard bolts in place of bridge bolts.

Another point to keep in mind is that some caliper designs have a slot cut in the face of the pistons that must align with an antisqueal shim. Make sure that the piston and shim align. It might be necessary to turn the piston to achieve proper alignment. To complete the caliper assembly job, install the bleeder screw.

Brake Pad Installation

It is a good practice to replace disc brake **hardware (Figure 52–40)** when replacing disc brake pads. The brake hardware typically consists of the guides, clips, and rubber parts used to hold and secure the pads and calipers. Replacement of the hardware ensures proper caliper movement and brake pad retention. It also aids in preventing brake noise and uneven brake pad wear.

One of the major causes of premature brake wear is rust. It causes improper slider and piston operation that leads to uneven pad wear. Tests have shown that when only the pads are replaced, the new pads can wear out in half the mileage they should if the calipers or slides are corroded. Therefore, if the calipers are corroded, replace them. You should always replace the pad guides. If the pads slide on a bracket that does not use replaceable guides, thoroughly clean the contact areas and lubricate as recommended in the service information.

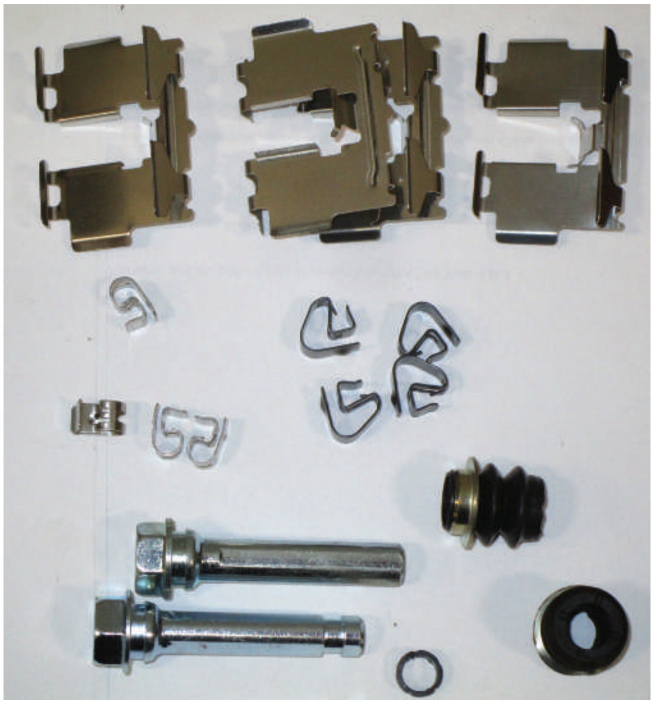


FIGURE 52–40 Replacement caliper hardware, pins, and bushings.

Fixed Caliper Brake Pads The designs of fixed caliper disc brakes vary slightly. Generally, to replace the pads, insert new pads and plates in the caliper with the metal plates against the end of the pistons. Be sure that the plates are properly seated in the caliper. Spread the pads apart and slide the caliper into position on the rotor. With some pads, mounting bolts are used to hold them in place. These bolts are usually tightened 80 to 90 ft.-lb (108 to 122 N-m). On some fixed disc brakes, the pads are held in place by retaining clips and/or retaining pins. Reinstall the antirattle spring/clips and other hardware (if so equipped).

Sliding Caliper Brake Pads Push the piston carefully back into the bore until it bottoms. Lightly lubricate the sliding surfaces of the caliper and the caliper anchor. Slide a new outer pad into the recess of the caliper. No free play between the brake pad flanges and caliper fingers should exist. If free play is found, remove the pad from the caliper and bend the flanges to eliminate all vertical free play. Install the pad.

Place the inner pad into position on the caliper anchor with the pad's flange on the machined sliding area. Fit the caliper over the rotor. Align the caliper to the anchor and slide it into position. Be careful not to pull the dust boot from its groove when the piston and boot slide over the inboard pad. Install the antirattle springs (if so equipped) on top of the retainer plate and tighten the retaining screws to specification.

On some calipers, especially those used as parking brakes, there is a notch or groove in the piston and a tab on the rear of the inner pad. During installation of the pad, the tab must fit into the groove in the piston **(Figure 52–41)**.

Floating Caliper Brake Pads For floating or pin caliper disc brakes, compress the flanges of the outer bushing in the caliper fingers and work them into position in the hole from the outer side of the caliper. Compress the flanges of the inner guide pin bushings and install them.

FIGURE 52–41 On some rear brake assemblies with rotating piston parking brake, there is a tab on the back of the pad that must line up with the groove in the piston.

Slide the new pad and lining assemblies into position in the adapter and caliper. Be sure that the metal portion of the pad is fully recessed in the caliper and adapter and that the proper pad is on the outer side of the caliper.

Hold the outer pad and carefully slide the caliper into position on the anchor and over the disc. Align the guide pin holes of the anchor with those of the inner and outer pads. Lightly lubricate and install the guide pins through the bushings, caliper, anchor, and inner and outer pads into the outer bushings in the caliper and antirattle spring.

When installing any type of caliper, follow these guidelines:

- Make sure the correct caliper is installed on the correct anchor plate. Also make sure that the bolts are tightened to specifications.
- Lubricate the rubber insulators (if so equipped) with silicone dielectric compound or as specified by the manufacturer.
- After the caliper assembly is in its mounting brackets, connect the brake hose to the caliper. If copper washers or gaskets are used, be sure to use new ones—the old ones might have taken a set and might not form a tight seal if reused. Torque the caliper hose bolt to specifications.
- Fill the master cylinder reservoirs and bleed the hydraulic system.
- Check for fluid leaks under maximum pedal pressure.
- Lower the vehicle and road test it.

Rear Disc Brake Calipers

Rear disc brake calipers with some type of parking brake mechanism have different inspection and overhaul procedures than front brake calipers.

Vehicles with electronic parking brake systems or hill-assist braking require special service. Before attempting to service the brakes on a vehicle equipped with either of these features, check the service information to understand how the system operates and how to properly service the brakes. Failure to follow the service procedures can cause serious damage to the brake calipers.

If the rear calipers have traditional parking brake cables and an electric motor that pulls the cables to apply the parking brake, retracting the piston is performed with tool to thread the piston back into the bore **(Figure 52–42)**.

To retract the piston on rear calipers with electrically driven pistons, a scan tool may be required to place the electronic parking brake into Service Mode. This retracts the parking brake motors and allows the piston to be retracted back into the caliper bore. Some vehicles can be placed into a special service mode without a scan tool to safely work on the rear brakes. An example of how to do this on Ford Fusion models is as follows:

1. Set the ignition to ON.
2. Press and hold the accelerator pedal and place the electric parking brake (EPB) switch to RELEASE. Continue to hold the pedal and EPB switch.
3. Set the ignition to OFF then to ON within 5 seconds. Continue to hold the accelerator pedal and EPB switch.
4. Set the ignition to OFF then release the accelerator pedal and EPB switch.

Once the brake service has been completed, take the vehicle out of Service Mode. To do this, complete the following steps:

1. Set the ignition to ON.
2. Press and hold the accelerator pedal and place the EPB switch to APPLY. Continue to hold the accelerator pedal and EPB switch.
3. Set the ignition to OFF then to ON within 5 seconds. Continue to hold the accelerator pedal and EPB switch.
4. Release the accelerator pedal and EPB switch.

This will fully apply the parking brake and set the air gap between the pads and rotors. Always refer to

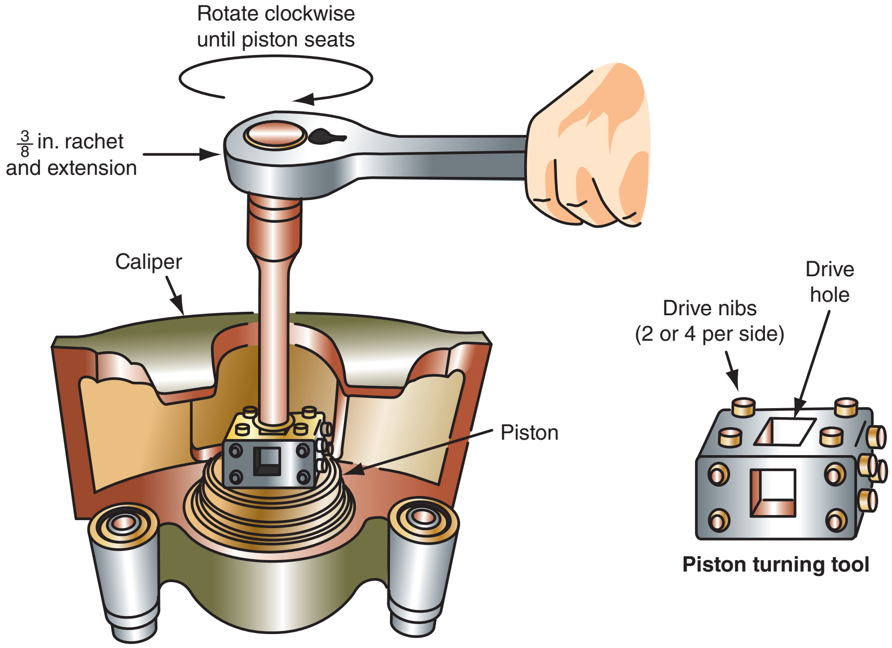


FIGURE 52–42 Using the tool to retract the caliper piston back into its bore.

the manufacturer's service information when working on any electronic parking brake or hill-assist system for specific procedures to prevent damage to the components.

Rotor Inspection

The rotors should be inspected whenever brake pads are replaced and when the wheels are removed for other services. They should be carefully checked to determine if they can be reused or machined or if they should be replaced. When inspecting the rotor, make sure you look at the sensor wheel for the wheel-speed sensor, if installed **(Figure 52–43)**.

If a good look at the surface is impossible because of dirt, clean the surfaces with a shop cloth dampened in brake cleaning solvent or alcohol. If the surface is rusted, remove it with medium-grit sandpaper or emery cloth and then clean it with brake cleaner or alcohol.

Most brake rotors have a discard thickness dimension cast into them. If you cannot find this dimension on the rotor or if it is hard to read, check the service information for thickness specifications. Rotor discard thickness dimensions are given in two or three decimal points (hundredths or thousandths of an inch or hundredths of a millimeter), such as 1.25 inches, 1.375 inches, 0.750 inch, or 24.75 mm. If you resurface the rotor, it must be 0.015 to 0.030 inch (0.38 to 0.76 mm) thicker than the discard dimension after machining to allow for wear. If a rotor is already below the minimal thickness spec, replace it. It is always wise to replace both rotors on the same axle.

FIGURE 52–43 Check the wheel-speed sensor's rotor when servicing a brake rotor.

SHOP TALK

Cross-drilled or slotted brake rotors may not be able to be machined. Therefore, if the rotor is scored or otherwise damaged, it should be replaced.

PROCEDURE

To overhaul a typical rear wheel caliper when there is no auxiliary drum parking brake follow these steps:

STEP 1 Unbolt the caliper.

STEP 2 Disconnect the parking brake cable from the lever on the caliper.

STEP 3 Disconnect the brake hose from the caliper, remove the caliper mounting bolts, and lift the caliper off its support.

STEP 4 Remove the brake pads and all pad shims and retainers.

STEP 5 Remove the piston from its bore; this procedure will vary based on the type of caliper being serviced. When the piston is free, remove the piston boot.

STEP 6 Carefully inspect the piston for wear. Replace the piston if it is worn or damaged in any way.

STEP 7 Remove the piston seal from the caliper using the tip of a screwdriver or a wooden or plastic scraper, being careful not to scratch the bore.

STEP 8 Service of the remaining internal components will vary depending on the caliper. Refer to the manufacturers' service information.

STEP 9 Coat the new piston seal and piston boot with silicone grease and install them in the caliper.

STEP 10 Coat the outside of the piston with brake fluid and install it on the adjusting bolt while rotating it clockwise with the locknut wrench.

STEP 11 Install the new brake pads, pad shims, retainers, and springs onto the caliper bracket.

STEP 12 Reinstall the caliper and the splash shield and tighten the caliper bolts to torque specifications.

STEP 13 Reconnect the brake hose to the caliper with new sealing washers and tighten the banjo bolt to specifications.

STEP 14 Then reconnect the parking brake cable to the arm on the caliper and reinstall the caliper shield.

STEP 15 Top off the master cylinder reservoir and bleed the brake system. Adjust the parking brake as needed. Before making adjustments, be sure the parking brake arm on the caliper touches the pin.

New rotors come with a protective coating on the friction surfaces. To remove this coating, use brake cleaner, or the solvent recommended by the manufacturer.

Thickness and Parallelism

To measure rotor thickness, place a brake disc micrometer about 1 inch in from the outer edge of the rotor and measure the thickness **(Figure 52–44).** Compare the measurement to specifications. Repeat the measurement at about eight points equidistant (45 degrees) around the surface of the rotor and compare each measurement to specifications. Take all measurements at the same distance from the edge so that rotor taper does not affect the measurements. If the rotor is thinner than the minimum thickness at any point or if thickness variations exceed limits, it must be replaced. Also check the service information for an allowable thickness variation. Many manufacturers hold

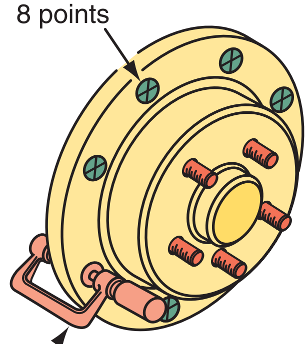


FIGURE 52–44 To check a rotor's thickness and parallelism, measure the rotor at eight different spots.

tolerances on thickness variations as close as 0.0005 inch (0.013 mm).

Rotor **parallelism** refers to thickness variations in the rotor from one measurement point to another around the rotor surface. If the rotor is out of parallel, it can cause excessive pedal travel; front end vibration; pedal pulsation; chatter; and, on occasion, grabbing of the brakes. The rotor then must be resurfaced or replaced.

Lateral Runout

Excessive lateral runout is the wobbling of a rotor from side to side when it rotates **(Figure 52–45)**. This wobble knocks the pads farther back than normal, causing the pedal to pulse and vibrate during braking. Over time, runout can cause excessive parallelism. This occurs as the rotor rubs against the pads as it rotates, wearing away at the rotor and causing it to become thinner in certain sections. Chatter can also result. Lateral runout also causes excessive pedal travel because the pistons have farther to travel to reach the rotor. If runout exceeds specifications, the rotor must be turned or replaced.

For the best braking performance, lateral runout should be less than 0.003 inch (0.08 mm) for most vehicles. Some manufacturers, however, specify runout limits as small as 0.002 inch (0.05 mm) or as great as 0.008 inch (0.20 mm).

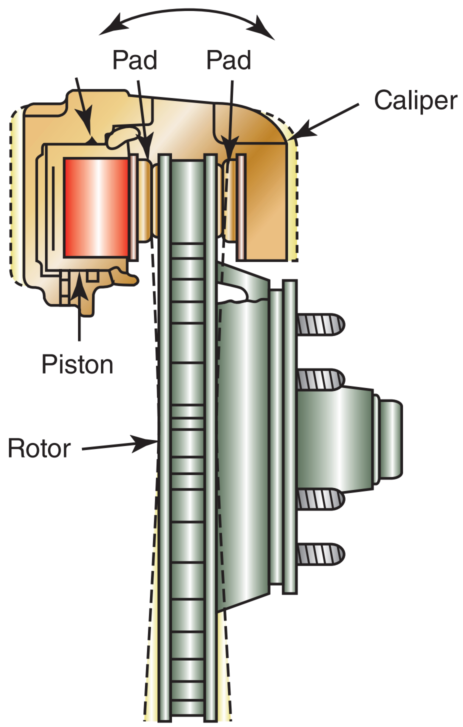


FIGURE 52–45 Excessive lateral runout causes the rotor to wobble from side to side when it rotates.

Runout measurements are taken only on the outboard surface of the rotor, using a dial indicator and suitable mounting adapters **(Figure 52–46)**. If the rotor is mounted on adjustable wheel bearings, readjust the bearings to remove bearing end play. Do not overtighten the bearings. On rotors bolted solidly to the axles of FWD vehicles, bearing end play is not a factor in rotor runout measurement. If there is excessive bearing end play, the bearing assembly must be replaced. Bearing end play is best checked with a dial indicator.

Clamp the dial indicator support to the steering knuckle or other suspension part that will hold it securely as you turn the rotor. Position the dial indicator so that its tip contacts the rotor at 90 degrees. Place the indicator tip on the friction surface about 1 inch in from the outer edge of the rotor. Do not place the dial indicator on a dirty, rusted, grooved, or scored area. Rotate the rotor until the lowest reading appears on the dial indicator; then set the indicator to zero. Turn the rotor through one complete revolution and compare the lowest to the highest reading. This is the maximum runout of the rotor.

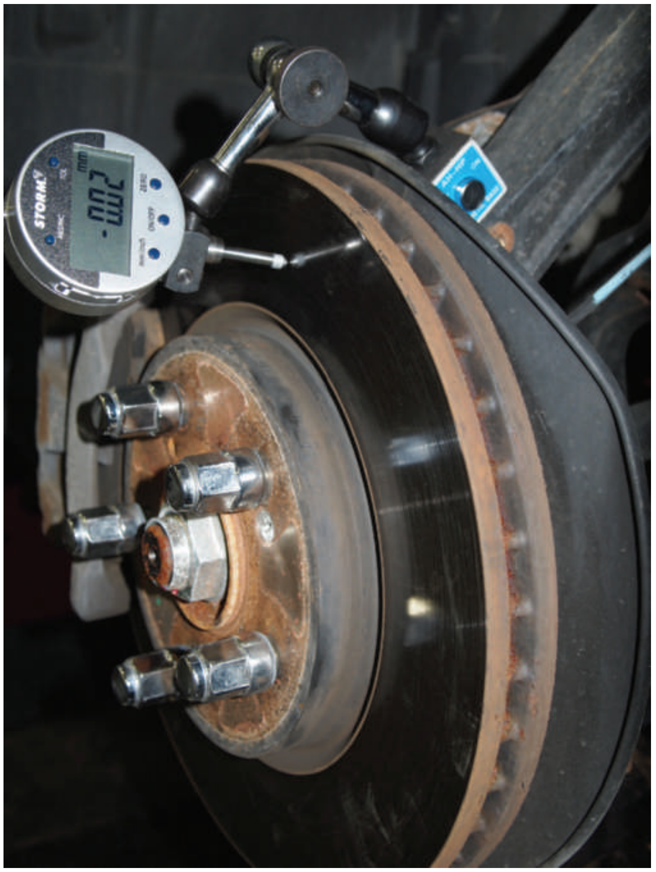


FIGURE 52–46 Runout measurements are taken on the outboard surface of the rotor, using a dial indicator and suitable mounting adapters.

Additional Checks

The following are some of the typical rotor conditions that warrant disc replacement or machining.

Grooves and Scoring Inspect both rotor surfaces for scoring and grooving. Scoring or small grooves up to 0.010 inch (0.25 mm) deep are usually acceptable for proper braking performance. Scoring can be caused by linings that are worn through to the rivets or backing plate or by friction material that is harsh or unkind to the mating surface. Rust, road dirt, and other contamination could also cause rotor scoring. Any rotor having score marks more than 0.15 inch should be refinished or replaced **(Figure 52–47)**.

If the rotor is deeply grooved, it must be thick enough to allow the grooves to be completely removed without machining the rotor to less than its minimum thickness. Measure rotor thickness at the bottom of the deepest groove. If rotor thickness at the bottom of the deepest grooves is at or near the discard dimension, replace the rotor.

Cracks Check the rotor thoroughly for cracks or broken edges. Replace any rotor that is cracked or chipped, but do not mistake small surface checks in the rotor for structural cracks. Surface checks will normally disappear when a rotor is resurfaced. Structural cracks, however, will be more visible when surrounded by a freshly turned rotor surface.

SHOP TALK

Some older rotors, particularly on GM vehicles, have a single deep groove manufactured into each surface. This groove helps to keep the pads from moving outward and also reduces operating noise.

FIGURE 52-47 Any rotor having score marks more than 0.15 inch deep should be refinished or replaced.

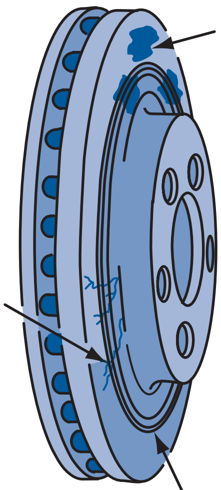


FIGURE 52-48 Some of the typical conditions that should be looked for on a brake rotor.

Bluing or Heat Checking Inspect the rotor surfaces for heat checking and hard spots **(Figure 52–48)**. Heat checking appears as many small interlaced cracks on the surface. Heat checking lowers the heat dissipation ability and friction coefficient of the rotor surface. Heat checking does not disappear with resurfacing. Therefore, a rotor with heat checks should be replaced.

Hard spots appear as round, shiny, bluish areas on the friction surface. Hard spots on the surface of a rotor usually results from a change in the metallurgy caused by brake heat. Pulling, rapid wear, hard pedal, and noise occur. These spots can be removed by machining. However, only the raised surfaces are removed, and they could reappear when heat is again encountered. The rotor should be replaced.

Rust If the vehicle has not been driven for a period of time, the discs will rust in the area not covered by the lining and cause noise and chatter. This also can result in excessive wear and scoring of the discs and pads. Wear ridges on the discs can cause temporary improper pad contact if the ridges are not removed before the installation of new pads. Rusted rotors should be cleaned before any measurements are taken.

Inspect the fins of vented rotors for cracks and rust. Rust near the fins can cause the rotor to expand and lead to rotor thickness variations and excessive runout

FIGURE 52-49 A severely rusted brake rotor, obviously this should be replaced.

problems. Machining the rotor may remove runout and thickness variations, but rotor expansion due to rust may cause these problems to reappear soon. Rusted rotors should be replaced **(Figure 52–49)**.

Rotor Service

If the thickness of the rotor is below or close to the minimal allowable thickness or is badly distorted, it must be replaced. If the thickness is greater than the minimum specifications, it can be trued and smoothened with a brake lathe. Rotors that have minor imperfections or are slightly unparallel can be turned true and smooth with a brake lathe.

Removing a Rotor

To remove a rotor, raise the vehicle and remove the wheel. Then remove the caliper from the rotor and suspend it with wire from the suspension of the vehicle. Before you remove a rotor, mark it "L" or "R" for left or right so that it gets reinstalled on the same side of the vehicle from which it was removed. If the rotors have not been off before, make an index mark on the rotor to a wheel stud or hub so that the rotor can be reinstalled in the same position on the hub.

If the rotor is a floating rotor, remove it from the hub by pulling it off the hub studs. If you cannot pull the rotor off by hand, apply penetrating oil on the front and rear rotor-to-hub mating surfaces. Strike the rotor between the studs using a ball-peen hammer. If this does not free the rotor, attach a three-jaw puller to the rotor and pull it off.

Whenever you separate a floating rotor from the hub flange, clean any rust or dirt from the mating surfaces of the hub and rotor. Neglecting to clean rust and dirt from the rotor and hub mounting surfaces before installing the rotor will result in increased rotor lateral runout, leading to premature brake pulsation and other problems.

If the rotor and hub are a one-piece assembly, remove the outer wheel bearing and lift the rotor and hub off the spindle. Some rotors, such as that shown in **Figure 52–50**, are bolted to the hub and bearing assembly and can only be removed by removing the hub unit. Once removed, the rotor is unbolted from the hub **(Figure 52–51)**.

FIGURE 52-50 Some rotors are bolted to the hub and bearing assembly and can only be removed by removing the hub unit.

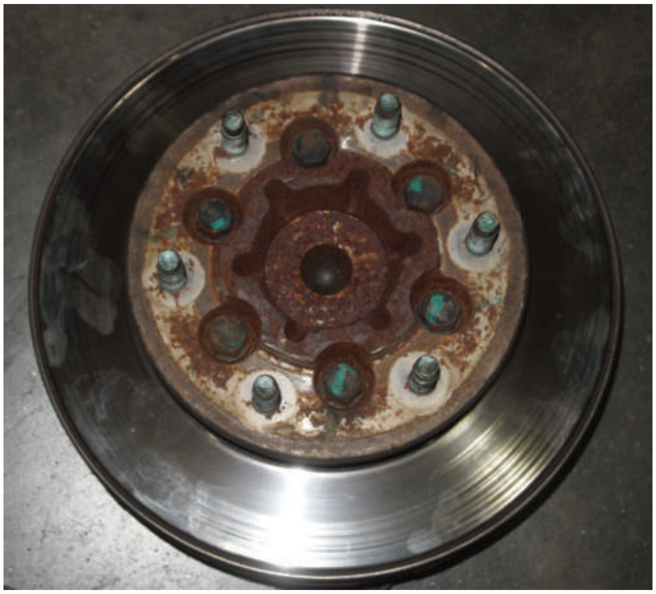


FIGURE 52-51 Once the hub unit and rotor are removed, the rotor can be unbolted from the hub.

SHOP TALK

New rotors have the correct surface finish, which may be disturbed by them turning on a lathe. Clean any oil film off a new rotor with brake cleaning solvent or alcohol and let the rotor air dry before installing it on the vehicle.

Caution! Do not attempt to use a brake lathe without proper training. You can be seriously injured if the lathe is not properly set up or is operated improperly.

FIGURE 52–52 A typical bench lathe.

Brake Lathes

A brake lathe cuts metal away to achieve the desired surface finish. There are basically two types of brake disc lathes used by the industry. The first one, a bench brake lathe, has the capability of resurfacing brake drums and brake discs after they have been removed from the vehicle. The lathe rotates the disc as cutting tools work their way across the braking surface of the disc. The second type is an on-vehicle brake lathe. This type of brake lathe is a time saver because the rotor does not need to be removed from the vehicle. Special fixtures are used to straddle the rotor so the cutting tools can precisely cut both sides of the rotor. An electric motor is used to rotate the disc and hub assembly during cutting. On-car lathes have become the standard for refinishing front brake rotors due to their ability to compensate for any runout in the front hub assembly.

Whenever you refinish a rotor, remove the least amount of metal possible to achieve the proper finish. This helps to ensure the longest service life from the rotor. Never turn the rotor on one side of the vehicle without turning the rotor on the other side. Left- and right-side rotors should be the same thickness, generally within 0.002 inch to 0.003 inch. Similarly, equal amounts of metal should be cut off both surfaces of a rotor.

Bench Lathes On a bench, off-vehicle lathe, the rotor is mounted on the lathe's arbor and turned at a controlled speed while a cutting bit passes across the rotor surface to remove a few thousandths of an inch of metal **(Figure 52–52)**. The lathe turns the rotor perpendicularly to the cutting bits so that the entire rotor surface is refinished. Most rotor cutting assemblies have two cutting bits. The rotor mounts between the bits and is pinched between them. As the cut is made, the same amount of surface material should be cut from both sides of the rotor.

When using a bench lathe, clean the rotor's hub and mounting surfaces before mounting the rotor on the lathe. This helps reduce any runout caused by improper setup. Select the correct mounting adaptors and secure the rotor on the lathe. Start the lathe and check for rotor runout; remount the rotor as needed. Install the vibration dampers and position the cutting head over the rotor and perform a scratch cut to check rotor setup. Make a slight cut on both sides of the rotor then remount it 180 degrees from the starting point and make another slight cut. The two cuts should be parallel, indicating the rotor is mounted correctly. If the cuts are 180 degrees apart, there is runout in the mounting setup that needs to be corrected before machining.

Once properly setup, perform a fast cut to clean and true the surfaces. Inspect the rotor once the cut is complete. If the surface is clean and true, perform a slow cut. The slow cut machines the rotor to the correct surface roughness. Once complete, apply a nondirectional finish **(Figure 52–53)** to break up the radial lines caused by machining. Wash the rotor in warm soapy water, dry completely, and measure the final thickness.

On-Vehicle Brake Lathes The advantage of an on-vehicle lathe **(Figure 52–54)** is that the rotor does not need to be removed. On-vehicle lathes also are ideal for rotors with excessive runout problems.

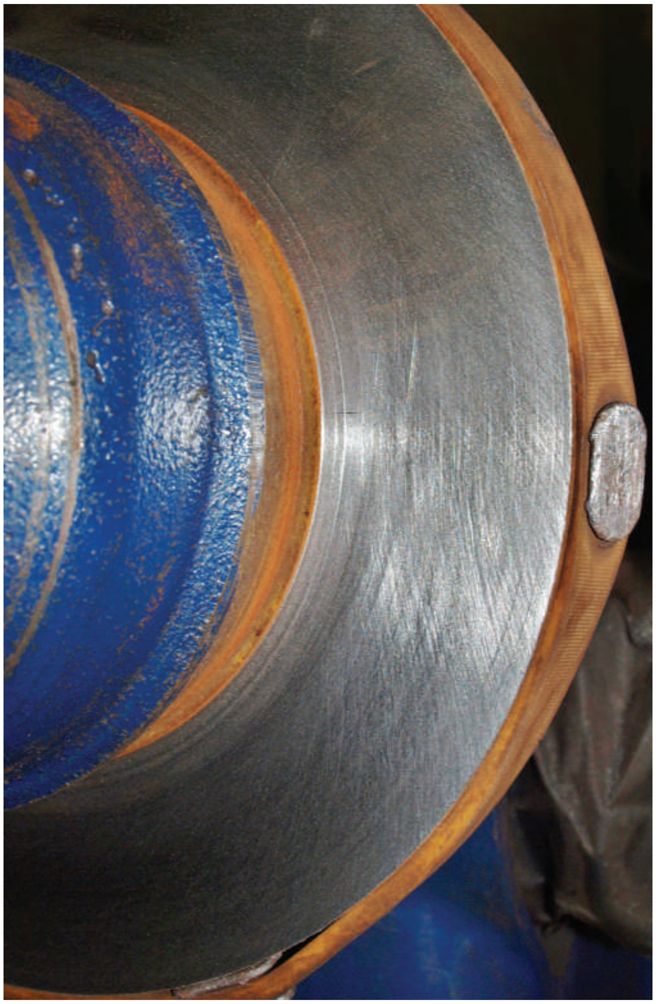


FIGURE 52-53 A non-directional finish.

FIGURE 52-54 An on-vehicle brake lathe.

To install the lathe, remove the wheel and then remove the caliper. If any end play is present in an adjustable tapered roller bearing, carefully tighten the adjusting nut by hand just enough to remove the end play before installing the lathe. After turning the rotor, readjust the bearing.

Select the correct mounting adaptor to fit the lug pattern and install it onto the hub. Do not overtighten the mounting nuts. Position the lathe to the adaptor and secure it in place. Make sure the lathe and adaptor are properly aligned to prevent damage to either. Next, move the cutting head to fit over the rotor and adjust it into place.

Before machining begins, compensate the lathe for runout. On some models this is a manual adjustment. Most common lathes have automatic compensation. Follow the manufacturer's operating instructions for runout compensation. Improper setup and compensation can increase runout in the rotor, causing you to lose time and money.

Once the lathe is setup and compensated, proceed to machine the rotor. Remove only as much material as is needed to true the rotor. Some on-car lathes require only one pass over the rotor so separate fast and slow cuts are not needed. After machining, remeasure rotor thickness and check it against specifications. Dismount the lathe and mark the rotor's location on the hub. Remove and clean the rotor with warm soapy water and dry completely. Reinstall the rotor and brakes, torquing all fasteners to specifications.

Installing a Rotor

If the rotor is a floating rotor, make sure all mounting surfaces are clean. Apply a small amount of antiseize compound to the pilot diameter of the disc brake rotor before installing the rotor on the hub. Reinstall the caliper. If the rotor is a fixed rotor, one-piece assembly with the hub that contains the wheel bearings, clean and repack the bearings and install the rotor.

Install the wheel and tire on the rotor and torque the wheel nuts to specifications, following the recommended tightening pattern. Failure to tighten in the correct pattern may result in increased lateral runout, brake roughness, or pulsation as well as damage to the wheels.

Final Checks and Pad Break-In

After lowering the vehicle to the ground, pump the brake pedal several times before moving the vehicle. This positions the brake linings against the rotor and ensures that the brake pedal pumps up and is firm under pressure. Typically, four-wheel disc brake equipped vehicles have a firm, high, brake pedal with minimal travel before the brakes apply. Vehicles with disc/drum systems may have

slightly more pedal travel depending on the rear shoe adjustment.

Verify that the brake fluid level is correct in the master cylinder, and then test-drive the vehicle. During the test-drive, note the feel of the brake pedal and listen for any noise when braking.

Follow the brake pad manufacturer's recommendations for breaking-in or bedding-in the pads before returning the vehicle to the customer. The break-in process is important so the pads deposit a layer of material onto the rotors. The following are examples of pad break-in procedures:

- Make approximately 20 normal stops from 30 mph.
- Make approximately 20 slow-downs from 50 to 20 mph.
- Make five moderate stops from 40 to 10 mph without letting the breaks cool.

Caution! When working on vehicles with carbon ceramic brake rotors, use guide pins to properly locate the wheels during installation **(Figure 52–55)**. Carbon ceramic rotors are brittle and can be chipped when reinstalling the wheel. With these rotors costing up to $4,000 a piece, use caution and care when working around them.

FIGURE 52–55 Wheel locating pins help prevent damage to ceramic rotors.

The break-in procedure will vary with pad manufacturer and type of pad. It is important to follow the pad manufacturer's instructions to achieve the correct contact between the pads and the rotors. Proper break-in will reduce noise and vibration and prolong the life of the pads.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2010	**Make:** Ford	**Model:** Fusion	**Mileage:** 61,052	**RO:** 19145
Concern:	Customer states brakes smell and feel like they are dragging at the rear.			
History:	Customer installed new brake pads on rear of vehicle recently.			
After driving the vehicle and confirming the complaint, the technician performs a complete brake system inspection. When checking the rear brakes she finds the left rear brake assembly is discolored and is dragging. Thinking the parking brake is not releasing, she checks the parking brake operation but it is working correctly. Since the brake pads had recently been replaced, she unbolts the caliper to inspect the pads.				
Cause:	Found caliper piston not retracted properly. Locating notch on piston was not aligned with locating tab on the pad.			
Correction:	Retracted piston so alignment between the pad and piston was correct. Brake no longer drags when unapplied.			

KEY TERMS

Fixed caliper
Fixed rotor
Floating caliper
Floating rotor
Hardware
Parallelism
Sliding caliper

SUMMARY

- Disc brakes offer four major advantages over drum brakes: resistance to heat fade, resistance to water fade, increased straight-line stopping ability, and automatic adjustment.
- The typical rotor is attached to and rotates with the wheel hub assembly. Heavier vehicles generally use ventilated rotors. Splash shields protect the rotors and pads from road moisture and dirt.
- The caliper assembly includes cylinder bores and pistons, dust boots, and piston hydraulic seals.
- Brake pads are placed in each side of the caliper and together straddle the rotor. Some brake pads have wear sensors.
- Fixed caliper disc brakes do not move when the brakes are applied. Floating caliper disc brakes slide back and forth on pins or bolts. Sliding calipers slide on surfaces that have been machined smooth for this purpose.
- In a rear disc brake system the inside of each rear wheel hub and rotor assembly is used as the parking brake drum.
- Rear disc parking brakes have a mechanism that forces the pads against the rotor mechanically.
- The general procedures involved in a complete caliper overhaul include tasks such as: caliper removal, brake pad removal, caliper disassembly, caliper assembly, brake pad installation, and caliper installation.
- The first step in proper caliper service is to remove the caliper assembly from the vehicle.
- Disc brake pads should be checked periodically or whenever the wheels are removed. They should be replaced if they fail to exceed minimum lining thickness as listed in the service information.
- To disassemble the caliper, the piston and dust boot must first be removed. Compressed air is used to pop the piston out of the bore.
- Before assembling the caliper, all metal parts and the phenolic piston are cleaned in denatured alcohol or brake fluid. The grooves and passageways of the caliper are cleaned out and dried with compressed air.
- It is a good practice to replace disc brake hardware when replacing disc brake pads.
- Disc brake rotor conditions that must be corrected include lateral runout, lack of parallelism, scoring, blueing or heat checking, and rusty rotors.

REVIEW QUESTIONS

Short Answer

1. Name the three major assemblies that make up a disc brake.
2. Name the three types of calipers used on disc brakes.
3. Describe the differences between floating and fixed rotors.
4. What is the difference between floating and sliding calipers?
5. What is rotor parallelism and how is it checked?
6. Why is brake fluid removed from the master cylinder prior to working on disc brakes?
7. Describe the procedure for using compressed air to remove a piston from a brake caliper.
8. List three conditions that dictate that a rotor should be refinished.
9. Give two main advantages of an on-vehicle lathe versus a bench lathe.
10. What should be done to remove rust, corrosion, pitting, and scratches from the piston bore?
11. What type of brake uses the inside of each rear wheel hub and rotor assembly as a parking brake drum?

True or False

1. *True or False?* Disc brakes are not as likely to fade during heavy braking as are drum brakes.
2. *True or False?* All calipers have at least one piston that pushes the brake pad against the rotor.

Multiple Choice

1. Which term refers to variations in thickness of the rotor?
   a. Torque
   b. Lateral runout
   c. Parallelism
   d. Pedal pulsation
2. Which of the following is not likely to cause a pulsating brake pedal?
   a. Loose wheel bearings
   b. Worn brake pad linings
   c. Excessive lateral runout
   d. Nonparallel rotors

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that a hard brake pedal on a vehicle with disc brakes can be caused by air in the hydraulic system. Technician B says that a pulsating pedal on a vehicle with disc brakes can be caused by a restricted brake line. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. When replacing brake pads on a vehicle: Technician A works on one wheel before beginning work on another. Technician B uses a minimum of 52 psi of air pressure to force the piston from the caliper housing. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. When examining disc brakes: Technician A visually inspects the rotor and says that the rotor can be reused if it is not damaged or scored. Technician B says that it is normal for the inboard pad to be slightly more worn than the outside pad. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. When reassembling an overhauled brake caliper: Technician A cleans brake components in denatured alcohol. Technician B cleans brake components in clean brake fluid. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. While discussing how to remove the piston from a brake caliper: Technician A says that the dust boot should be removed, then a large dull screwdriver should be inserted into the piston groove to pry the piston out. Technician B says that air pressure should be injected into the bleeder screw's bore to force the piston out of the caliper. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. The functions of a splash shield are being discussed: Technician A says that disc brakes will function normally without a splash shield in place. Technician B says that a splash shield helps to direct cooling air over the rotor. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. Technician A says that the piston seal retracts the caliper piston when hydraulic pressure is released. Technician B says that a return spring is used to retract a caliper piston. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. Technician A says that fixed calipers use a piston on each side of the rotor to apply the brakes. Technician B says that sliding calipers typically use only one piston or pistons on one side of the rotor. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

9. While installing new brake pads: Technician A coats the caliper bushings with silicone grease before installing the mounting bolts and sleeves of floating calipers. Technician B lubricates the caliper ways on the caliper support and the mating parts of the sliding caliper housings with the recommended lubricant. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

10. Loaded calipers are being discussed: Technician A says that loaded calipers are replacement calipers that come with pads and hardware already installed. Technician B says that loaded calipers should always be installed in axle sets. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

ANTILOCK BRAKE, TRACTION CONTROL, AND STABILITY CONTROL SYSTEMS

CHAPTER 53

OBJECTIVES

- Explain how antilock brake systems work to bring a vehicle to a controlled stop.
- Describe the differences between an integrated and a nonintegrated antilock brake system.
- Describe the operation of the major components of an antilock brake system.
- Describe the operation of the major components of automatic traction and stability control systems.
- Explain the best procedure for finding ABS faults.
- List the precautions that should be followed whenever working on an antilock brake system.

Antilock brake systems (ABS) and traction and electronic stability control (ESC) systems, once expensive options, are now standard equipment on all passenger cars and light-duty vehicles. These systems add yet another group of electronically controlled systems to the increasingly complex modern vehicle. For example, under the umbrella of ABS and ESC are often other systems such as electronic brake force distribution, traction control, hill start assist, supplemental braking, adaptive cruise control, and collision avoidance.

Antilock Brakes

Modern antilock brake systems **(Figure 53–1)** can be thought of as electronic/hydraulic pumping of the brakes for straight-line stopping under panic conditions. Good drivers have always pumped the brake pedal during panic stops to avoid wheel lockup and the loss of steering control. Antilock brake systems simply get the pumping job done much faster and in

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE		REPAIR ORDER		
Year: 2000	**Make:** Cadillac	**Model:** SLS	**Mileage:** 92,585	**RO:** 19189
Concern:	Customer states the ABS light is staying on all the time. Brakes feel normal.			
History:	Car had front struts installed elsewhere recently. Was told problem was unrelated.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

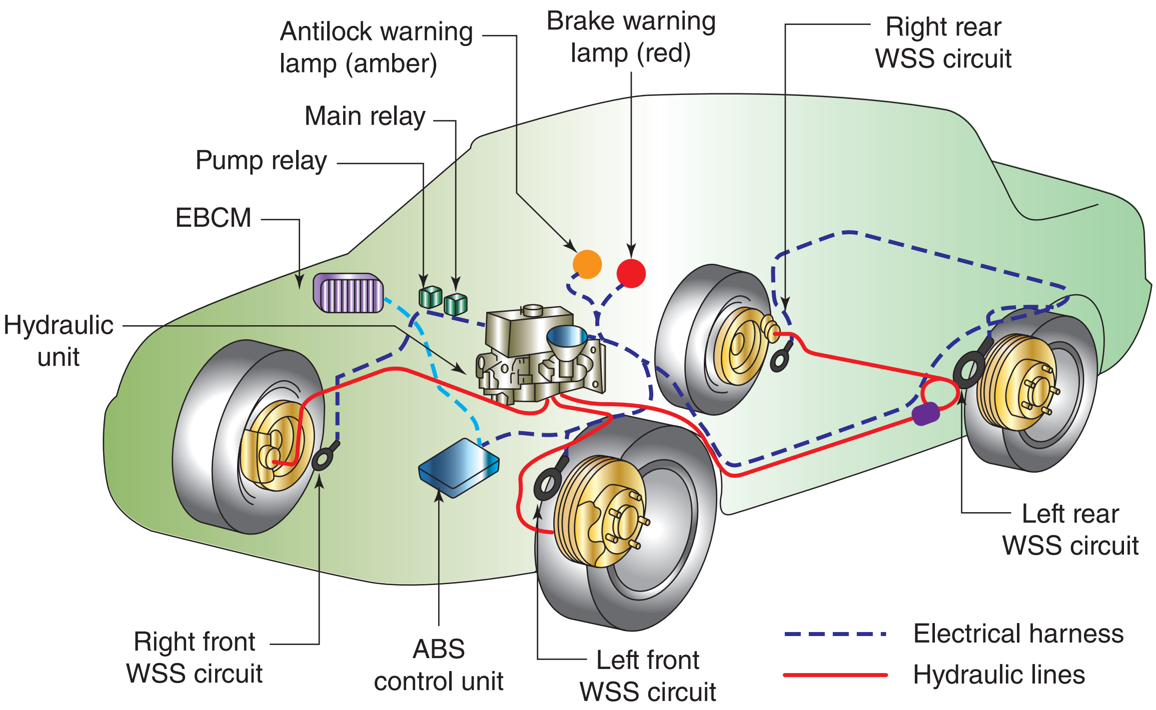


FIGURE 53–1 A common four-wheel antilock brake system.

a much more precise manner than the fastest human foot. Keep in mind that a tire on the verge of slipping produces more friction with respect to the road than one that is locked and skidding. Once a tire loses its grip, friction is reduced, control is compromised, and the vehicle takes longer to stop.

Pressure Modulation

When the driver quickly and firmly applies the brakes and holds the pedal down, the brakes of a vehicle not equipped with ABS will almost immediately lock the wheels. The vehicle slides rather than rolls to a stop. During this time, the driver also has a very difficult time keeping the vehicle straight and the vehicle can skid out of control. The skidding and lack of control was caused by the locking of the wheels. If the driver was able to release the brake pedal just before the wheels locked up then reapply the brakes, the skidding could be avoided.

This release and apply of the brake pedal is exactly what an antilock system does. When the brake pedal is pumped or pulsed, pressure is quickly applied and released at the wheels. This is called **pressure modulation**. Pressure modulation works to prevent wheel locking. Antilock brake systems can modulate the pressure to the brakes as often as fifteen times per second. By modulating the pressure to the brakes, friction between the tires and the road is maintained and the vehicle is able to come to a controllable stop.

Because the ABS is already controlling system pressure, most modern systems can control the hydraulic pressure to the wheel brakes in place of the metering and proportioning valves used on non-ABS systems. Electronic brake force distribution (EBD) is used to maintain balance between the front and rear brakes by monitoring the rear wheel speeds during braking. If the rear wheels slow down more quickly than the front wheels, the ABS can limit pressure to the rear while allowing pressure to the front brakes to build as needed.

The only time reduced friction aids in braking is when a tire is on loose snow. A locked tire allows a small wedge of snow to build up ahead of it, which allows it to stop in a shorter distance than a rolling tire.

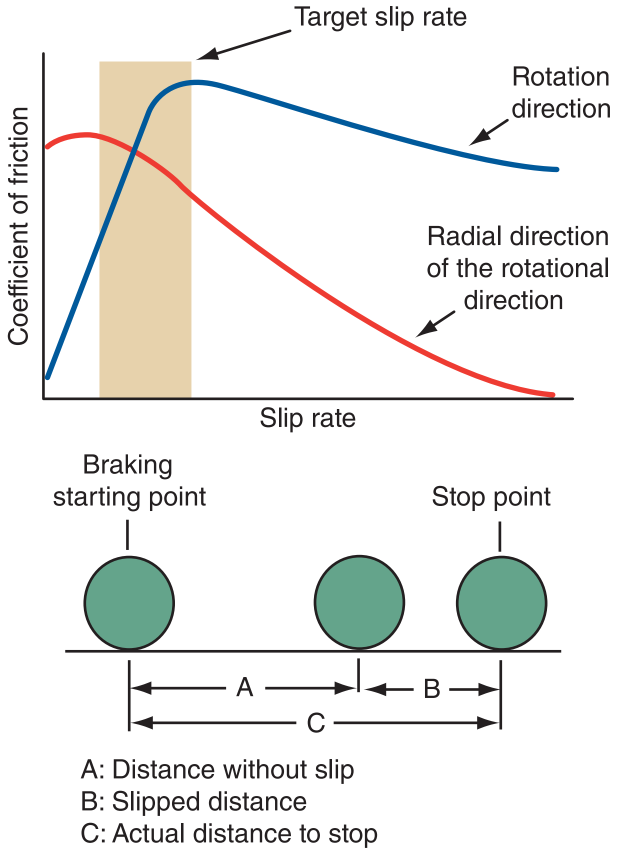
Steering is another important consideration. As long as a tire does not slip, it goes only in the direction in which it is turned. But once it skids, it has little or no directional stability. One of the big advantages of ABS, therefore, is the ability to keep control of the vehicle under all conditions.

Slip Rate

The maneuverability of the vehicle is reduced if the front wheels are locked, and the stability of the vehicle is reduced if the rear wheels are locked. A locked

tire skids on pavement and has poor traction. This condition allows for 100 percent tire slip, whereas a tire rolling freely has a slip of nearly 0 percent. Slip is the difference between the actual speed of the vehicle and the speed of the tire's tread as it rotates on the pavement. Antilock brake systems control the slip rate **(Figure 53–2)** of the wheels to ensure maximum grip force, or traction, at the tires. It is the traction of the tires that actually stops the vehicle; therefore, ABS can improve braking and handling by controlling the brake fluid pressure at each wheel to attain the target slip rate at that wheel.

Although ABS prevents complete wheel lockup, it allows some wheel slip in order to achieve the best braking possible. During ABS operation, the target slip rate can be from 10 to 30 percent. A slip rate of 25 percent means the velocity of a wheel is 25 percent less than that of a free rolling wheel at the same vehicle speed. Many things are considered when determining the target slip rate for a particular vehicle. For some the range is very low—5 to 10 percent—while on others it is high—20 to 30 percent.



$$\textbf{Slip rate} = \frac{B}{C} = \frac{\text{Vehicle speed} - \text{Wheel speed}}{\text{Vehicle speed}}$$

FIGURE 53–2 Defining slip rate.

CUSTOMER CARE

Remind your customers that pumping the brake pedal while stopping will prevent the ABS from activating. They should always keep firm steady pressure on the brake pedal during braking.

Pedal Feel

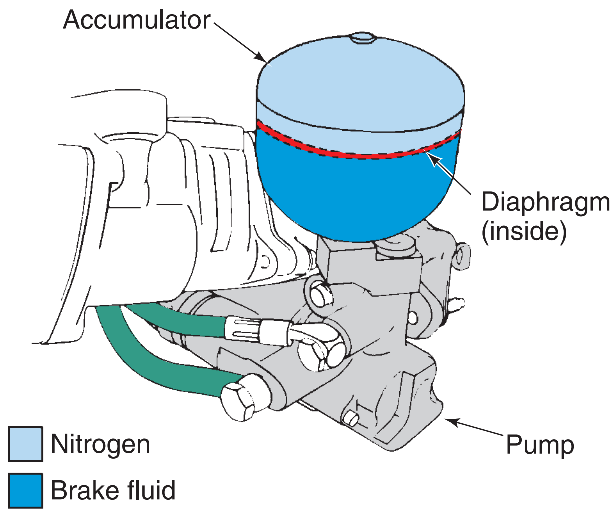
The brake pedal on a vehicle equipped with ABS has a different feel than that of a conventional braking system. When the ABS is activated, a small bump followed by rapid pedal pulsations will continue until the vehicle comes to a stop or the ABS turns off. These pulsations are the result of the modulation of pressure to the brakes and are felt more on some systems than on others. This is due to the use of damping valves in some modulation units. If pedal feel is of concern during diagnosis of a brake problem, compare the brake pedal feel with that of a similar vehicle with a normal operating antilock brake system. With ABS, the brake pedal effort and pedal feel during normal braking are similar to that of a conventional power brake system.

ABS Components

Many different designs of antilock brake systems are found on today's vehicles. These designs vary in their basic layout, operation, and components. There are also variations based on the type of power-assist used. Systems that combine ABS and power assist functions are called integral systems. The ABS components that may be found on a vehicle can be divided into two categories: hydraulic and electrical/electronic components. Keep in mind that no one system uses all of the parts discussed here. Normal or conventional brake parts are part of the overall brake system but are not in the following discussion.

Hydraulic Components

Accumulator An accumulator is used to store hydraulic fluid to maintain high pressure in the brake system and to provide residual pressure for power-assisted braking. Normally, the accumulator is charged with nitrogen gas **(Figure 53–3)** and is an integral part of the modulator unit. This unit is typically found on vehicles with a hydraulically assisted brake system.



Courtesy of Federal-Mogul Corporation.

FIGURE 53-3 Pressure in an accumulator.

FIGURE 53-5 A master brake cylinder in this typical integrated system uses an electric pump for power boost.

Antilock Hydraulic Control Valve Assembly This assembly controls the release and application of brake system pressure to the wheel brake assemblies. It may be of the integral type, meaning this unit is combined with the power-boost and master cylinder units into one assembly **(Figure 53–4)**. The nonintegral type is mounted externally from the master cylinder/power booster unit and is located between the master cylinder and wheel brake assemblies. Both types generally contain solenoid valves that control the releasing, the holding, and the applying of brake system pressure.

Booster Pump The booster pump is an assembly of an electric motor and pump. The booster pump is used to provide pressurized hydraulic fluid for the ABS. The pump's motor is controlled by the system's control unit. The booster pump is also called the electric pump and motor assembly.

Booster/Master Cylinder Assembly The booster/master cylinder assembly **(Figure 53–5)**, sometimes referred to as the hydraulic unit, contains the valves and pistons needed to modulate hydraulic pressure in the wheel circuits during ABS operation. Power brake-assist is provided by pressurized brake fluid supplied by a hydraulic pump.

Fluid Accumulators Different than a pressure accumulator, fluid accumulators temporarily store brake fluid removed from the wheel brake units during an ABS cycle. This fluid is then used by the pump to build pressure for the brake hydraulic system. There are normally two fluid accumulators in a hydraulic control unit, one each for the primary and secondary hydraulic circuits.

Hydraulic Control Unit This assembly contains the solenoid valves, fluid accumulators, pump, and an

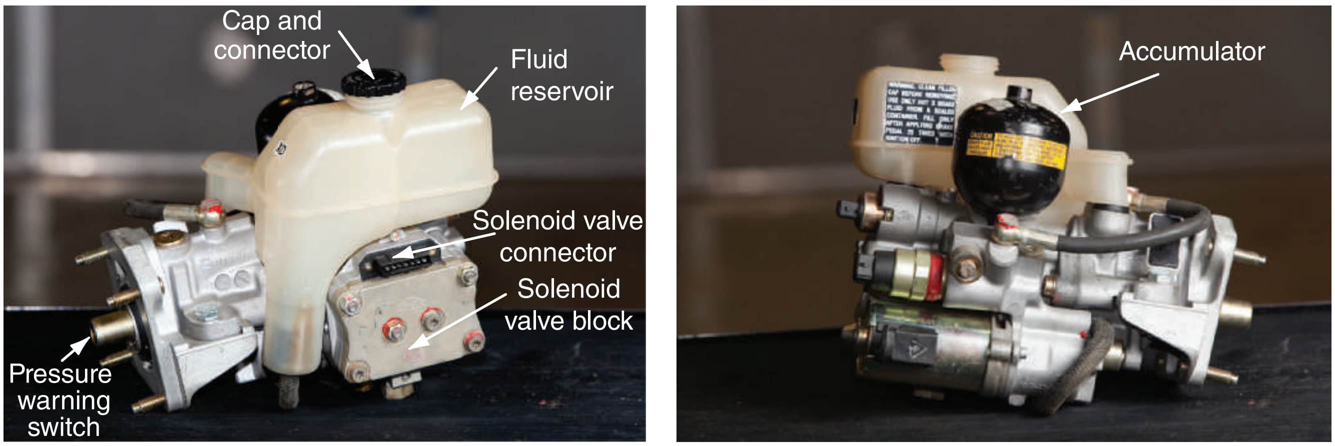


FIGURE 53-4 An integrated ABS combines the master cylinder, brake booster, and ABS components in a single unit.

electric motor. This is actually a combination unit of many individual components found separately in some systems. The unit may have one pump and one motor or it will have one motor and two pumps: one pump for half of the hydraulic system and the other for the other half.

Main Valve This two-position valve is also controlled by the ABS control module and is open only in the ABS mode. When open, pressurized brake fluid from the booster circuit is directed into the master cylinder (front brake) circuits to prevent excessive pedal travel.

Modulator Unit The modulator unit **(Figure 53–6)** controls the flow of pressurized brake fluid to the individual wheel circuits. Normally the modulator is made up of solenoids that open and close valves, several valves that control the flow of fluid to the wheel brake units, and electrical relays that activate or deactivate the solenoids through the commands of the control module. This unit may also be called the hydraulic actuator, hydraulic power unit, or the electrohydraulic control valve.

Solenoid Valves The solenoid valves are located in the modulator unit and are electrically operated by signals from the control module. The control module switches the solenoids on or off to increase, decrease, or maintain the hydraulic pressure to the individual wheel units.

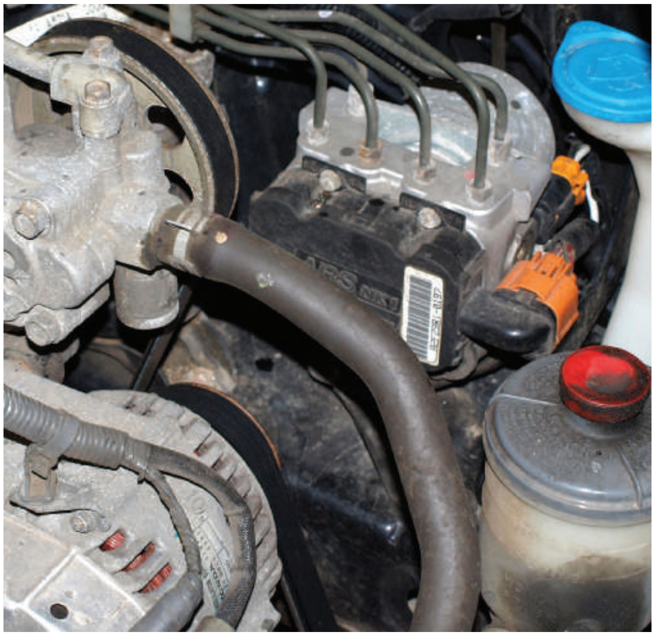


FIGURE 53–6 An ABS modulator assembly.

Valve Block Assembly The valve block assembly attaches to the side of the booster/master cylinder and contains the hydraulic wheel circuit solenoid valves **(Figure 53–7)**. The control module controls the position of these solenoid valves. The valve block is serviceable separate from the booster/master cylinder but should not be disassembled. An electrical connector links the valve block to the ABS control module.

Wheel Circuit Valves Two solenoid valves are used to control each circuit or channel. One controls the inlet valve of the circuit, the other controls the outlet valve. When inlet and outlet valves of a circuit are used in combination, pressure can be increased, decreased, or held steady in the circuit. The position of each valve is determined by the control module. Outlet valves are normally closed, and inlet valves are normally open. Valves are activated when the ABS control module switches 12 volts to the circuit solenoids. During normal driving, the circuits are not activated.

Electrical/Electronic Components

ABS Control Module This small control computer is normally mounted to the master cylinder **(Figure 53–8)**, or is part of the hydraulic control unit. It monitors system operation and controls antilock function when

FIGURE 53–7 The valve block assembly attaches to the side of the booster/master cylinder and contains the hydraulic wheel circuit solenoid valves.

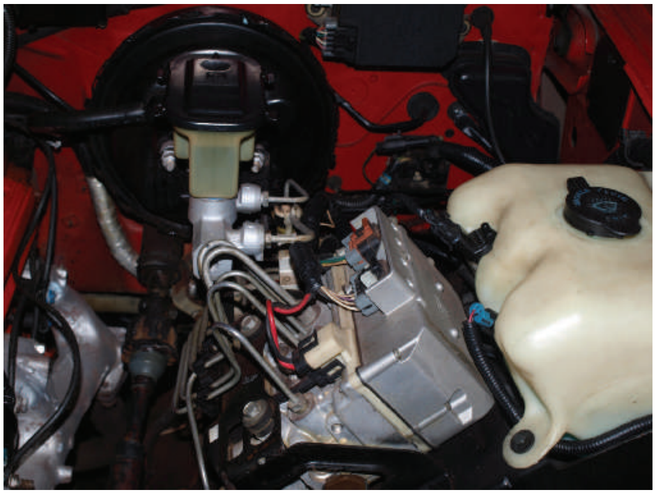


FIGURE 53-8 The ABS control module is typically mounted to the master cylinder.

FIGURE 53-9 All vehicles have a *red* warning light. This lamp lights when the brake fluid level is low, when there is a problem with the brake system, or when the parking brake is on. An *amber* warning lamp lights when there is a fault in the ABS.

needed. The module relies on inputs from the wheel-speed sensors and feedback from the hydraulic unit to determine if the antilock brake system is operating correctly and to determine when the antilock mode is required. The module has a self-diagnostic function including numerous trouble codes. This module may also be called the ECU (electronic control unit), EBCM (electronic brake control module), the antilock brake controller, or the ECM (electronic control module). The name used depends on the manufacturer and year of the vehicle. Regardless of the name used, the control module may control ABS, ESC, and many other related systems.

Data Link Connector (DLC). The DLC provides access and/or control of vehicle information, operating conditions, and diagnostic information.

Diagnostic Trouble Code (DTC). These trouble codes are numeric identifiers for fault conditions identified by the ABS's internal diagnostic system.

Brake Pedal Position Sensor The antilock brake pedal position sensor is used by the ABS module to determine when the brake pedal is pressed, how far or how hard the pedal is pressed. The BPP sensor input is used by the ABS, ESC, the engine control module, transmission control module, cruise control, and others.

Indicator Lights Most ABS-equipped vehicles are fitted with two different brake warning lights. One of the warning lights is tied directly to the ABS, whereas the other lamp is part of the base brake system. All vehicles have a *red* warning light. This lamp lights when the brake fluid level is low, when there is a problem with the brake system, or when the parking brake is on. An *amber* warning lamp lights when there is a fault in the ABS. Both lamps will illuminate if there is a major problem in the base system, causing the ABS to be inhibited **(Figure 53–9)**.

Lateral Acceleration/Longitudinal/Yaw Sensors Used on vehicles with stability control, these sensors monitor the sideward movement, forward/rearward motion, and movement around the center of vehicle's axis. These sensors may be part of the restraint system and the data can be shared with the ABS and ESC. Data from these sensors may be used to ensure proper braking during turns, to keep the vehicle stable in corners, and for torque vectoring to improve stability and performance.

Pressure Switch This switch controls pump motor operation and the low pressure warning light circuit. The pressure switch grounds the pump motor relay coil circuit, activating the pump when accumulator pressure drops below 2,030 psi (14,000 kPa). The switch cuts off the motor when the pressure reaches 2,610 psi (18,000 kPa). The pressure switch also contains switches to activate the dash-mounted warning light if accumulator pressure drops below 1,500 psi (10,343 kPa). This unit is typically found on vehicles with a hydraulically assisted brake system.

Pressure Differential Switch The pressure differential switch is located in the modulator unit. This switch sends a signal to the control module whenever there is an undesirable difference in hydraulic pressures within the brake system.

Relays Relays are electromagnetic devices used to control a high-current circuit with a low-current switching circuit. In ABS, relays are used to switch motors and solenoids. A low-current signal from the control module energizes the relays that complete the electrical circuit for the motor or solenoid.

Toothed Ring The toothed ring, also called a tone or reluctor ring, can be located on an axle shaft, differential gear, or a wheel's hub. This ring is used in conjunction with the wheel-speed sensor. The ring has a number of teeth around its circumference. The number of teeth varies by manufacturer and vehicle model. As the ring rotates and each tooth passes by the wheel-speed sensor, an AC voltage signal is generated between the sensor and the tooth. As the tooth moves away from the sensor, the signal is broken until the next tooth comes close to the sensor. The end result is a pulsing signal that is sent to the control module. The control module translates the signal into wheel speed. The toothed ring may also be called the reluctor, tone ring, or gear pulser.

Wheel-Speed Sensor

The wheel-speed sensors (WSS) **(Figure 53–10)** are mounted near the different toothed rings. Two types of sensors are in use: passive sensors, which generate AC voltage signals, and active sensors, which generate digital DC signals. As the ring's teeth rotate past the sensor, an AC voltage is generated. As the teeth move away from the sensor, the signal is broken until the next tooth comes close to the sensor. The end result is a pulsing signal that is sent to the control module **(Figure 53–11)**. The control module translates the signal into wheel speed. The sensor is normally a small coil of wire with a permanent magnet (PM) in its center.

Active sensors may have two or three wires and are either Hall-effect or magnetoresistive sensors that produce a square-wave digital signal **(Figure 53–12)**. Active sensors are now commonly used because unlike PM sensors, digital sensors can be used down to zero mph and can determine the direction the wheel is turning. This is necessary for electronic

FIGURE 53–10 Wheel-speed sensors are mounted near the toothed rings attached to drive shafts or gears.

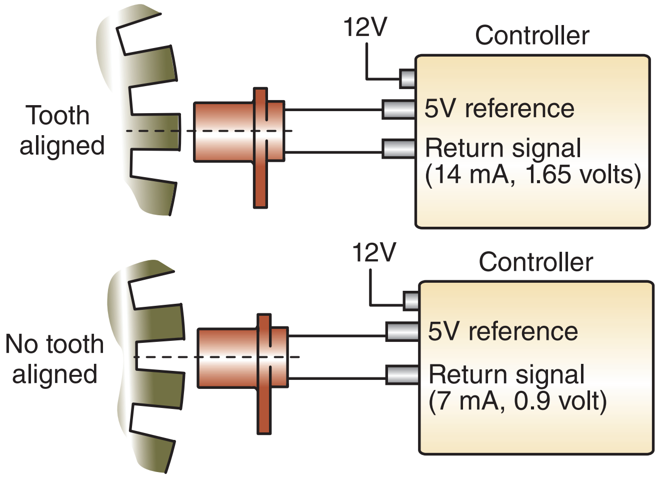


FIGURE 53–12 Active sensors have two or three wires and are either Hall-effect or magnetoresistive sensors that produce a square-wave digital signal.

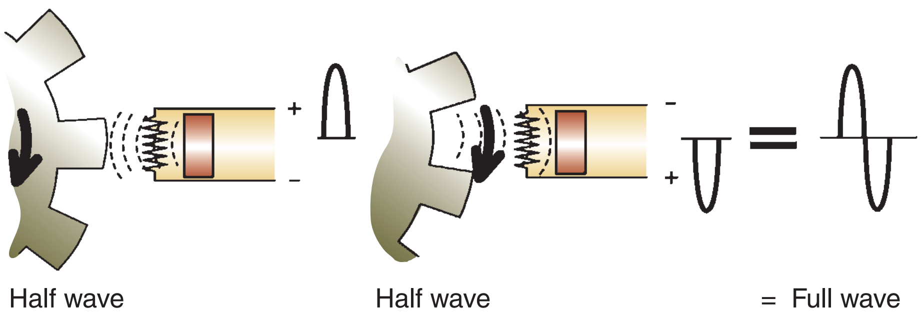


FIGURE 53–11 The output signal from a wheel-speed sensor.

stability system operation as well as vehicles with hill assist takeoff.

Multiplexing

The electronic circuit and wiring of an ABS is tied into the vehicle's CAN network **(Figure 53–13)**. This allows the ABS control unit to communicate with other control modules and share input devices with them. CAN communications is especially important when ABS is modified with additional features, such as traction and stability control.

Basic Operation

The control unit processes inputs and controls the operation of **isolation/dump valves** in the hydraulic modulator unit. The isolation/dump valves block off or isolate the master cylinder from certain brakes. As long as the brakes are applied and the vehicle is moving, the master cylinder remains isolated so additional fluid cannot be directed to those brakes. At the same time, the dump valve opens and allows a very small amount of fluid from the brake lines to enter an accumulator **(Figure 53–14)**. This reduces

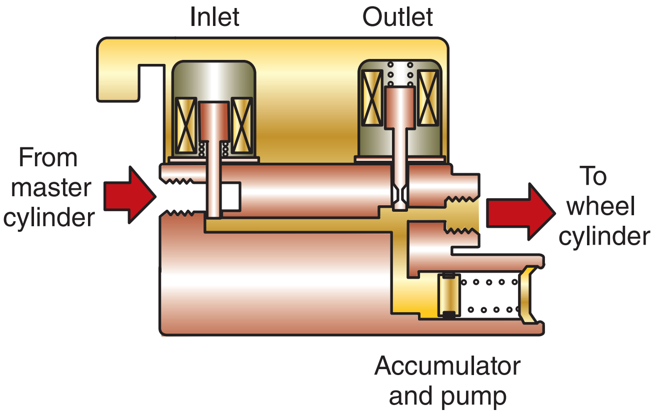


FIGURE 53–14 The control unit processes inputs and controls the operation of the isolation/dump valves to block off or isolate the master cylinder from the brakes.

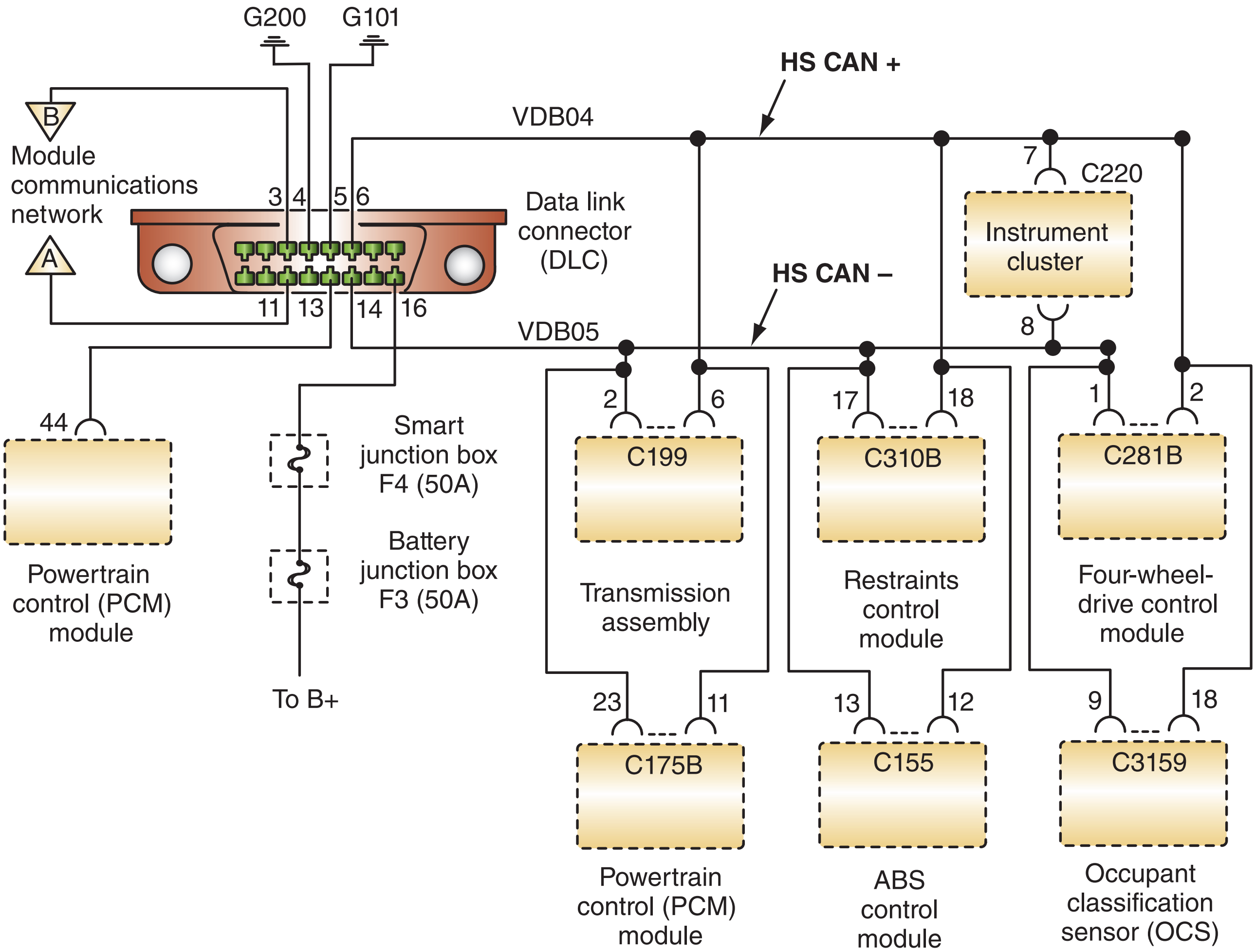


FIGURE 53–13 The electronic circuit and wiring of an ABS control unit is tied to the CAN network. This allows it to communicate with other control modules and share input devices with them.

the hydraulic pressure delivered to the brake and it is slightly released to allow the wheels to turn. If the wheels speed up too much, the dump valve reverses and the accumulator forces a small amount of fluid back into the brake. This constant dump/recharge is what causes the pulsation of the brake pedal during a panic or ABS stop. Most systems have a dedicated isolation/dump valve for each wheel.

Types of Antilock Brake Systems

The ABSs found on today's vehicles are manufactured by one of many different companies. Each manufacturer has a unique way to accomplish the same thing—vehicle control during braking. When working with ABS, it is important that you identify the exact system you are working with and follow the specific service procedures for that system. Often the system is initially identified by the manufacturer and then its model number; for example, a Teves Mark 20 system was manufactured by Teves and this model 20 is found on 1997 and later Chrysler vehicles. Keep in mind that there have been nearly 50 different ABSs used by the industry in recent years.

The exact manner in which hydraulic pressure is controlled depends on the ABS design. Many of the earlier ABSs were integrated or **integral antilock brake systems**. They combine the master cylinder, hydraulic booster, and ABS hydraulic circuitry into a single hydraulic assembly. These systems are becoming more prevalent because of the increasing number of hybrid and electric vehicles on the market. Integral systems use electric pumps instead of vacuum boosters to supply assist.

Nearly all of today's systems on non-hybrid vehicles are **nonintegral antilock brake systems**. They use a conventional vacuum-assist booster and master cylinder. The ABS hydraulic control unit is a separate mechanism. In some nonintegrated systems, the master cylinder supplies brake fluid to the hydraulic unit. Although the hydraulic unit is a separate assembly, it still uses a high-pressure pump/motor, an accumulator, and fast-acting solenoid valves to control hydraulic pressure to the wheels.

Both integral and nonintegral systems operate in much the same way; therefore, an understanding of one system will lend itself to the understanding of the other systems.

General Motors' electromagnetic ABS is a different type of nonintegral system that uses a conventional vacuum power booster and master brake cylinder. But it does not use a high-pressure pump/motor, an accumulator, and fast-acting solenoid valves to control hydraulic pressure. Instead, it uses motors in a hydraulic modulator.

In addition to being classified as integral and nonintegral ABSs, systems can be broken down into the level of control they provide. ABSs can be one-, two-, three-, or four-channel, two- or four-wheel systems. A channel is merely a hydraulic circuit to the brakes.

Two-Wheel Systems

These basic systems offer antilock brake performance to the rear wheels only. They do not provide antilock performance to the steering wheels. Two-wheel systems are most often found on older light trucks and some sport utility vehicles **(Figure 53–15)**.

These systems can be either one- or two-channel systems. In one-channel systems, the rear brakes on both sides of the vehicle are modulated at the same time to control skidding. These systems rely on the input from a centrally located speed sensor. The speed sensor is normally positioned on the ring gear in the differential unit **(Figure 53–16)**, transmission, or transfer case.

Two-channel systems may be found on some diagonally split brake systems. These systems use two speed sensors to provide wheel speed data for the regulation of all four wheels. One sensor has input that controls the right front wheel; the other sensor performs identically for the left front wheel.

Brake hydraulic pressure to the opposite rear wheel is controlled simultaneously with its diagonally located front wheel. For example, the right rear wheel receives the same pumping instructions as the left front wheel. This system is an upgrade from

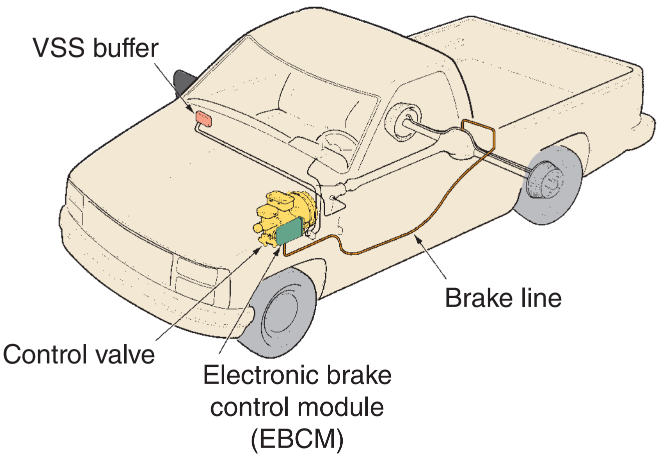


FIGURE 53–15 The main components of a rear wheel ABS.

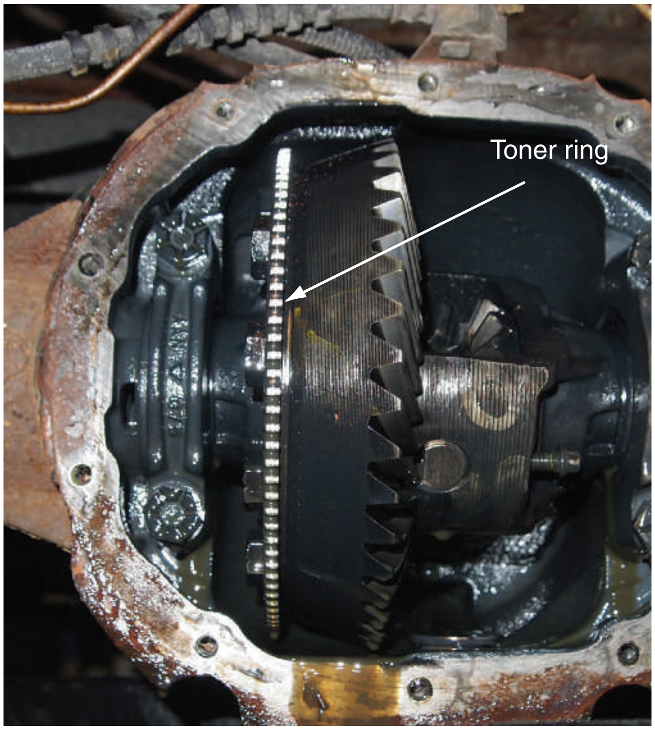


FIGURE 53–16 The speed sensor for both rear wheels is located on the differential unit.

the two-wheel system since it does provide steering control. However, it can have shortcomings under certain operating conditions.

Full (Four-Wheel) Systems

Some hydraulic systems that are split from front to rear use a three-channel system and are called four-wheel antilock brake systems. These systems have individual hydraulic circuits to each of the two front wheels, and a single circuit to the two rear wheels.

The most effective and most common ABSs are four-channel systems, in which sensors monitor each of the four wheels. With this continuous information, the ABS control module ensures that each wheel receives the exact braking force it needs to maintain both antilock and steering control.

ABS Operation

The exact operation of an antilock brake system depends on its design and manufacturer. It would take many pages to try to explain the operation of each, and as soon as you read the explanations there would be two or more new systems that would have to be explained. The exact operation of any system can be easily understood if you understand the basic operation of a few. The primary difference in operation between them all is based on the components used by the system. Therefore, the following systems were chosen as examples of how certain systems operate with the components they have.

Two-Wheel Systems (Nonintegral)

These systems are used to prevent rear wheel lockup on older pickup trucks and SUVs, especially under light payload conditions. They consist of a standard power brake system, an electronic control unit (control module), and an isolation/dump valve assembly. The valve assembly is attached to the master cylinder at the rear brake line. Both rear wheel brake assemblies are controlled by the valve assembly under ABS conditions.

Under normal braking, pressure will pass through the valve assembly. If the control module detects a deceleration rate from the VSS that would indicate probable rear wheel lockup, it activates the isolation valve, which stops the buildup of pressure to the rear wheels. If further deceleration occurs that would indicate lockup, the control module will rapidly pulse the dump valve to release brake pressure into the accumulator. The control module continues to pulse the dump valve until rear wheel deceleration matches the vehicle's deceleration rate or the desired slip rate. When wheel-speed picks up, the control module will turn off the isolation valve, allowing the fluid in the accumulator to return to the master cylinder and normal braking control to resume.

The control module continuously monitors the speed of the differential ring gear through signals from the rear wheel-speed sensor. The control module also receives signals from the brake light switch, brake warning lamp switch, reset switch, and the 4WD switch.

This system is disabled on four-wheel drive vehicles when in the four-wheel drive mode due to transfer case operation. Switching the transfer case into two-wheel drive mode will re-enable the ABS.

Four-Wheel Systems (Nonintegral)

The hydraulic circuit for this system is an independent four-channel type **(Figure 53–17)**. The hydraulic control unit is a separate unit. In the hydraulic control unit there are two valves per wheel; therefore, a total of eight valves are used. Some systems have three channels, one for each of the front wheels and one for the rear axle. Obviously these systems have only three pairs of solenoids **(Figure 53–18)**.

The system prevents wheel lockup during an emergency stop by modulating brake pressure. It

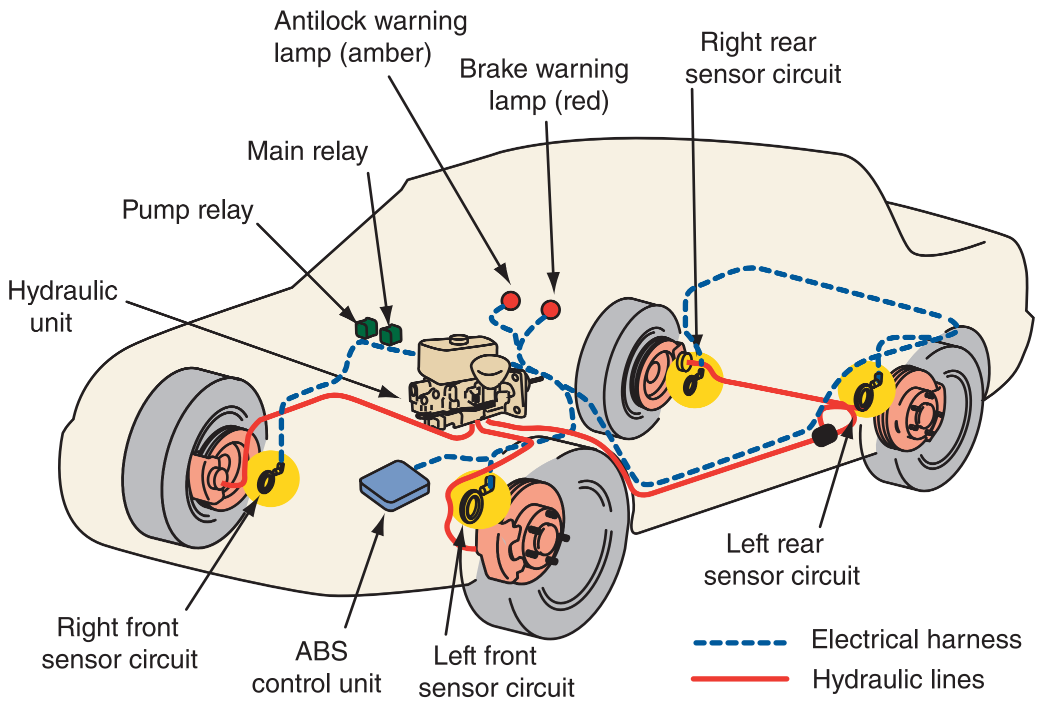


FIGURE 53–17 The basic electrical and hydraulic components of a four-wheel antilock brake system.

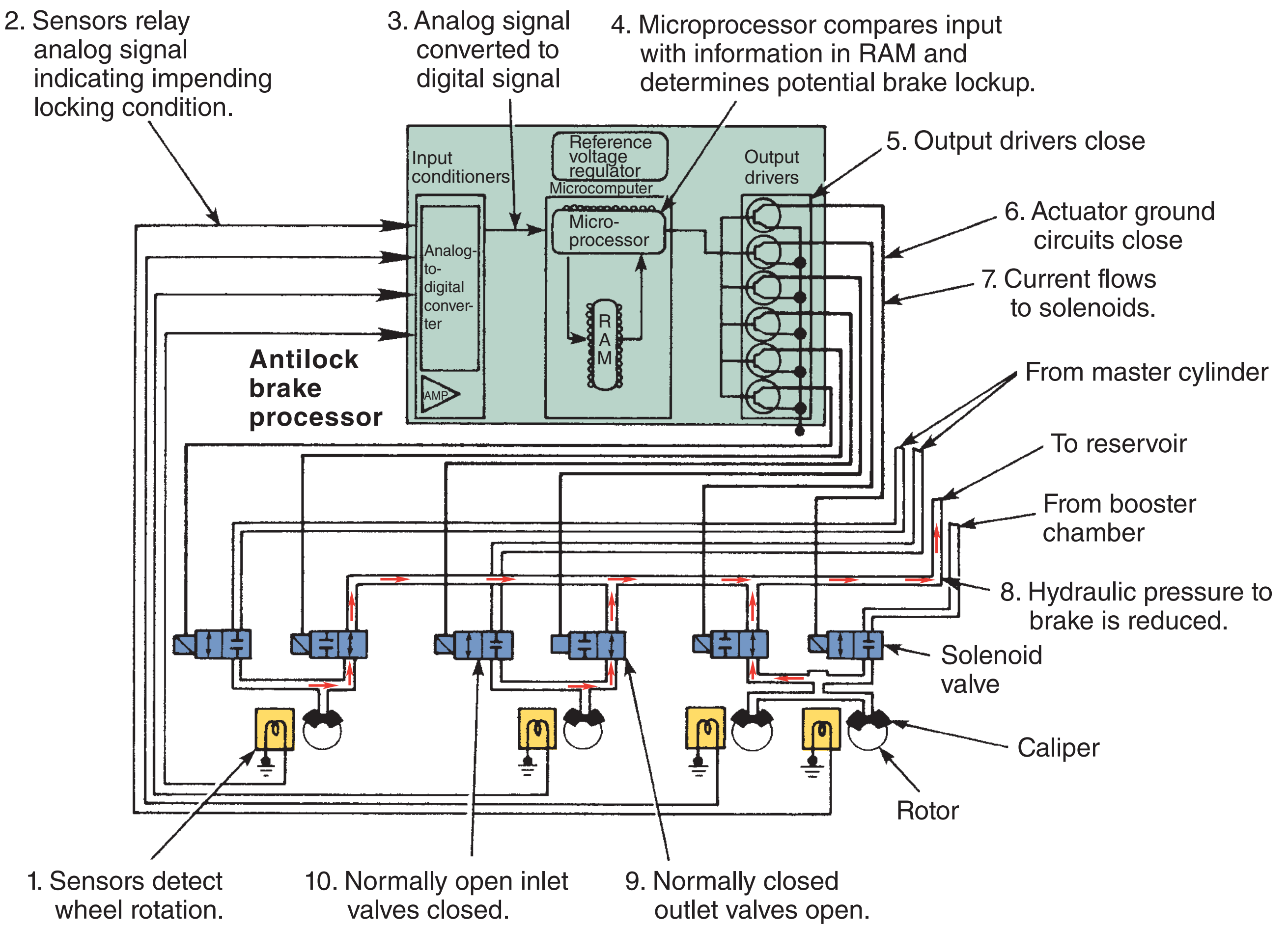


FIGURE 53–18 ABS operation—potential brake lock condition.

allows the driver to maintain steering control and stop the vehicle in the shortest possible distance under most conditions. During ABS operation, the driver will sense a pulsation in the brake pedal and a clicking sound.

Operation The ABS control module calculates the slip rate of the wheels and controls the brake fluid pressure to certain wheel brakes to reach the target slip rate. If the control module senses that a wheel is about to lock, based on input sensor data, it pulses the normally open inlet solenoid valve closed for that circuit. This prevents any more fluid from entering that circuit. The ABS control module then looks at the sensor signal from the affected wheel again. If that wheel is still decelerating faster than the other three wheels, it opens the normally closed outlet solenoid valve for that circuit. This dumps any pressure that is trapped between the closed inlet valve and the brake back to the master cylinder reservoir. Once the affected wheel returns to the same speed as the other wheels, the control module returns the valves to their normal condition, allowing fluid flow to the affected brake.

Wheel speed at each wheel is measured by the wheel-speed sensors (WSS). As the teeth on the gear pulser or tone wheel rotate past the sensor, a signal is generated. The frequency changes in accordance with the wheel speed.

Modulator Assembly The ABS modulator assembly consists of the inlet solenoid valve, outlet solenoid valve, reservoir, pump, pump motor, and the damping chamber. The hydraulic control has three modes: pressure reduction (decrease), pressure retaining (hold), and pressure intensifying (increase).

While in the pressure reduction decrease mode **(Figure 53–19)**, the inlet valve is closed and the outlet valve is open. During this mode, fluid pressure to the wheel brake is blocked and the existing fluid in the

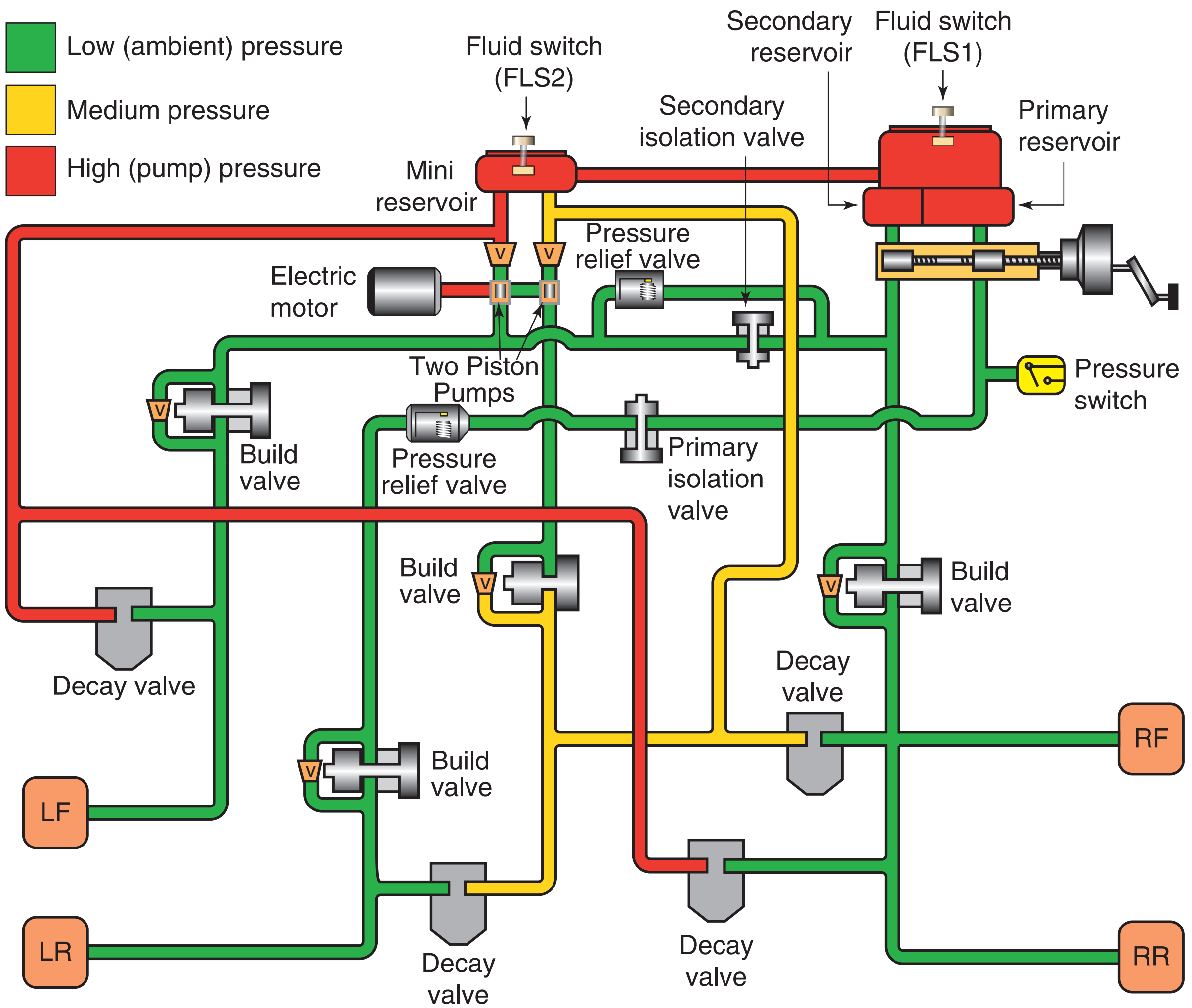


FIGURE 53–19 Antilock braking, pressure reduction.

caliper flows through the outlet valve back to the master cylinder reservoir. During the pressure-intensifying mode **(Figure 53–20)**, the inlet valve is open and the outlet valve is closed. Pressurized fluid is pumped to the caliper. To keep the pressure at the caliper during the pressure-retaining mode, the inlet and outlet valves are closed.

The pump/motor provides the extra fluid required during an ABS stop. The pump is supplied fluid that is released to the accumulators when the outlet valve is open during an ABS stop. The accumulators provide temporary fluid storage for use during an ABS stop. The pump also drains the accumulator circuits after the ABS stop is complete. The pump is run by an electric motor controlled by a relay that is controlled by the ABS control module. The pump is continuously on during an ABS stop and remains on for about 5 seconds after the stop is complete.

Keep in mind that the activity of the solenoid valves changes rapidly, several times each second. This means the fluid under pressure must be redirected quickly; this is the primary job of the pump.

Integral Four-Wheel Systems

When the brakes are released, the piston in the master cylinder retracts. The booster chamber is vented to the reservoir, and the fluid in the chamber is at the same low pressure as the reservoir. When the brakes are applied, under normal conditions, the brake pedal actuates a pushrod **(Figure 53–21)**. This moves a lever, which moves a spool valve. When the spool valve moves, it closes the port from the booster chamber to the reservoir and partially opens the port from the accumulator in proportion to the pressure on the brake pedal. This allows hydraulic fluid under pressure from the accumulator to enter the booster chamber. As hydraulic pressure enters, it pushes the booster piston forward, providing hydraulic assist to the mechanical thrust from the pushrod.

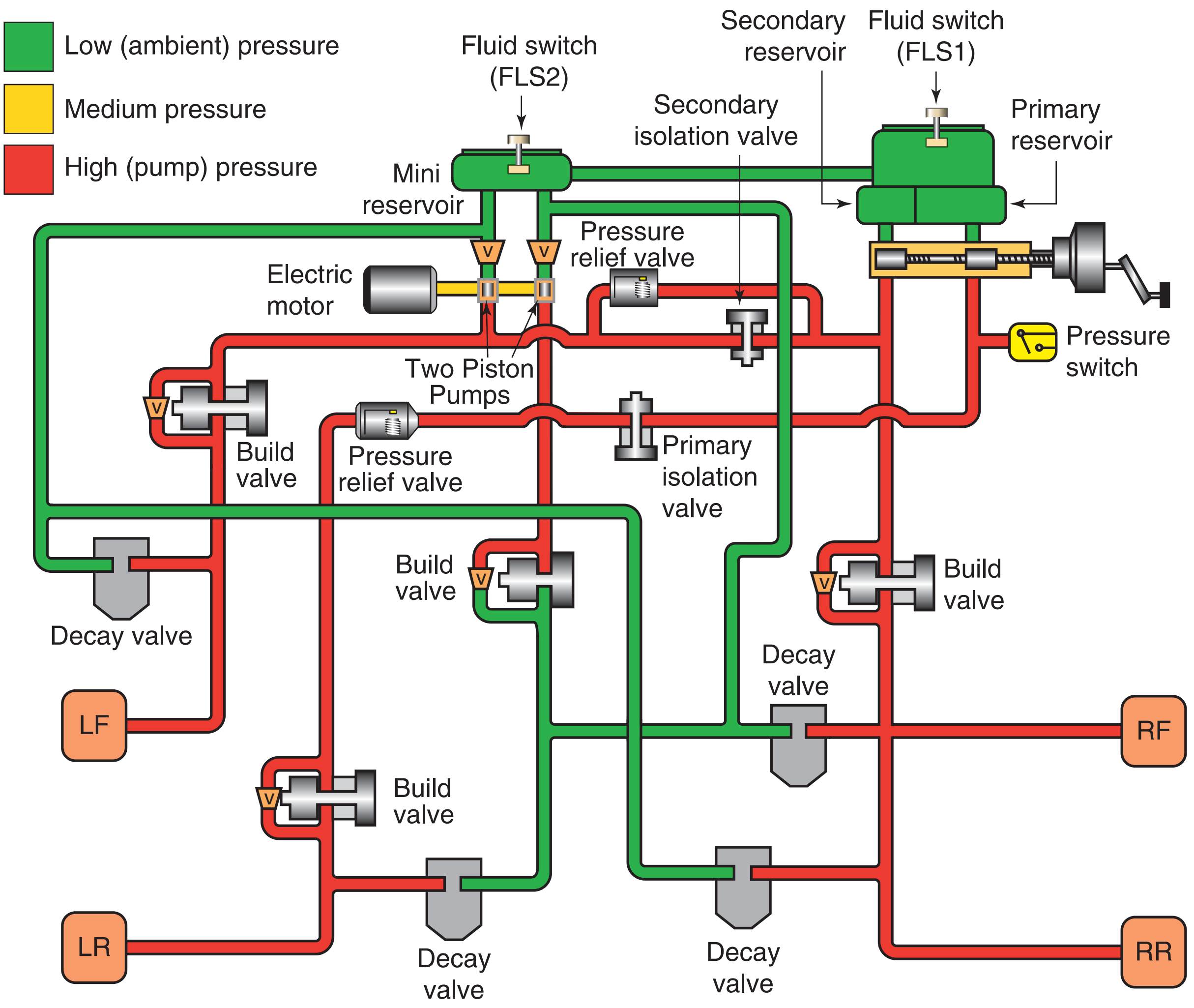


FIGURE 53-20 Antilock braking, pressure increase.

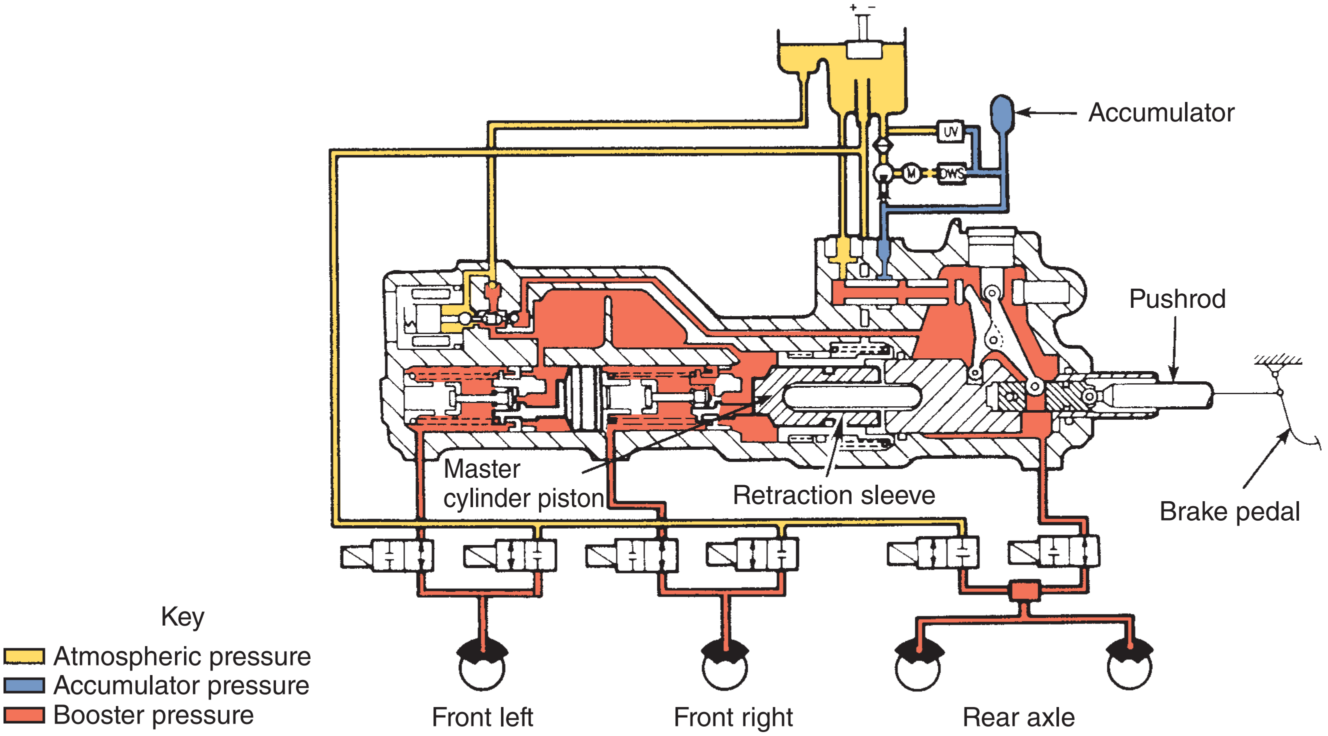


FIGURE 53–21 Normal braking with antilock system.

When the control module determines that the wheels are locking up, it opens a valve that supplies one chamber between the two master cylinder pistons and another chamber between the retraction sleeve and the first master cylinder piston. The hydraulic pressure on the retraction sleeve retracts the pushrod, pushing back the brake pedal. In effect, the hydraulic pressure to the wheels is now supplied by the accumulator, not by the brake pedal action. The control module also opens and closes the solenoid valves to cycle the brakes on the wheels that have been locking up.

When the solenoid valves are open, the master cylinder pistons supply hydraulic fluid to the front brakes, and the boost pressure chamber provides hydraulic pressure to the rear. When the solenoid valves are closed, the hydraulic fluid from the master cylinder pistons and booster pressure chamber is cut off. The hydraulic fluid is returned from the brakes to the reservoir.

Adaptive Braking

Many modern automobiles are now equipped with electronic brake-assist systems that can prepare or apply the brakes based on operating conditions. Some vehicles apply the brakes slightly when driving in rain or wet conditions. This keeps the pads and rotors dry and more responsive when applied.

Many systems can determine if an emergency braking event is occurring with input from forward-facing cameras and/or radar signals from the adaptive cruise control system. Each manufacturer has a different name for their system but all use forward-facing detection systems to determine if an obstacle is in the path of the vehicle. During low-speed driving, the system can precharge the brakes, keeping the pads closer to the rotors in anticipation of stopping. If someone or something enters the path of the vehicle, the driver is alerted and if the brakes are not applied, the system will stop the car on its own. Their operation is similar to vehicles with adaptive cruise control. Once the distance to the vehicle in front is set, the ABS will apply the brakes as needed to maintain the clearance to the vehicle ahead.

Automatic Traction Control

Automakers use the technology and hardware of ABSs to control tire traction and vehicle stability. As explained earlier, an ABS pumps the brakes when a braking wheel attempts to go into a locked condition.

Automatic traction control (ATC) systems apply the brakes when a drive wheel attempts to spin and lose traction **(Figure 53–22)**. Manufacturers have used various basic designs for these systems and they are referred to as ATC, traction control systems (TCS), and acceleration slip reduction (ASR) systems.

Controlling wheel slip is the goal of both ABS and ATC. ABS controls negative wheel slip by modulating the hydraulic pressure to the wheel, or wheels, which is skidding. An ATC system controls positive wheel spin by modulating hydraulic pressure at the wheel that is spinning to slow down the wheel. Many systems use other methods before applying brake pressure.

ATC is most helpful on four-wheel or all-wheel drive vehicles where loss of traction at one wheel could hamper driver control. It is also desirable on high-powered front-wheel drive vehicles for the same reason. Often if traction control is fitted to a FWD vehicle, the ABS modified system is a three-channel system because ATC is not needed at the rear wheels. On RWD and 4WD vehicles, the system is based on a four-channel ABS.

In order to use the brakes to control wheel spin, the ABS must have a pump to develop hydraulic pressure and an accumulator to store reserve pressure. During braking, the driver's foot applies pressure to the brake pedal. During acceleration, the driver's foot is nowhere near the brake pedal; so if brake pressure is to be used to stop wheel spin, the brake system must have an independent source of hydraulic pressure.

During operation, the ATC system monitors the wheel-speed sensors. If a wheel enters a loss-of-traction situation, the module applies braking force to the wheel in trouble. Loss of traction is identified by comparing the vehicle's speed to the speed of the wheel. If there is a loss of traction, the speed of the wheel will be greater than expected for the particular vehicle speed. Wheel spin is normally limited to a 10 percent slippage. Some TCSs use separated hydraulic valve units and control modules for the ABS and ATC, whereas others integrate both systems into one hydraulic control unit and a single control module. The pulse rings and wheel-speed sensors remain unchanged from the ABS to the ATC.

Some ATC systems function only at low road speeds of 5 to 25 miles per hour. These systems are designed to reduce wheel slip and maintain traction at the drive wheels when the road is wet or snow covered. If during acceleration the module detects drive wheel slip and the brakes are not applied, the control module enters into the traction control mode. The inlet and outlet solenoid valves are pulsed and allow the brake to be quickly applied and released. The pump/motor assembly is turned on and supplies pressurized fluid to the slipping wheel's brake.

Engine Controls

More advanced systems work at higher speeds and integrate some engine control functions into the control loop. Most ATC systems rely on inputs available

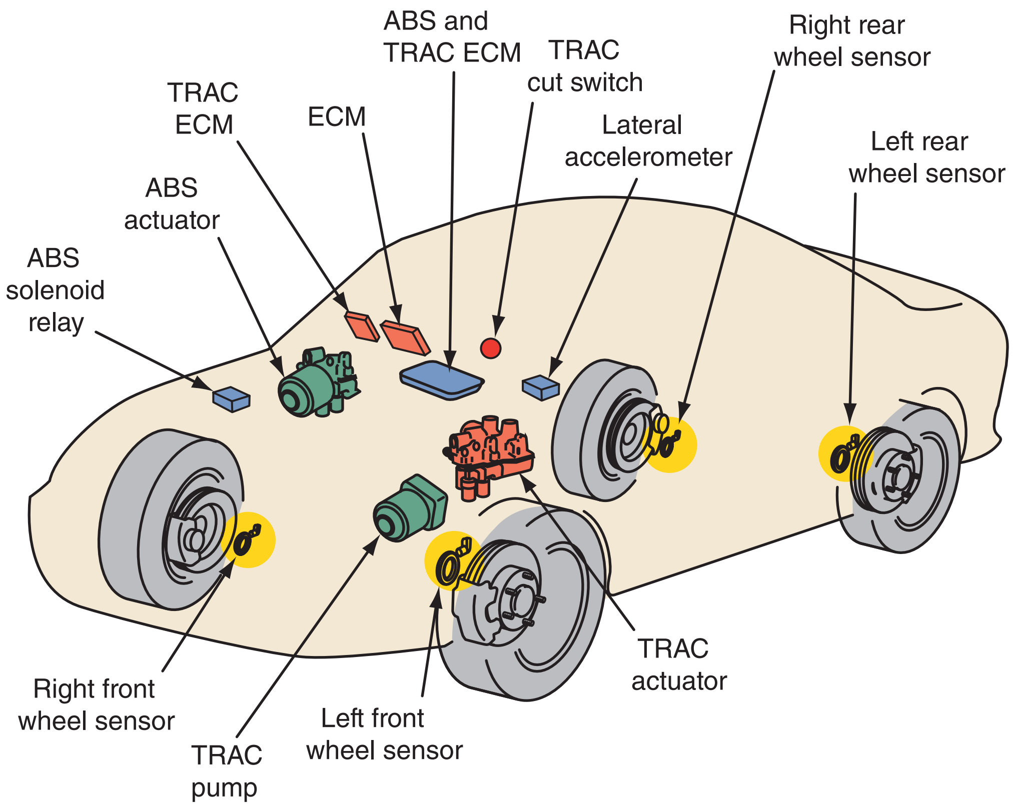


FIGURE 53–22 A typical ATC system.

on the CAN bus and compare front wheel speeds to rear wheel speeds to determine if drive wheels lose traction.

When drive wheel slip is detected while the brake is not applied, the electronic brake control module (EBCM) will enter into the traction control mode. At that time, the PCM will initiate an engine torque reduction routine to slow down the drive wheels. The following shows how the PCM reduces torque to the drive wheels:

- By retarding spark timing
- By decreasing the opening of the throttle plate
- By reducing or cutting off fuel injection pulses to one or more cylinders
- By increasing exhaust gas recirculation (EGR) flow
- By momentarily upshifting the transmission to a higher gear

If the engine torque reduction does not eliminate drive wheel slip, the EBCM will gradually apply the brakes at the driving wheels **(Figure 53–23)**. The master cylinder's isolation valve closes to isolate the cylinder from the rest of the hydraulic system. Then prime valve opens to allow the pump to accumulate brake fluid and build hydraulic pressure. The drive wheel inlet and outlet solenoid valves then open and close and pass through stages of pressure hold, pressure increase, and pressure decrease.

Driver Controls and Indicators

Most TCSs have two warning lights. However, some vehicles display the status of the system with messages on the instrument cluster. Normally, an amber lamp will illuminate or a service message will appear as any of the ABS-disabling DTCs is set. When this occurs, the TCS is automatically disabled by the control unit. When the system is actively controlling wheel spin, a green lamp lights or a message is displayed saying the system is active.

There may also be a manual cut-off switch so the driver can turn off the TCS. This will cause the amber lamp to light or a message displayed, stating the system is off.

Automatic Stability Control

Various stability control systems are found on today's vehicles. Like TCSs, stability controls are based on and linked to the ABS **(Figure 53–24)**. On some vehicles, the stability control system is also linked to the electronic suspension system. Most often, the stability control system is called an electronic stability control (ESC) system, although many other names

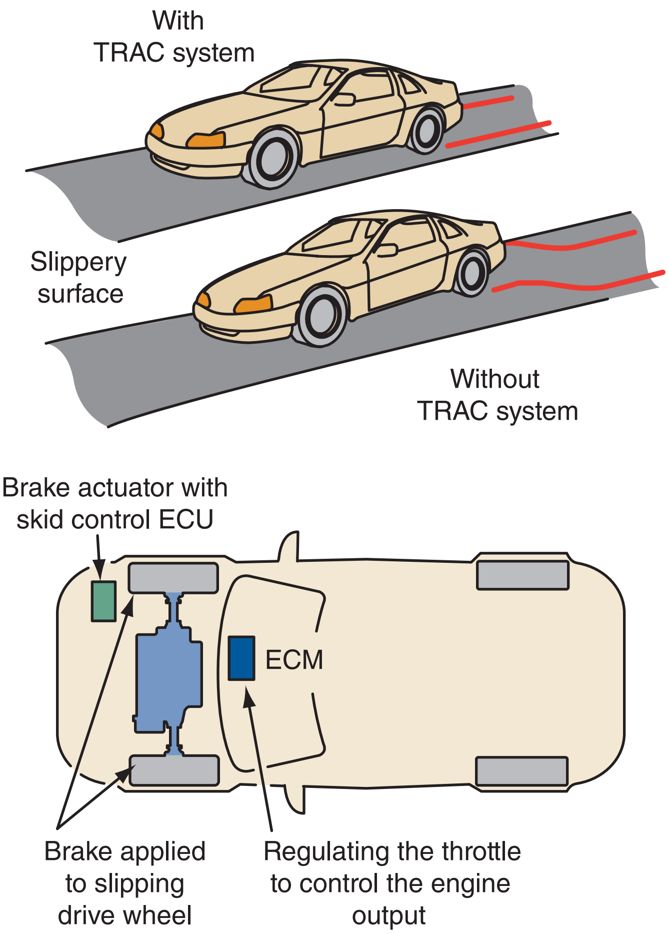


FIGURE 53–23 On this FWD vehicle, the ATC (TRAC) system applies the appropriate brakes and regulates engine output to help prevent wheel slippage when accelerating on slippery surfaces.

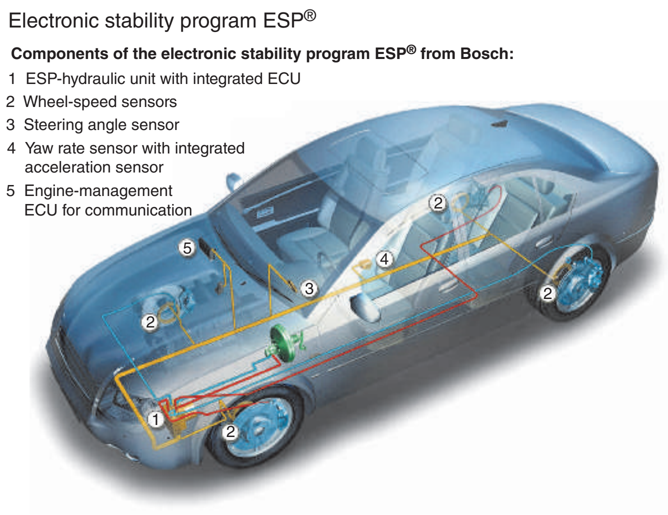


Image courtesy of Robert Bosch GmbH.

FIGURE 53–24 The components of a typical vehicle stability control (ESC) system.

are used. ESC helps prevent skids, swerves, and rollover accidents. Basically the system applies the brakes at one or more wheels to help correct the steering. In some cases, power to the drive wheels is also reduced.

It is important to remember that a vehicle's tendency to roll is influenced by its height, track width, and the stiffness of its suspension. ESC cannot override a car's physical limits nor can it increase traction. If the vehicle is pushed beyond its traction limits, ESC may not be able to correct the vehicle's movement. ESC simply helps the driver maintain control using the available traction.

ESC systems can control the vehicle during acceleration, braking, and coasting. If the brakes are applied but oversteer or understeer is occurring, the fluid pressure to the appropriate brake is increased **(Figure 53–25)**. Understeer is a condition where the vehicle is slow to respond to steering changes. When the system senses understeer in a turn, the brake at the inside rear wheel is applied to regain vehicle stability. Oversteer occurs when the rear wheels try to swing around or fishtail. When this occurs, the ESC system will apply the brake at the outer rear or front wheel in an attempt to neutralize the oversteering.

The control unit, normally the EBCM, receives signals from the wheel-speed sensors, a steering angle sensor (typically part of the combination switch body behind the steering wheel), a lateral-acceleration sensor, a yaw sensor, roll sensors, and a brake-pressure sensor. It also communicates with other control units through the CAN bus **(Figure 53–26)**. The sensors basically let the control unit know the current status of the vehicle.

The ESC control unit compares the driver's intended direction (by monitoring steering angle) to

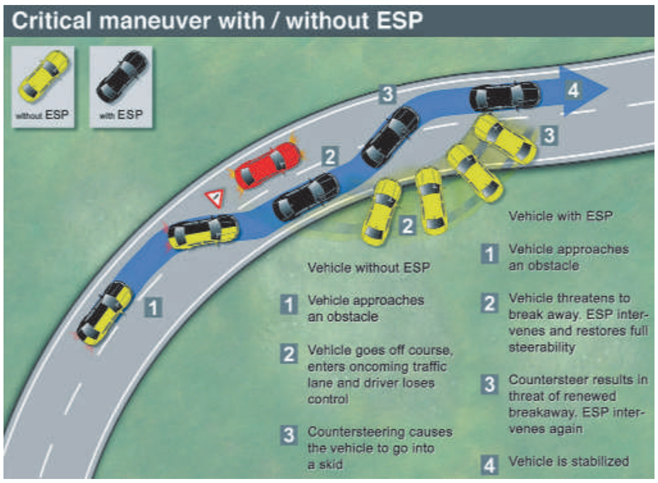


Image courtesy of Robert Bosch GmbH.

FIGURE 53–25 The effects of a stability control (ESP = Electronic Stability Program) system.

the vehicle's actual direction (by measuring lateral acceleration, yaw, and individual wheel speeds). If there is a difference between the two, the control unit intervenes by modulating individual front or rear wheels and/or reducing engine power output.

ESC continuously monitors key inputs such as yaw rate and wheel speed. **Yaw** is defined as the natural tendency of a vehicle to rotate on its vertical center axis or twist during a turn. A vehicle may also rotate naturally on its horizontal axis; this movement is called roll and pitch.

A yaw rate sensor is a gyroscopic sensor that measures the side-to-side twist of the vehicle. Two types of yaw rate sensors are used: micromechanical and piezoelectric. A micromechanical sensor relies on an oscillating element. The movement of this element is changed in response to yaw and speed. During a turn, the vehicle tends to yaw and the output from the sensor changes. The control unit uses those signals to determine how much yaw is occurring.

A piezoelectric sensor has a vibration-type gyroscope shaped like a tuning fork **(Figure 53–27)**. The device is divided into two sections: upper and lower. Both sections have piezoelectric elements attached to them. As current flows through the piezoelectric materials, the sections oscillate from one side to the other. When the vehicle is making a turn, the movement of the vehicle causes the upper elements to move away from the lower elements. This action generates an AC voltage signal that represents the vehicle's speed and yaw rate. In a right turn, the signal voltage increases and decreases when the vehicle is turning right. The output signals range from 0.25 to 4.75 volts. When the vehicle has 0 yaw, the output signal will be 2.5 volts.

The control unit looks at the actual yaw rate and compares it to the calculated desired rate. It responds to the difference between the two. This difference represents the amount of understeer or oversteer that is occurring. To correct the yaw, the system applies the brake at the appropriate wheel.

Typically the yaw rate sensor and lateral accelerometer share the same housing. They are mounted in the center of the vehicle. The lateral accelerometer monitors acceleration, deceleration, and cornering forces. These sensors are commonly Hall-effect or piezoelectric units. Semiconductor materials are placed on a plate and are set 45 degrees away from the centerline of the vehicle. The plate is supported by four beams **(Figure 53–28)**. The beams are designed to be able to flex in response to the movement of the vehicle. The amount of flex determines the output signal from the sensor. The signal can range from 0.25 to 4.75 volts depending on the G-forces the vehicle is experiencing.

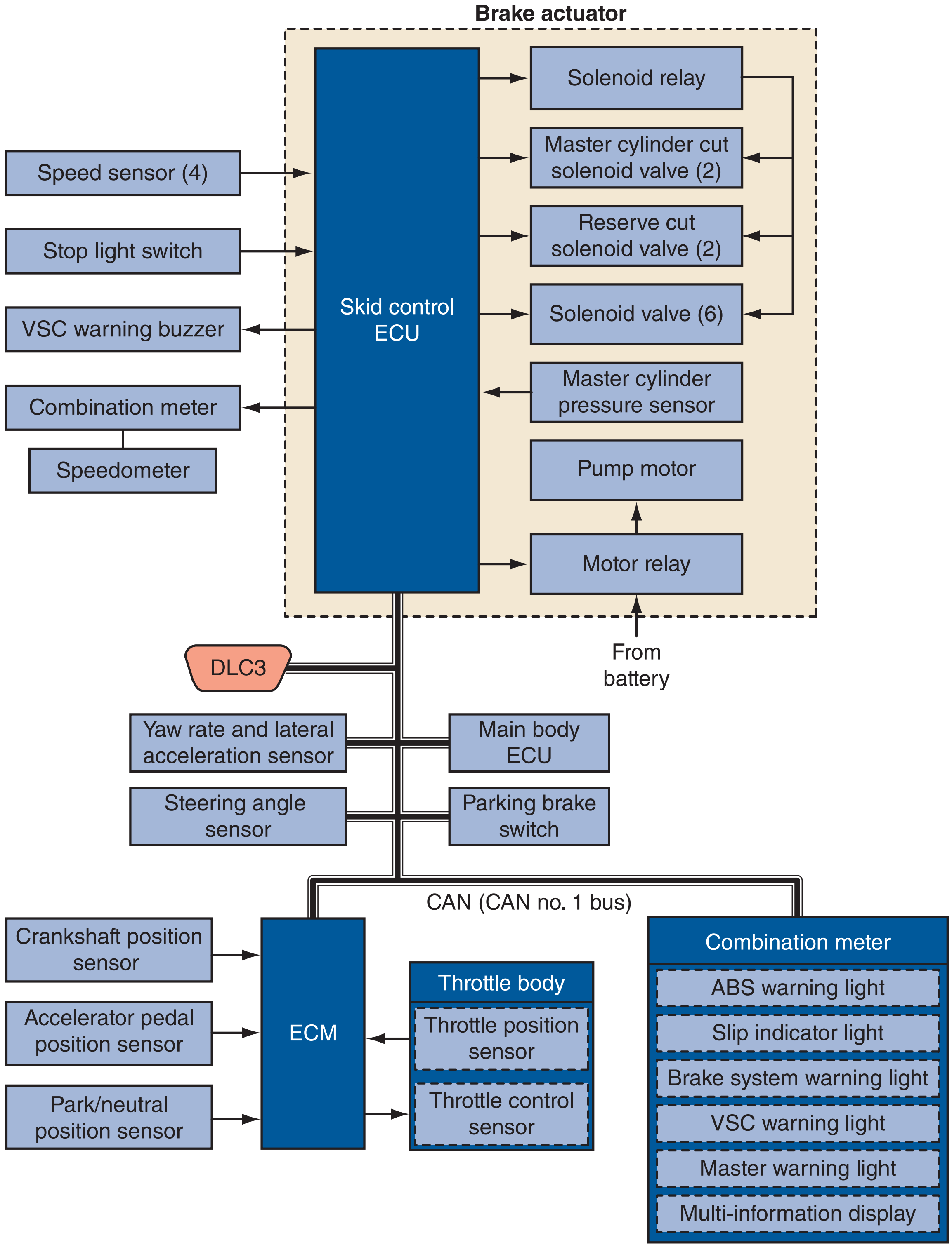


FIGURE 53–26 A typical system diagram for an ESC system.

G-force is a measurement of a vehicle's acceleration. The term is based on the normal acceleration rate due to gravity (32.174 ft./s^2 or 9.80665 m/s^2). A G-force value of 1 means the acceleration rate of the vehicle is the same as the acceleration rate of gravity. A value of less than 1 means the rate is lower than that of gravity. Values greater than 1 indicate that the forces acting on the vehicle are greater than the normal acceleration rate of gravity. Most lateral accelerometer sensors have an operating range of

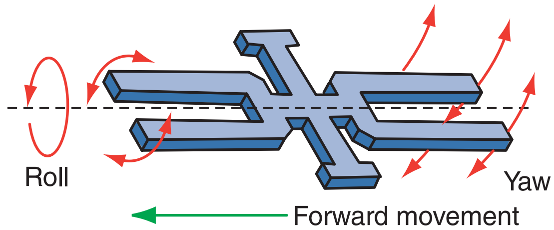


FIGURE 53–27 The basis of a yaw rate sensor.

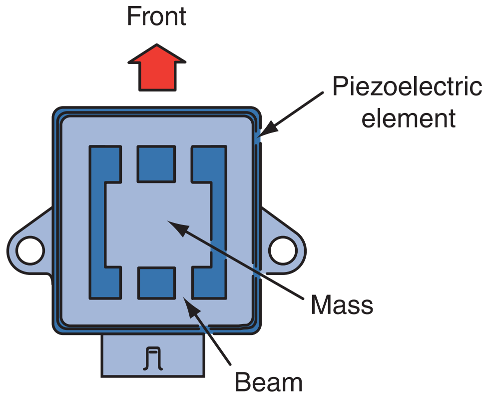


FIGURE 53–28 An acceleration/deceleration sensor. The semiconductor material rests on a plate that is supported by four beams that flex as thrust is applied in any direction.

–1.5 to +1.5 g. Zero lateral acceleration provides a 2.5-volt output signal. The voltage of the signal increases with an increase in lateral acceleration.

Stability Control System Indicators

ESC systems use an indicator light or the message center on the dash to tell the driver when the system is active (i.e., it has detected and corrected yaw rates). A lamp or the message center will also inform the driver when the system is turned off. If the control unit detects a problem in the system, it may shut down the system and alert the driver of needed service. Also, many ESC systems have an "off" switch so the driver can disable ESC, for example, when stuck in mud or snow **(Figure 53–29)**. However, ESC defaults to "on" when the ignition is restarted. When the system has been turned off by the driver, a warning lamp or message is displayed.

FIGURE 53–29 Many ESC (stability) systems have an "off" switch so the driver can disable the system.

Antilock Brake System Service

Most of the service done to the brakes of an antilock brake system are identical to those in a conventional brake system. There are, however, some important differences. Always refer to the recommended procedures in the appropriate service information before attempting to service the brakes on an ABS-equipped vehicle.

Many ABS components are simply remove-and-replace items. Normal brake repairs, such as replacing brake pads, caliper replacement, rotor machining or replacement, brake hose replacement, master cylinder or power booster replacement, or parking brake repair, can all be performed as usual. In other words, brake service on an ABS-equipped vehicle is similar to brake service on a conventional system with a few exceptions. Before beginning any service, check the service information. It may be necessary to depressurize the accumulator to prevent personal injury from high-pressure fluid.

Safety Precautions

- When replacing brake lines and/or hoses, always use lines and hoses designed for and specifically labeled for use on ABS vehicles.
- Never use silicone brake fluids in ABS vehicles. Use only the brake fluid type recommended by the manufacturer (normally DOT 3 or 4).
- Never begin to bleed the hydraulic brake system on a vehicle equipped with ABS until you have checked the service information for the proper procedure.
- Never open a bleeder screw or loosen a hydraulic brake line or hose while the ABS is pressurized.
- Disconnect all vehicle computers, including the ABS control unit, before doing any electrical welding on the vehicle.

- Never disconnect or reconnect electrical connectors while the ignition switch is on.
- Never install a telephone or CB antenna close to the ABS control unit or any other control module or computer.
- Check the wheel-speed sensor to sensor ring air gap after any parts of the wheel-speed circuit have been replaced.
- Keep the wheel sensor clean. Never cover the sensor with grease unless the manufacturer specifies doing so; in those cases, use only the recommended type.
- When replacing speed (toothed) rings, never beat them on with a hammer. These rings should be pressed onto their flange. Hammering may result in a loss of polarization or magnetization.

Relieving Accumulator Pressure

Some services require that brake tubing or hoses be disconnected. Many ABSs use hydraulic pressures as high as 2,800 psi (19,300 kPa) and an accumulator to store this pressurized fluid. Before disconnecting any lines or fittings in many systems, the accumulator must be fully depressurized. A common method of depressurizing the ABS follows:

1. Turn the ignition switch to the off position.
2. Pump the brake pedal between twenty-five and fifty times.
3. The pedal should be noticeably harder when the accumulator is discharged.

Procedures for depressurizing the system vary with the design of the system. Always refer to the service information.

Diagnosis and Testing

Always follow the vehicle manufacturer's procedures when diagnosing an ABS. In general, ABS diagnostics requires three to five different types of testing that must be performed in the specified order listed in the service information. Types of testing may include the following:

1. Prediagnostic inspections and test drive
2. Warning light symptom troubleshooting
3. On-board ABS control module testing (trouble code reading)
4. Individual trouble code or component troubleshooting

Caution! Following the wrong sequence or bypassing steps may lead to unnecessary replacement of parts or incorrect resolution of the symptom. The information and procedures given in this chapter are typical of the various antilock systems on the market. For specific instructions, consult the vehicle's service information.

Prediagnostic Inspection

Before undertaking any actual checks, take a few minutes to talk with the customer about his or her ABS complaint. The customer is a very good source of information, especially when diagnosing intermittent problems. Make sure you find out what symptoms are present and under what conditions they occur.

All ABSs have some sort of self-test. This test is activated each time the ignition switch is turned on. You should begin all diagnosis with this simple test.

Warning Lamps Place the ignition switch in the start position while observing both the red brake system light and amber ABS indicator lights **(Figure 53–30)**. Both lights should turn on. Start the vehicle. The red brake system light should quickly turn off. This lamp will stay illuminated if the brake fluid level is low, the parking brake switch is closed, or the bulb test switch section of the ignition switch is closed, or when certain ABS trouble codes are set.

With the ignition switch in the run position, the antilock brake control module will perform a preliminary self-check on the antilock electrical system. The self-check takes 3 to 6 seconds, during which

FIGURE 53–30 The warning lights for a typical ABS-, ATC-, and ESC-equipped vehicle.

time the amber antilock indicator light remains on. Once the self-check is complete, the ABS indicator light should turn off. If any malfunction is detected during this test, the amber lamp will either flash or light continuously to alert the driver of the problem. In some systems, a flashing ABS indicator lamp indicates that the control unit detected a problem but has not suspended ABS operation. However, a flashing ABS indicator lamp is a signal that repairs must be made to the system as soon as possible.

A solid ABS indicator lamp indicates that a problem has been detected that affects the operation of ABS. No antilock braking will be available, but normal, nonantilock brake performance will remain. In order to regain ABS braking ability, the ABS system must be serviced.

If both brake indicators stay on and the parking brake is fully released, the front-to-rear braking distribution system may be shut down due to a pressure loss.

If the lamp does not light when the ignition is turned on, the computer probably will not go into its self-test mode. The problem may be as simple as a burned-out bulb, or it may be a problem with the computer itself. To identify the cause for the bulb not illuminating, begin by checking the bulb. If the bulb is good, you will need to make some voltage tests at a diagnostic connector. Follow the testing procedures given by the manufacturer. Nearly all diagnostic connectors have a ground terminal that is used for one or more test modes. Use a voltmeter or ohmmeter to check the continuity between the diagnostic ground terminal and the battery negative terminal. High ground resistance or an open circuit can keep the computer out of the self-test mode and may be a clue to other system problems.

Various other terminals on the diagnostic connector may have other levels of voltage applied to them at different times. Some may have battery (system) voltage under certain conditions, whereas others may have 5 volts, 7 volts, or a variable voltage applied to them.

SHOP TALK Dirty or damaged wheel-speed sensors and damaged sensor wiring harnesses are leading triggers to turn on ABS warning lamps. Do not rush to condemn the ABS computer or hydraulic module before checking the speed sensors and tone wheels.

Visual Inspection

The prediagnosis inspection consists of a quick visual check of system components. Problems can often be spotted during this inspection, which can eliminate the need to conduct other more time-consuming procedures. This inspection should include the following:

1. Check the master cylinder fluid level.
2. Inspect all brake hoses, lines, and fittings for signs of damage, deterioration, and leakage. Inspect the hydraulic modulator unit for any leaks or wiring damage.
3. Inspect the brake components at all four wheels. Make sure that no brake drag exists and that all brakes react normally when they are applied.
4. Inspect for worn or damaged wheel bearings that may allow a wheel to wobble.
5. Check the alignment and operation of the outer CV joints.
6. Make sure the tires meet the legal tread depth requirements and that they are the correct size.
7. Inspect all electrical connections for signs of corrosion, damage, fraying, and disconnection.
8. Inspect the wheel-speed sensors and their wiring. Check the air gaps between the sensor and ring, and make sure these gaps are within the specified range. Also check the mounting of the sensors and the condition of the toothed ring and wiring to the sensor.

Test Drive

After the visual inspection is completed, test drive the vehicle to evaluate the performance of the entire brake system. Begin the test drive with a feel of the

SHOP TALK Many vehicles have the WSS built into the wheel bearing assembly and a worn wheel bearing can affect ABS operation.

SHOP TALK Remember that faulty base brake system components may cause the ABS to shut down. Do not condemn the ABS too quickly.

brake pedal while the vehicle is sitting still. Then accelerate to a speed of about 20 mph (32 km/h). Bring the vehicle to a stop using normal braking procedures. Look for any signs of swerving or improper operation. Next, accelerate the vehicle to about 25 mph (40 km/h) and apply the brakes with firm and constant pressure. You should feel the pedal pulsate if the antilock brake system is working properly.

Perform several low-speed parking maneuvers while turning the wheels. This places the front wheel bearings under load. Many front wheel speed sensors are built into the front wheel bearings and hubs and worn bearings can cause unwanted ABS activation at low speeds. If the ABS activates when parking, check for loose and worn wheel bearings.

During the test drive, both brake warning lights should remain off. If either of the lights turns on, take note of the condition that may have caused it. After you have stopped the vehicle, place the gear selector into park or neutral and observe the warning lights. They should both be off.

If the control module detects a problem with the system, the amber ABS indicator lamp will either flash or light continuously to alert the driver of the problem. In some systems, a flashing ABS indicator lamp indicates that the control unit detected a problem but has not suspended ABS operation. However, a flashing ABS indicator lamp is a signal that repairs must be made to the system as soon as possible.

A solid ABS indicator lamp indicates that a problem has been detected that affects the operation of ABS. No antilock braking will be available, but normal, nonantilock, brake performance will remain. In order to regain ABS braking ability, the ABS must be serviced.

The red brake warning lamp will be illuminated when the brake fluid level is low, the parking brake switch is closed, the bulb test switch section of the ignition switch is closed, or when certain ABS trouble codes are set.

Intermittent problems can often be identified during the test drive. If the scan tool is equipped with a “snap-shot” feature, use it to capture system performance during normal acceleration, stopping, and turning maneuvers. If this does not reproduce the malfunction, perform an antilock stop on a low coefficient surface such as gravel, from approximately 30 to 50 mph (48 to 80 km/h) while triggering the snapshot mode on the scan tool.

Self-Diagnostics

The control module monitors the electromechanical components of the system. A malfunction of the system will cause the control module to shut off or inhibit the system. However, normal power-assisted braking remains. Malfunctions are indicated by a warning indicator in the instrument cluster. The system is self-monitoring. When the ignition switch is placed in the run position, the ABS control module will perform a preliminary self-check on its electrical system indicated by a second illumination of the amber ABS indicator in the instrument cluster. During vehicle operation, the control module monitors all electrical ABS functions and some hydraulic functions during normal and antilock braking. With most malfunctions of the ABS, the amber ABS indicator will be illuminated and a DTC recorded.

The electronic control system of most ABSs includes sophisticated on-board diagnostics that, when accessed with the proper scan tool, can identify the source of a problem within the system. Each of the DTCs represents a specific possible problem in the system **(Figure 53–31)**. The service information contains a detailed step-by-step troubleshooting chart for each DTC.

Each system has its own self-diagnostic capabilities. Data available for troubleshooting includes wheel-speed sensor readings, vehicle speed, battery voltage, individual motor and solenoid command status, warning light status, and brake switch status. Numerous trouble codes are programmed into the control module to help pinpoint problems. Other diagnostic modes store past trouble codes. This data can help technicians determine if an earlier fault code, such as an intermittent wheel-speed sensor, is linked to the present problem, such as a completely failed wheel sensor. Another mode enables testing of individual system components.

Testers and Scanning Tools

Different vehicle manufacturers provide ABS test and scan tools with varying capabilities **(Figure 53–32)**. Some testers are used simply to access the digital trouble codes. Others may also provide functional test modes for checking wheel sensor circuits, pump operation, solenoid testing, and so forth. Current ABSs are tied to the CAN bus and do not require special testers.

On some vehicles, the amber ABS light and red brake light flash out the digital trouble codes. As you can see, it is important to research the capabilities and proper use of the test equipment the vehicle manufacturer provides. Misuse of test equipment can be dangerous. For example, connecting test equipment during a test drive that is not designed for this use may lead to loss of braking ability.

DTC	Definition
C1211	ABS indicator signal circuit high
C1214	System relay contact or coil circuit open
C1217	BPMV pump motor control circuit shorted
C1218	Pump motor voltage
C1221–C1224	Wheel-speed sensor input signal is zero
C1225–C1228	Excessive wheel-speed sensor variation
C1232–C1235	Wheel-speed sensor circuit open or shorted
C1236	Low system voltage
C1237	High system voltage
C1238	Drive wheel brake rotor excessive temperature
C1242	BPMV pump motor shorted to ground
C1243	BPMV pump motor stalled
C1245	Tire inflation monitor
C1246	Brake lining wear circuit open
C1248	Dynamic rear proportioning control system
C1253	RSS indicated malfunction
C1252	LF normal force malfunction
C1253	RF normal force malfunction
C1254	Checksum error
C1255	EBTCM internal malfunction (ABS/TCS disabled)
C1256	EBTCM internal malfunction
C1261	LF inlet solenoid valve malfunction
C1262	LF outlet solenoid malfunction
C1263	RF inlet solenoid valve malfunction
C1264	RF outlet solenoid malfunction
C1265	LR inlet solenoid valve malfunction
C1266	LR outlet solenoid malfunction
C1266	RR inlet solenoid valve malfunction
C1267	RR outlet solenoid malfunction
C1271	LF TCS master cylinder isolation valve malfunction
C1272	LF TCS prime valve malfunction
C1273	RF TCS master cylinder isolation valve malfunction
C1274	RF TCS prime valve malfunction
C1276	Delivered torque signal circuit malfunction
C1277	Requested torque signal circuit malfunction
C1278	TCS temporarily inhibited by PCM
C1281	Steering sensor uncorrelated malfunction
C1282	Yaw rate sensor bias circuit malfunction
C1283	Excessive time to center steering
C1284	Lateral accelerometer self-test malfunction
C1285	Lateral accelerometer circuit malfunction
C1286	Steering sensor bias malfunction
C1287	Steering sensor rate malfunction
C1288	Steering sensor circuit malfunction
C1291	Open brake switch contacts during deceleration
C1293	DTC C1291 set in previous ignition cycle
C1294	Brake light switch circuit always active
C1295	Brake light switch circuit open
C1298	Class 2 serial data link malfunction
P1571	Requested torque signal circuit malfunction
P1644	Delivered torque signal voltage invalid
P1689	Delivered torque signal voltage invalid

FIGURE 53–31 Examples of some of the DTCs that can be set by an ABS, ATC, ESC system.

Courtesy of SPX Service Solutions.

FIGURE 53-32 A hand-held antilock brake system scan tool.

Once all system malfunctions have been corrected, clear the ABS' DTCs. Codes cannot be erased until all codes have been retrieved, all faults have been corrected, and the vehicle has been driven above a set speed (usually 18 to 25 mph [30 to 40 km/h]). It may be necessary to disconnect a fuse for several seconds to clear the codes on some systems. After service work is performed on the ABS, repeat the previous test procedure to confirm that all codes have been erased.

Testing Components with ABS Scan Tools

ABS scan tools and testers can often be used to monitor and/or trigger input and output signals in the ABS. This allows you to confirm the presence of a suspected problem with an input sensor, switch, or output solenoid in the system. You can also check that the repair has been successful before driving the vehicle. Manual control of components and automated functional tests are also available when using many diagnostic testers. Details of typical functional tests follow.

> **Warning!** Certain components of the ABS are not intended to be serviced individually. Do not attempt to remove or disconnect these components. Only those components with approved removal and installation procedures in the manufacturer's service information should be serviced.

Testing Components with a Lab Scope

Like most electrical/electronic systems, antilock brake traction control and stability control system components can be tested with a lab scope. A lab scope offers one distinct advantage over many other testing tools. You can watch the component's activity over time. For example, all antilock-based systems rely on the cycling of solenoid valves. When looking at the solenoid on the lab scope, you should see a change in the waveform as soon as ABS operation begins. When a wheel tries to slip, the ABS control module should begin pulsing the solenoid to that wheel.

A critical input to the antilock brake, traction control, and stability control systems is from the wheel sensors. These too can be monitored on a lab scope **(Figure 53–33)**. As the wheel begins to spin, the waveform of a PM sensor's output should begin to oscillate above and below zero volts. The oscillations should get taller as speed increases. If the wheel's speed is kept constant, the waveform should also stay constant. Photo Sequence 50 shows the normal way to check a wheel-speed sensor with a lab scope.

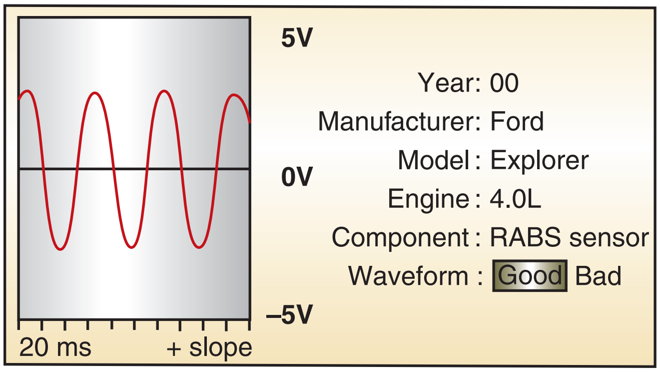
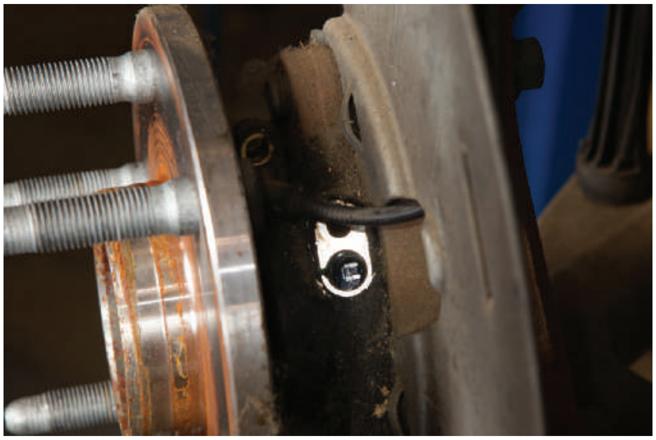


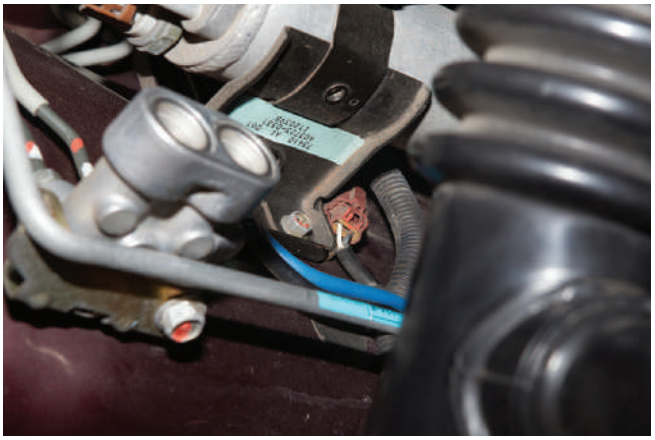
FIGURE 53-33 The waveform from a wheel-speed sensor.

PHOTO SEQUENCE 50

Inspect/Test a Wheel-Speed Sensor with Scope

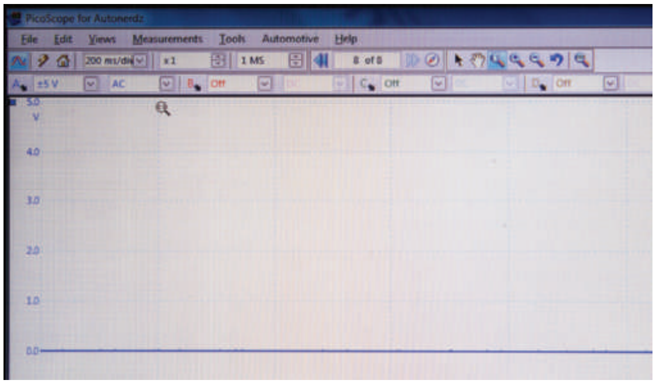


P50-1 Begin by inspecting the tone ring of the wheel-speed sensor for chipped teeth or cracks in the ring. Damage to the ring will affect sensor output.

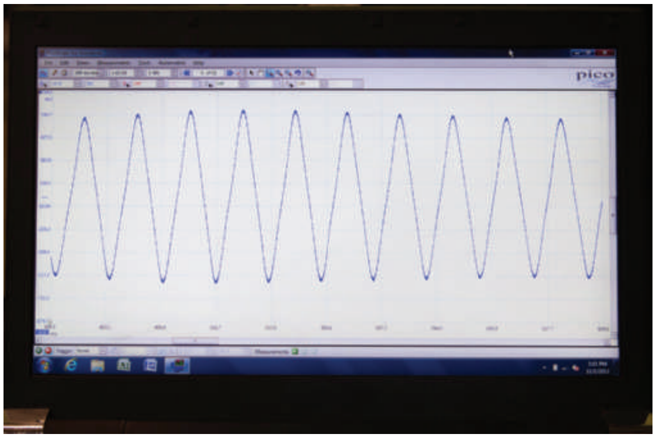


P50-2 Locate the wheel-speed sensor connection to the harness.

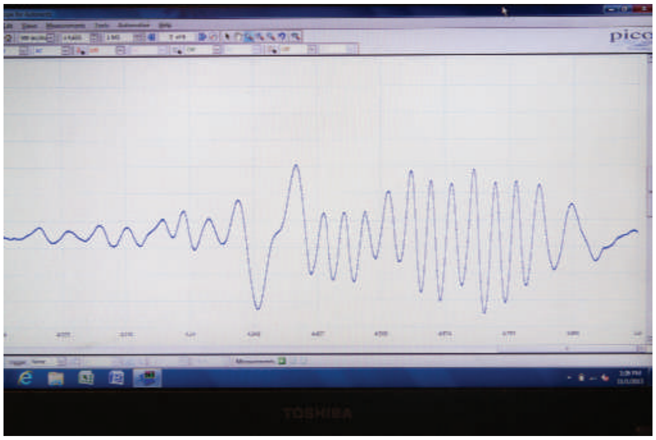
P50-3 Using two back probe pins, back probe the connector so that the scope can be connected to the sensor circuit.



P50-4 Set the scope to display AC voltage over a period of several seconds. Because the output is low, set the voltage to read less than 5 volts if possible.



P50-5 Rotate the wheel by hand and observe or freeze the scope pattern. The pattern should show a uniform positive and negative voltage as the wheel spins.



P50-6 This sensor pattern shows how a damaged tone ring affects the output of the sensor signal. The crack in the tone ring causes a variation in the signal due to the disruption of the magnetic fields between the sensor and the tone ring.

Component Replacement

A typical antilock braking system consists of a conventional hydraulic brake system (the base system) plus a number of antilock components. The base brake system consists of a vacuum power booster, master cylinder, front disc brakes, rear drum or disc brakes, interconnecting hydraulic tubing and hoses, a low fluid sensor, and a red brake system warning light.

Antilock components are added to this base system to provide antilocking braking ability. Most ABSs use the same operational principles, but the major components may be configured and/or named differently.

The electrical components of the ABS are generally very stable. Common electrical system failures are usually caused by poor or broken connections. Other common faults can be caused by malfunction of the wheel-speed sensors, pump and motor assembly, or the hydraulic module assembly.

Many of the components of ABSs are serviced by replacement only. On some systems, wheel-speed sensors must be adjusted. Normal brake repairs, such as replacing brake pads, caliper replacement, rotor machining or replacement, brake hose replacement, master cylinder or power booster replacement, or parking brake repair, can all be performed as usual. In other words, brake service on an ABS-equipped vehicle is similar to service on a conventional system with a few exceptions.

Always refer to the service information for the correct adjustment and replacements procedures for any and all brake parts in an ABS.

Wheel-Speed Sensor Service

Visually inspect each wheel-speed sensor pulsers for chipped or damaged teeth. Use a feeler gauge to measure the air gap between the sensor and rotor **(Figure 53–34)**. Check the gap while rotating the drive shaft, wheel, or rear hub unit by hand. If there is a specification on this gap, make certain the gap is within the required specification (typically 0.02 to 0.04 inch or 0.4 to 1.0 mm). If the gap exceeds specifications, the problem is likely a distorted knuckle that should be replaced.

Also check for a buildup of metal and rust on the sensor. Some sensors have a very strong magnet that will attract metal from all around the area. This buildup can cause the sensor to have inaccurate readings. If the collected material cannot be cleaned, replace the sensor.

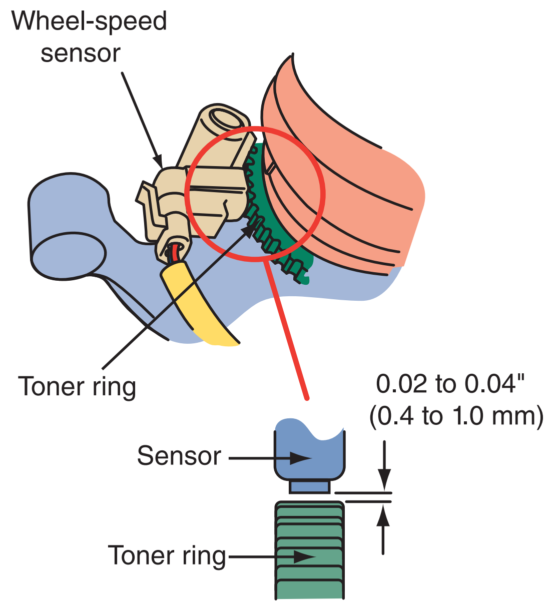


FIGURE 53-34 Wheel-speed sensor gap measurement.

Sensors are replaced by simply disconnecting the wiring at the sensor and unbolting the fasteners. Be careful not to twist the wiring cables or harness when installing the sensors. Many vehicles have a jumper harness made of highly flexible twisted pair wiring between each wheel-speed sensor and the main wiring harness. Many wheel-speed sensors are PM generators that have AC voltage outputs. Radio signals are also AC-modulated signals; therefore, the signal produced by PM generators can be affected by radio frequency interference (RFI). The wires to and from a PM generator must be shielded from other wires in the vehicle that radiate electromagnetic interference (EMI). Because the suspension must be able to move as the vehicle travels, the electrical wiring to the wheel-speed sensors cannot be shielded in conduit. Instead the wires are twisted at least one turn for every 1.75 inches. These are not serviceable and must be replaced if they are damaged or corroded. Never attempt to solder, splice, or crimp these harnesses because eventual failure will likely result.

Brake System Bleeding This is one service area that is most likely to vary with the different designs of the ABS. Always refer to the service information before attempting to bleed the brake system on a vehicle with ABS.

Some systems require that the accumulator be depressurized and the power source to the ABS control module be disconnected. Depressurizing the accumulator often requires pumping the brake pedal up to 40 times. After these have been done, the

system can be bled like a conventional brake system. On other systems, the bleeder screws are opened while the system is turned on, and they have one procedure for the front brakes and another for the rear brakes.

Failure to follow the correct procedure can result in personal injury, destruction of ABS components, or the trapping of more air in the system.

Testing Traction and Stability Control Systems

When troubleshooting a traction or stability control system, it is important to remember that the systems will be automatically disabled by the control unit if a fault occurs. Because TCS and ESC are combined with ABS and share many input signals and output functions, TCS and ESC will be disabled if an ABS fault occurs.

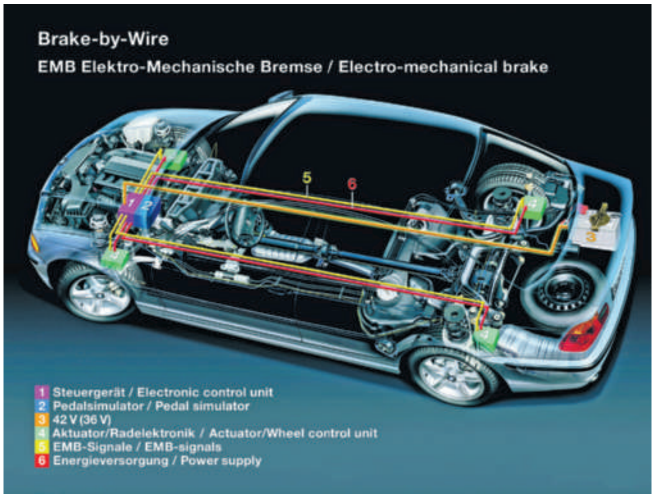
Traction and stability control systems add very few, if any, extra components to a vehicle. The operation of these systems is principally based on altering the control programs of the brake and engine control systems. It follows then that TCS and ESC testing should be based on retrieving DTCs and then testing individual components. Scan tools can read trouble codes and operating system data. The scan tool will also identify any communications errors that may be present. Proper communications is important for both traction and stability control systems. As with other electronic tests, you should refer to the manufacturer's troubleshooting procedures for the vehicle you are servicing.

New Trends

The widespread use of ABS has allowed engineers to pursue many different features for an automobile. Not only have ABS, traction control, and stability control systems advanced, but the entire brake system is in a state of evolution.

Brake-by-Wire

In a brake-by-wire system, the braking command of the brake pedal is electronically processed. A control module receives sensor input from the brake pedal and activates the master cylinder **(Figure 53–35)**. For safety purposes, the normal linkage from the pedal to the master cylinder may still exist. The



Courtesy of BWW of North America, LLC.

FIGURE 53–35 The layout for a brake-by-wire system.

advantage of brake-by-wire is simply that the pressure on the pedal can be immediately and directly relayed to the master cylinder and wheel brakes. Brake-by-wire is currently used in electric vehicles and HEVs so that braking energy can be captured and used to recharge the battery.

In a true brake-by-wire system, the hydraulic system has been totally eliminated; these systems are currently being analyzed.

Electronic Wedge Brake (EWB)

Much development is being done with electronic wedge brakes **(Figure 53–36)**. This system is totally electrically operated and electronically controlled. There is no hydraulic system. This development opens the door for brake-by-wire systems. One of

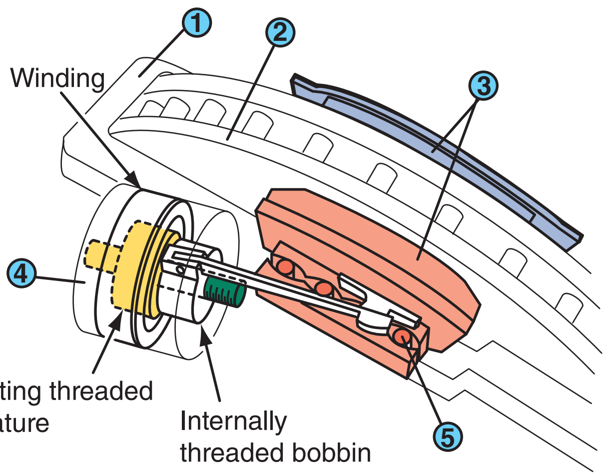


FIGURE 53–36 The layout of an electronic wedge brake. The brake caliper (1) spans the brake disc (2) on two sides. The brake disc is braked by a pad (3) that is moved by an electric motor (4) via several rollers (5) along wedge-shaped faces.

the obstacles to brake-by-wire systems has been providing enough clamping power on the rotor to safely stop the vehicle. The electronic wedge brake uses metal wedges with a series of interlocking triangular teeth between the caliper and the disc.

The wedges are designed to react to the speed of the wheels; as speed increases, so does the clamping pressure of the brakes. When the pad is pushed against the rotor, the momentum of the rotating disc draws the pads farther up the interlocking series of wedges, applying greater braking pressure and increasing braking efficiency. This allows for the use of a low-power 12-volt electric motor to initially push the brake pad toward the rotor. The motor turns roller screws that press the wedge and pads against the rotor.

The system relies on the vehicle's battery for power but also has a built-in backup battery. This is important because one of the fears of brake-by-wire systems is the loss of power. Because the system uses a low-power motor, a small backup battery can power the brakes if needed. Also, as a safety feature, each wheel brake in the system is independent of the others. This means if one brake fails, there are three others that can be used to stop the vehicle. The system can also quickly retract the pads when the brake pedal is released; this reduces brake drag and allows for ABS cycling to occur up to six times faster.

It is claimed that EWB systems greatly shorten stopping distances, require much less energy than hydraulic brakes, allow for much better control in ATC and ESC systems, are light, and are more reliable and durable than hydraulic brake systems.

Several suppliers, such as Siemens VDO, Continental AG, Robert Bosch LLC, Delphi Corporation, and TRW Automotive, also are working on electromechanical brake programs.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2000	**Make:** Cadillac	**Model:** SLS	**Mileage:** 92,585	**RO:** 19189
Concern:	Customer states the ABS light is staying on all the time. Brakes feel normal.			
History:	Car had front struts installed elsewhere recently. Was told problem was unrelated.			
After confirming the complaint, the technician installs a scan tool and retrieves an ABS trouble code for the right front wheel-speed sensor. Leaving the scan tool connected, he drives the vehicle and notes all wheel-speed sensors but the RF indicates its wheel speed. In the shop, he inspects the wheel's speed sensor wiring and finds damage at the connector. He tests the sensor and it produces a signal as it should. He then tests for the sensor signal at the connector but cannot get a signal.				
Cause:	Damaged WSS harness connector creating an open circuit in the sensor circuit.			
Correction:	Replaced the sensor harness from module to WSS.			

KEY TERMS

Integral antilock brake system
Isolation/dump valves
Nonintegral antilock brake system
Pressure modulation
Yaw

SUMMARY

- Brake fluid is the lifeblood of any hydraulic brake system. DOT 3 is recommended for most antilock brake systems and some power brake systems.
- Modern antilock brake systems provide electronic/hydraulic pumping of the brakes for straight-line stopping under panic conditions.
- In addition to being classified as integral and nonintegral, antilock brake systems can be divided into the level of control they provide. They can be one-, two-, three-, or four-channel, two- or four-wheel systems.
- Pressure modulation works to prevent wheel locking. Antilock brake systems can modulate the pressure to the brakes as often as fifteen times per second.
- Integrated antilock brake systems combine the master cylinder, hydraulic booster, and hydraulic

circuitry into a single assembly. On a nonintegrated ABS, the master cylinder and hydraulic valve unit are separate assemblies and a vacuum boost is used. In some nonintegrated systems, the master cylinder supplies brake fluid to the hydraulic unit.

- Automatic traction control (ATC) is a system that applies the brakes when a drive wheel attempts to spin and loses traction.
- Automatic stability systems correct oversteer and understeer by applying one wheel brake.
- Malfunction of the ABS causes the electronic control module to shut off or inhibit the system. However, normal power-assisted braking remains. Malfunctions are indicated by one or two warning lights inside the vehicle.
- Loss of hydraulic fluid or power booster pressure disables the antilock brake system.

REVIEW QUESTIONS

Short Answer

1. What is the primary difference between an automatic traction control system and a stability control system?
2. Briefly describe the proper steps and testing needed to accurately diagnose antilock braking systems.
3. An ABS modulates brake pressure. What does this mean?
4. Explain the difference between oversteer and understeer.
5. List the various methods used by traction control systems to eliminate wheel spin.
6. Besides indicating ABS faults for some systems, the red brake warning lamp on the instrument panel can indicate failure of the ___ brake system, application of the ___ brake, or low fluid level in the ___.
7. What are the functions of an isolation/dump valve?
8. Describe the normal pedal feel when the ABS is activated during hard braking.
9. Define the difference between an integrated and a nonintegrated antilock braking system.
10. Why are the wires leading to some wheel-speed sensors twisted?
11. Describe the differences between passive and active wheel speed sensors.

Multiple Choice

1. Which of the following is a *true* statement?
   a. In some antilock brake systems, the power brake assist is provided by pressurized brake fluid supplied by the hydraulic accumulator.
   b. The accumulator is a small, sealed chamber mounted to the pump/motor assembly.
   c. The accumulator holds a highly pressurized nitrogen gas that is used to generate a charging pressure.
   d. All of the statements are true.
2. What is the name for the gas-filled pressure chamber that is part of the antilock braking system's pump and motor assembly?
   a. Control module
   b. Accumulator
   c. Sensor
   d. Reservoir
3. When inspecting wheel-speed sensors, check for all of the following *except* ___.
   a. buildup of metal or rust on the sensor
   b. proper contact between the pole piece and tone ring
   c. secure sensor mounting
   d. condition of the tone ring teeth
4. Which type of ABS is not commonly used on modern vehicles?
   a. Four-wheel nonintegral
   b. Two-wheel nonintegral
   c. Four-wheel integral
   d. None of the above

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that a malfunction of the ABS causes the control module to shut off or inhibit the system. Technician B says that a loss of hydraulic fluid or power booster pressure disables the antilock brake system. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

2. While road testing a car equipped with an ABS: Technician A says that during heavy braking, several pulses may be felt through the brake pedal. Technician B says that a spongy pedal during normal braking is normal. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. Technician A says that the accumulator in an ABS is used to store hydraulic fluid to provide residual pressure for power-assist braking. Technician B says that the booster pump in an antilock system provides pressurized hydraulic fluid for the ABS. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. Technician A says that it is normal for the amber brake lamp to light when the ABS is activated during braking. Technician B says that it is normal for the red brake lamp to be on whenever the ignition is on and the engine is off. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. Technician A says that some antilock brake systems use a lateral acceleration sensor in addition to the wheel-speed sensors. Technician B says that traction control systems apply one wheel brake to get the vehicle going in the direction in which it is being steered. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. Technician A says that wheel-speed sensors send an AC voltage signal to the control module. Technician B says that wheel speed signals create an AC signal voltage by altering a reference voltage received from the control module. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. A vehicle's ABS activates during low speed turns on dry pavement. Technician A says a loose wheel bearing may cause this. Technician B says this is normal because wheel speed sensors are not accurate at very low speeds. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. Technician A says that each ABS has its own diagnostic procedure involving use of the brake and antilock warning lamps, special testers, troubleshooting charts, and wiring diagrams. Technician B says that ABS codes are lost from memory when the ignition is turned off. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. Technician A says engine power may be reduced if positive wheel spin is detected by the ABS/ATC system. Technician B says positive wheel spin indicates a wheel is locked up. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. Technician A says that some traction control systems eliminate wheel spin by applying the brakes on the driving wheels. Technician B says that some traction control systems eliminate wheel spin by retarding ignition timing and cutting off fuel injection. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

PASSENGER COMFORT

SECTION 9

CHAPTER 54

HEATING AND AIR CONDITIONING

OBJECTIVES

- Identify the common parts of a heating system.
- Describe the operation of the vacuum and mechanical controls of a heating system.
- Diagnose temperature control problems in the heater/ventilation system.
- Describe how an automotive air-conditioning system operates.
- Describe how refrigerants are used in the air-conditioning system.
- Locate, identify, and describe the function of the various air-conditioning components.
- Describe the operation of the types of air-conditioning control systems.

The first automobiles had few features that provided for driver and passenger comfort. In winter, heavy coats and blankets were all that allowed passengers to survive the bitter cold and freezing winds. In summer, the breeze generated by 15 mph (25 km/h) travel was the only thing that cooled the passengers.

Today's vehicles have ventilation, heating, and air-conditioning systems to provide passenger comfort. Ventilation and heating systems are standard equipment on all passenger vehicles and air conditioning is standard on most and available for nearly all. These systems move heat to warm or cool the passengers.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 1997	**Make:** Buick	**Model:** LeSabre	**Mileage:** 52,248	**RO:** 19268
Concern:	Customer states the passenger floor is wet.			
History:	Car had cooling system flushed and refilled 6 months ago.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

GO TO Chapter 3 for a detailed discussion of heat and heat transfer.

Ventilation System

The ventilation system on most vehicles is designed to supply outside air to the passenger compartment through upper or lower vents or both. Several systems are used to vent air into the passenger compartment, the most common of which is the flow-through system **(Figure 54–1)**. In this arrangement, a supply of outside air, called ram air, flows into the car when it is moving. When the car is not moving, a steady flow of outside air can be produced by the heater fan. In operation, ram air is forced through an inlet grille. The pressurized air then circulates throughout the passenger and trunk compartment. From there the air is forced outside the vehicle through an exhaust area.

Rather than using ram air (especially if the vehicle is stopped), a ventilation fan can be used. It can be accessible from under the dashboard or from inside the engine compartment. A blower motor and fan assembly is placed inside the blower housing. As the fan, often called a squirrel cage, rotates, it produces a strong suction on the intake. A pressure is also created on the output. When the fan motor is energized by using the temperature controls on the dashboard, air is moved through the passenger compartment. Most vehicles have a cabin filtration system that cleans the air before it enters the passenger compartment.

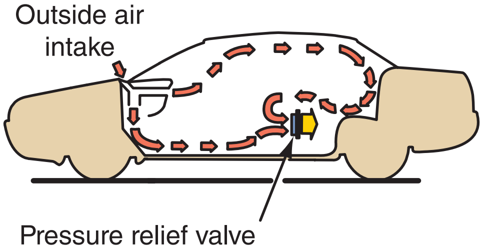


FIGURE 54–1 A flow-through ventilation system.

Automotive Heating Systems

The heating system's primary job is to provide a comfortable passenger compartment temperature and to keep car windows clear of fog or frost. The heating system works together with the engine's cooling system to maintain proper temperatures inside the car.

GO TO Chapter 14 for details of the engine cooling system.

To meet federal safety standards, all vehicles must be equipped with passenger compartment heating and windshield defrosting systems. The main components of an automotive heating system are the heater core, the heater control valve, the blower motor and the fan, and the heater and defroster ducts **(Figure 54–2)**. The heating system works with the engine's cooling system and converts the heat from the coolant circulating inside the engine to hot air, which is blown into the passenger compartment.

SHOP TALK

In most vehicles, the air conditioning will turn on when the defroster is selected by the driver and the ambient temperature is more than 35 °F (1.67 °C). This is done to remove moisture from the vehicle's interior.

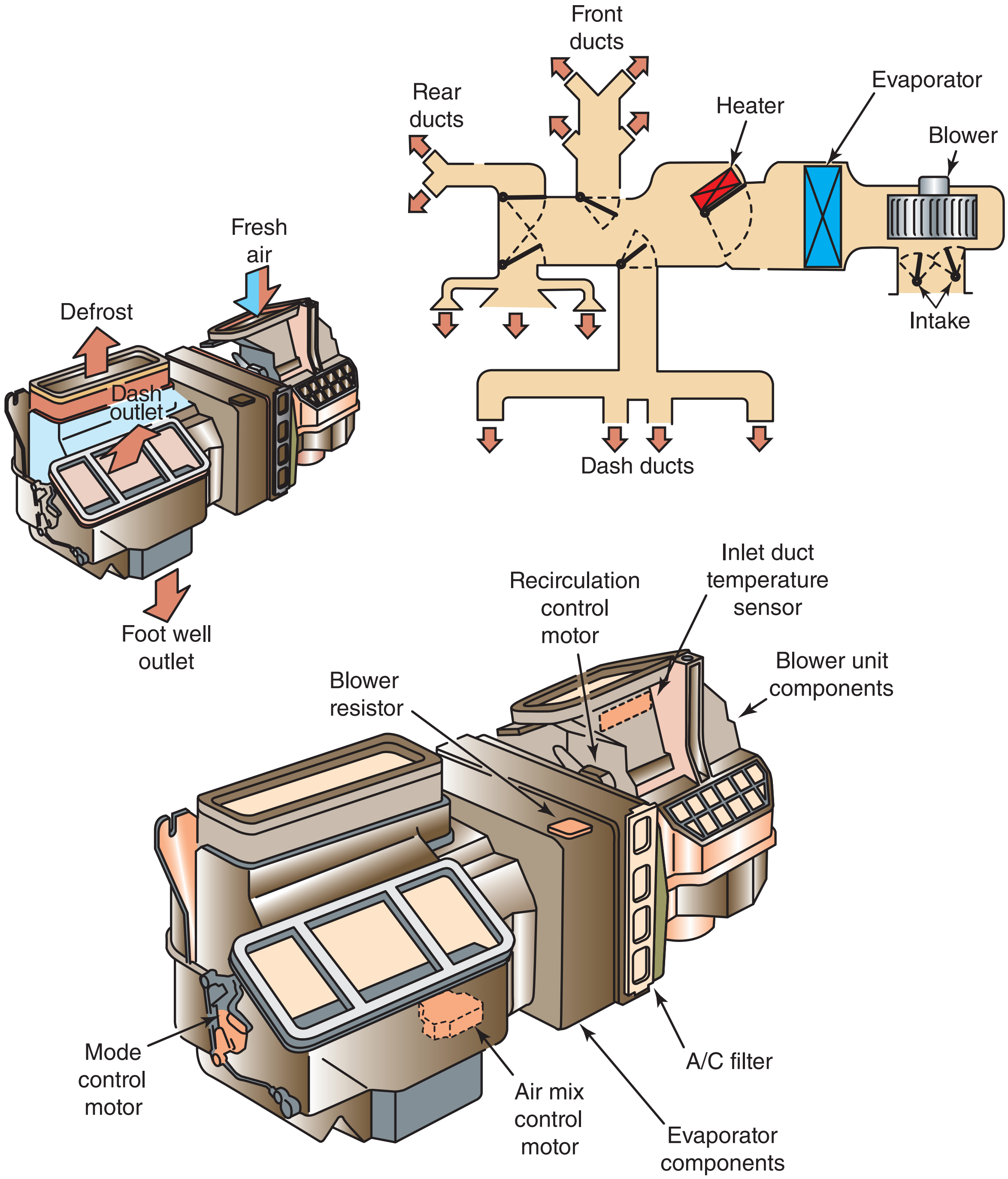


FIGURE 54–2 A typical HVAC airflow and components for the heater and air conditioning system.

In the liquid-cooling system, heat from the coolant circulating inside the engine is converted to hot air, which is blown into the passenger compartment. Hot coolant from the engine is transferred by a heater hose to the heater control valve and then to the heater core inlet **(Figure 54–3)**. As the coolant circulates through the core, heat is transferred from the coolant to the tubes and fins of the core. Air blown through the core by the blower motor and fan then picks up the heat from the surfaces of the core and transfers it to the passenger compartment of the car. After giving up its heat, the coolant is then pumped out through the heater core outlet, where it is returned to the engine to be heated again.

Heater Core

The **heater core** is generally designed and constructed much like a miniature radiator **(Figure 54–4)**.

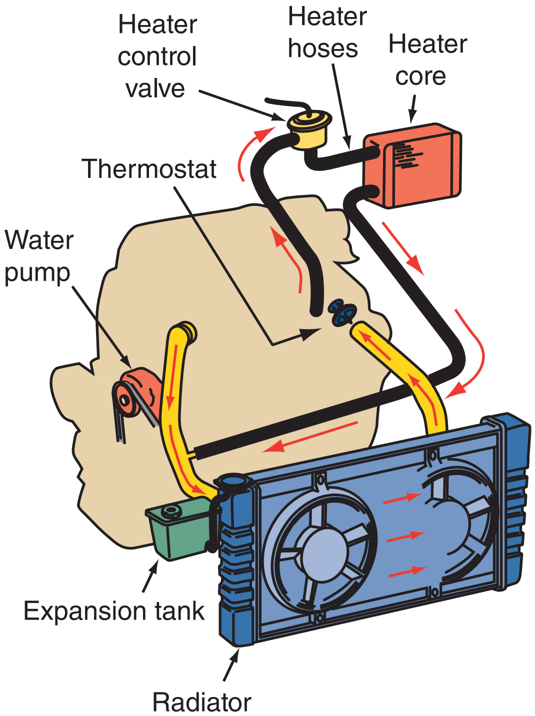


FIGURE 54-3 Hot coolant from the engine is sent from the upper portion of the engine to the heater core.

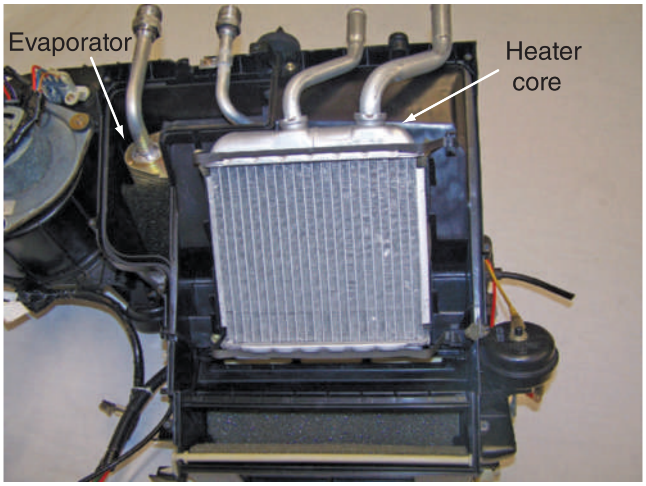


FIGURE 54-4 A heater core.

It features an inlet or outlet tube and a tube and fin core to facilitate coolant flow between them.

Although all heater cores basically function in the same manner, several variations in design and materials are used by different automakers to achieve the same results. Although the core construction varies, this type has an aluminum core with plastic tanks.

Heater Control Valve

The **heater control valve** (sometimes called the water flow valve) controls the flow of coolant into the heater core from the engine. In a closed position, the valve allows no flow of hot coolant to the heater core, keeping it cool. In an open position, the valve allows heated coolant to circulate through the heater core, maximizing heater efficiency. Heater control valves are operated in several ways: by cable, thermostat, vacuum, or electronically. Some vehicles do not use a heater control valve; rather, a heater door controls how much heat is released into the passenger compartment from the heater core.

Cable-operated valves are controlled directly from the heater control lever on the dashboard. Thermostatically controlled valves feature a liquid-filled capillary tube located in the discharge air stream off the heater core. This tube senses air temperature, and the valve modulates the flow of coolant to maintain a constant temperature, regardless of engine speed or temperature.

Many heater valves found in today's car are vacuum operated. These valves are normally located in the heater hose line or mounted directly in the engine block. When a vacuum signal reaches the valve, a diaphragm inside the valve is raised, either opening or closing the valve against an opposing spring. When the temperature selection on the dashboard is changed, vacuum to the valve is vented and the valve returns to its original position. Vacuum-actuated heater control valves are either normally open or normally closed designs.

Many newer vehicles use electrically controlled heater control valves. The valve may use a stepper motor to block the flow of coolant or use the motor to move a lever and block the flow as in non-electronic valves.

On late-model vehicles, heater control valves are typically made of plastic for corrosion resistance and light weight **(Figure 54–5)**. These valves feature few internal working parts and no external working parts. With the reduced weight of these valves, external mounting brackets are not required.

Systems without a Control Valve Some systems do not have a heater control valve; rather, heat inside the passenger compartment is controlled by changing the airflow over the heater core. In these systems, hot coolant always flows through the heater core. When heat is needed, air is allowed to flow through the heater core. The amount of heat is determined by the amount of air allowed to pass through the core.

Airflow is controlled by a blend door inside the blower housing. The blend door directs airflow either across the heater core or air-conditioning evaporator. This allows the driver to change the temperature of the air from the system. The movement of this

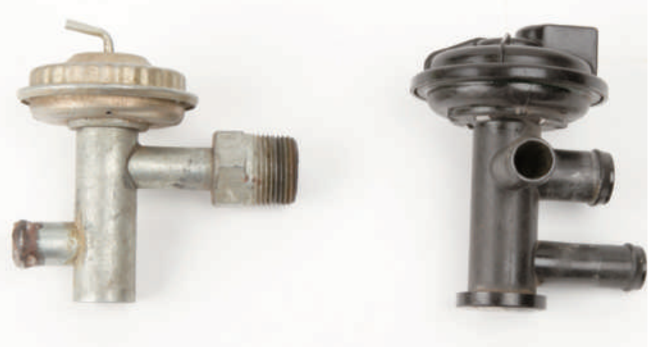


FIGURE 54–5 Two types of heater control valves: (left) a vacuum-operated plastic unit, and (right) a cable-operated valve.

door can be controlled by a cable, vacuum, or electrically with a motor.

PTC Heaters Today's engines are designed to reduce the amount of waste heat they emit; therefore, the amount of heat available for the heating system may be limited. This is especially true with hybrid vehicles with the stop-start feature. Also, in conventional vehicles, interior heat is not available until the coolant warms up and transfers heat through the heater core.

Some late-model vehicles, especially hybrids, have an auxiliary positive temperature coefficient (PTC) unit **(Figure 54–6)** or a PTC heating element in the heater core. These heaters are able to provide warm air before the engine's coolant warms up. PTC heaters are electronically controlled and work independently of the cooling system.

When current passes through a PTC element, heat is produced and the air that passes through the heater core is warmed. Some vehicles have an additional PTC element installed in an air duct from the blower housing; this helps to increase the air temperature in the ducts.

PTC elements react quickly to changes in current. The elements are small ceramic stones. These are typically barium titanate polycrystalline ceramics doped with metals. Most PTC elements are self-regulating, which means there is no need for a thermostat to control its operation. As the element heats, its resistance increases. Once a predetermined temperature is reached, the internal resistance increases significantly, reducing current flow and preventing further increase in temperature.

Blower Motor

The blower motor is usually located in the heater housing assembly. It ensures that air is circulated through the system **(Figure 54–7)**. Its speed is controlled by a multiposition switch in the control panel. The switch works in connection with a resistor block that is usually located on the heater housing.

On some vehicles, when the engine is running, the blower motor is in constant operation at low speed. On automatic temperature control systems, the blower motor is activated only when the engine reaches a predetermined temperature. The blower motor circuit is protected by a fuse located in the fuse panel.

The blower motor resistor block is used to control the blower motor speed. The typical resistor block is composed of three or four wire resistors in series with the blower motor that control its voltage and current. The speed of the motor is determined by the control panel switch, which puts the resistors in series. Increasing the resistance in the system slows the blower speed.

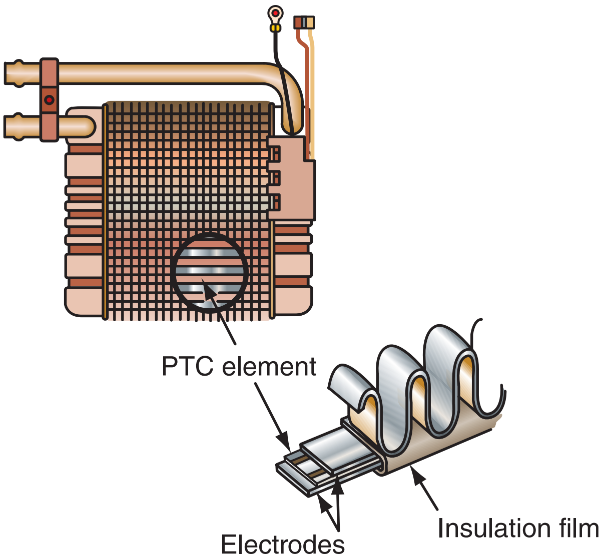


FIGURE 54–6 An electronic PTC auxiliary heater.

FIGURE 54–7 A blower motor assembly.

Vehicles with automatic climate control typically use pulse-width modulation to control blower speed. Instead of a fixed resistor block and fixed blower speeds, a control module pulses the blower motor power circuit on and off. By varying the on-time of the motor, fan speed is increased or decreased as needed.

Some late-model vehicles, including the Toyota Prius and some Mercedes-Benz models, use solar cells to power the blower motor to circulate air through the passenger compartment when the vehicle is off. The sunload and ambient temperature sensors provide input to the climate control module, which can vary blower speeds as needed. Circulating air through the cabin helps reduce the temperature and the load on the A/C system once the vehicle is restarted.

Heater and Defroster Duct Hoses

Transferring heated air from the heater core to the passenger compartment heater and defroster outlets is the job of the heater and defroster ducts. The ducts are typical parts of a large plastic shell that connects to the necessary inside and outside vents. This ductwork also has mounting points for the evaporator and heater core assemblies. Contained inside the duct are the mode doors required to direct air to the floor, dash, and/or windshield. Sometimes the duct is connected directly to the vents, whereas other times hoses are used.

Recirc/Fresh Door Many vehicles have a recirc/fresh mode. This feature allows the driver to recirculate (recirc) the air inside the vehicle. This mode is normally selected when outside air is entering the vehicle and it has unpleasant odors. Outside or fresh air normally enters the interior through the normal heating, ventilation, and A/C systems. While operating in the recirc mode, the system uses the air from the interior for those systems. A recirculation door closes off the outside airflow and opens the intake for interior air.

Some late-model vehicles use sensors to detect smog and pollution present in the incoming air. On some models, the sensor also is able to detect carbon monoxide, hydrocarbons, and oxides of nitrogen. Upon detection of contaminates, airflow is automatically switched to recirculation mode. The recirculated air passes through a dust and pollen filter and charcoal filter to remove any odors and contaminants.

Heating and A/C Systems in Hybrid Vehicles

In a hybrid electric vehicle, the engine can be used to supply the heat, so heating and defrosting systems are similar to those used in conventional vehicles. However, some hybrids have additional electrical heaters. These keep the passenger compartment warm when the engine is off.

Other systems have a 12- or 42-volt auxiliary electric water pump. This pump is used to circulate coolant through the engine to maintain heater performance during an idle stop. A heater control module operates the pump based on an idle stop signal from the PCM. If the engine's temperature drops below a predetermined level during an idle stop, the engine will restart. The system also has a temperature sensor at the heater core. This sensor monitors the activity of the electric water pump. If it senses that the heater core is losing heat quickly, the control module will assume that the pump has failed and will start the engine and set a DTC.

The cooling systems used in some hybrids feature coolant storage tanks. Hot coolant is stored in a container **(Figure 54–8)** where it can remain hot for several days. The hot coolant is circulated through the engine immediately after startup. The fluid also may circulate through the engine many hours after it is shut off. The stored coolant can provide heat for the passenger compartment and allows the engine to warm up quickly, thereby reducing emission levels during startup.

The heating and A/C system is also used on some hybrid vehicles to maintain HV battery temperature. Because temperature is important for battery efficiency, a network of heating and cooling lines may be attached to the battery box. Even if separate liquid heating and A/C lines are not used, there is a ventilation system for the HV battery. In many hybrids, such as the Prius, Honda IMA hybrids, and others, a battery ventilation fan and ductwork system is used to draw cabin air into and through the battery box. Air is then discharged outside the vehicle. It is important that the inlet for the battery cooling system not be blocked or restricted as this can increase battery temperature and set battery temperature DTCs.

Vehicles that use Li-Ion batteries, such as the Volt, have dedicated heating and A/C lines for the battery box. In addition to circulating coolant through the inverter and drive motor assemblies, the Volt uses a separate A/C evaporator, called a battery chiller, to remove heat from the battery charger and pack. Depending on operating conditions, the liquid cooling system can either be used to warm the battery pack or remove heat. When greater heat dissipation is required, the A/C compressor is turned on and the A/C system cools the battery.

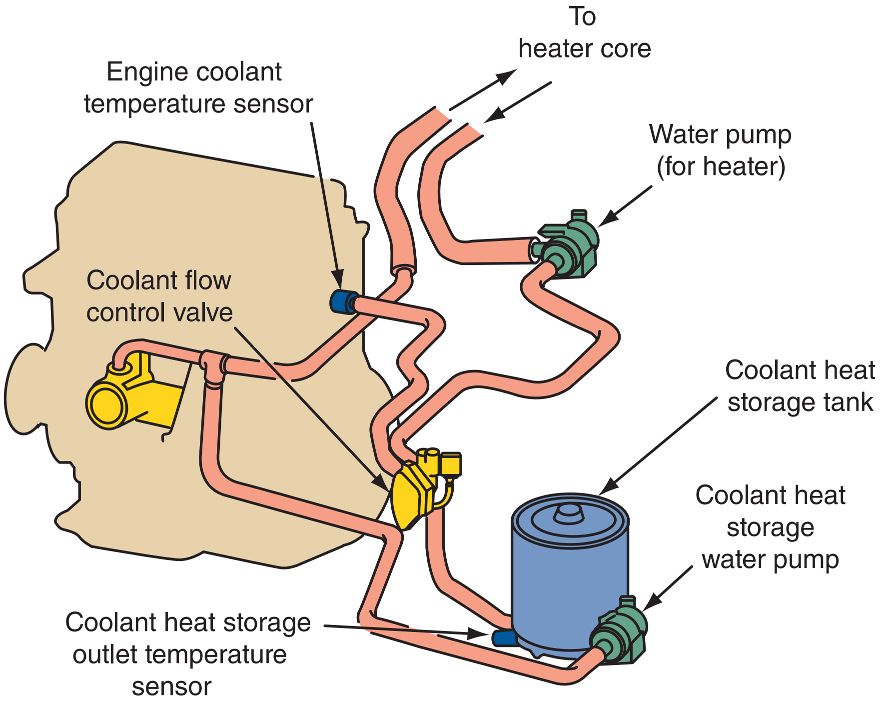


FIGURE 54-8 The coolant heat storage tank is a large vacuum-insulated container that is capable of storing hot coolant for a long period.

Heating System Service

When doing system checks and services, always follow the procedures recommended by the manufacturer. In most cases, problems with the heating system are problems with the engine's cooling system. Therefore, most service work and diagnosis are done to the cooling system. Problems that pertain specifically to the heater are few, these being the heater control valve and the heater core. Most often if these two items are faulty, the engine's cooling system will be negatively affected. Both of these items are replaced rather than repaired. Some problems will pertain only to the heater controls. In some cases, it is possible to make repairs to vacuum hose and electrical connections without removing the heater assembly. If it is necessary to remove the heater assembly, the cooling system must be drained before removing the heater core.

GO TO Chapter 14 for details on diagnosing and servicing engine cooling systems.

Basic Heater Inspection and Checks

When there is a problem of insufficient heat, begin your diagnosis with a visual inspection and a check of the coolant level and condition. If the level is correct, turn the heater controls on and run the engine until it reaches normal operating temperature. If the engine does not reach operating temperature, typically around, 220 °F (104.4 °C) suspect a faulty thermostat or fan clutch. Then measure the temperature of the upper radiator hose. The temperature can be measured with a pyrometer or thermocouple and a DMM. If these are not available, carefully touch the hose. You should not be able to hold the hose long because of the heat. While doing this, make sure you stay clear of the area around the cooling fan. A spinning fan can chop off your hand. If the temperature of the hose is not within specifications, suspect a faulty thermostat.

If the hose is the correct temperature, check the temperature of the two heater hoses. They should both be hot. If only one of the hoses is hot, suspect the problem to be the heater control valve or a plugged heater core.

Leaking heater cores are often easy to diagnose because of the presence of one or more of three symptoms: coolant leaking onto the floorboards, steam coming from the vents, and a sweet smell

inside the passenger compartment. Any of these conditions should prompt a complete inspection of the cooling system.

Heater Core Service

Like the radiator, heater core tanks, tubes, and fins can become clogged over time by rust, scale, and mineral deposits circulated by the coolant. Debris carried through the system can actually act as a sandblaster and eat away at the core from the inside, causing leaks. Feel the heater inlet and outlet hoses while the engine is idling and warm with the heater temperature control on hot. If the hose downstream of the heater valve does not feel hot, the valve is not opening.

If the heater core appears to be plugged, the inlet hose may feel hot up to the core but the outlet hose remains cool. Reverse flushing the core with a power flusher may open up the blockage, but usually the core has to be removed for cleaning or replacement. Air pockets in the heater core can also interfere with proper coolant circulation. Air pockets form when the coolant level is low or when the cooling system is not properly filled after draining.

When the heater core leaks and must be repaired or replaced, it is often a very difficult and time-consuming job, primarily because of the core's location deep within the bulkhead of the car. For this reason always leak test a replacement heater core before installation. Also flush the cooling system and replace the coolant.

The heater core is normally buried under the dash. Replacing the core may require evacuating the A/C system also. This is due to both the core and evaporator being in the same housing. Before starting to replace the core, read through the service information to determine what needs to come apart and how.

On some vehicles heater core replacement is much easier. To remove it, remove the access panel(s), drain the coolant from the system and then disconnect the heater hoses to the core. It is wise to place shop rags or towels under the core so that fluid does not leak out onto the vehicle's carpet. Unbolt the core and remove it, make sure nothing is damaged as you pull the core out. The procedure for installing a heater core follows the reverse steps as removing it.

When replacing the heater core, inspect the heater hoses and replace if necessary. Most heater hoses are molded into specific shapes and must be replaced with the same size and shape hose. Bulk heater hose can kink if bent to fit into place, reducing flow through the core. Because the heater hoses

SHOP TALK

A common procedure for servicing a cooling system is reverse flushing it. However, some manufacturers do not recommend reverse flushing their heater cores. Always check with the service information before reverse flushing a system.

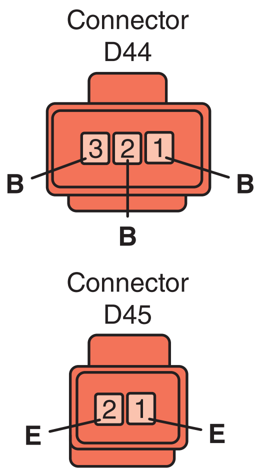
can be difficult to access and remove from the core, many technicians cut the old hoses at the pipe connections and replace the hoses.

PTC Heaters PTC heaters can be checked by measuring the resistance of the heating element. If the resistance does not meet specifications **(Figure 54–9)**, the assembly should be replaced.

Heater Control Valve Service

When there is a problem with the control valve, it is typically caused by the controls or the valve itself. When the valve is bad, it should be replaced. If the heater control valve or its controls prevent the valve from opening all the way, heating will be reduced in the passenger compartment. If the valve does not completely close, the compartment will not cool properly when the A/C is turned on.

With cable-operated control valves, check the cable for sticking, slipping (loose mounting bracket), or misadjustment. With valves that are vacuum operated, there should be no vacuum to the valve when the heater is on (except for those that are normally closed and need vacuum to open).



Connections for testing
D44-2 (B) to D45-1 (E)
D44-2 (B) to D45-2 (E)
D44-3 (B) to D45-2 (E)
Value for all: 0.5 to 2.5Ω

FIGURE 54–9 Resistance testing points at the terminals on a PTC heater.

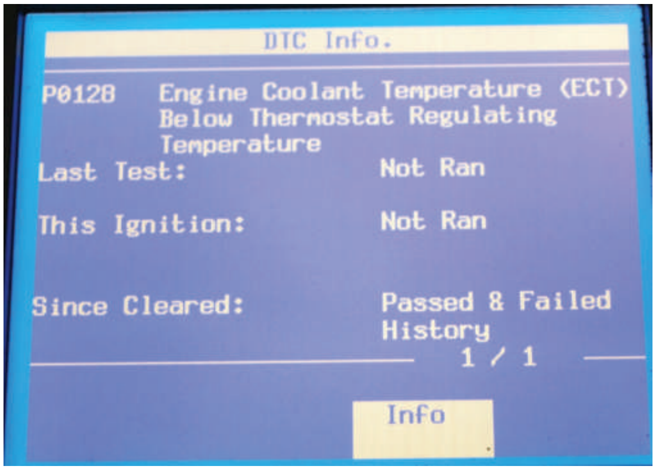


FIGURE 54–10 An example of a DTC for insufficient coolant temperature.

Thermostat Service The thermostat, which helps regulate the coolant temperature in the cooling system, plays a large part in the heating system. A malfunctioning thermostat can cause the engine to overheat or not reach normal operating temperature, or it can be the cause of poor heater performance.

Late-model vehicles can set a DTC if the thermostat is not allowing the engine to reach normal operating temperature **(Figure 54–10)**. A thermostat that is stuck open or is opening too soon can often be diagnosed by watching the flow of coolant in the radiator during engine warm up or by monitoring coolant temperature. Most engines have thermostats that begin to open around 175 °F (79.4 °C) and are fully open at 195 °F (90.5 °C). If the coolant temperature remains low, not even reaching 195 °F (90.5 °C), suspect a defective thermostat.

Replacing a thermostat varies greatly from engine to engine so refer to the manufacturer's service information for details. Make sure the new thermostat is installed properly with the wax pellet oriented toward the engine. Also, make sure the thermostat seats and seals properly in its housing before tightening the housing bolts to specs. Once the thermostat has been replaced, refill the cooling system using the specified coolant and make sure all air is bled from the system.

SHOP TALK

Poor heating can be caused by many things. A low coolant level can starve the heater, resulting in little or no heat output. Check the coolant level in the radiator (not the overflow tank) to see if it is low. Air pockets can form in long heater hoses or where the heater is mounted higher than the radiator. To vent the trapped air, some vehicles have bleeder valves on the hoses. Opening the valves allows air to escape as the system is filled.

Blower Motor Service

If the blower motor does not operate, use a DMM to make sure there is voltage on both sides of the fuse. Then check to see if there is voltage and ground at the motor. Some systems supply constant power and vary the ground while others ground the motor and vary the voltage **(Figure 54–11)**. If the system uses a PWM motor, connect a scan tool and check for DTCs and try to control the blower with the scan tool. You may need to connect a meter or scope to the fan's wiring to determine if the fan control circuit is operating.

For non-PWM blower motors, if the blower motor is getting voltage and has a good ground, the problem is a burned-out blower motor. If voltage is present but the motor does not run, ground the motor to check if it operates. If the motor now works, the problem is likely an open resistor or switch. In situations where no voltage is available at the motor, backtrack to check for an open resistor, switch, or relay. Check for proper relay operation and for burned or corroded connections at the blower relays or in the bulkhead connectors. Carefully inspect all wiring and connectors in the fan circuit. A faulty connection can overheat, melting the plastic and damaging the connector and terminals.

As the blower motor ages and/or debris accumulates in the blower housing, blower motor speed can be reduced. This can cause the motor to increase its current draw. Excessive current draw by the motor can then cause burned resistors and damaged connections. Many technicians measure blower motor current draw whenever replacing a blower resistor and compare the reading to specs or against similar vehicles. If the motor is drawing more current than specified, it should be replaced.

Heater and Defroster Duct Service

If the blower motor runs but no air comes out of the ducts, the problem is either a stuck or an inoperative airflow control valve or blend door or plugged cabin filter. This can also affect the operation of the defrosters. These doors may be cable, electrically, or vacuum operated. To further diagnose the problem, change the

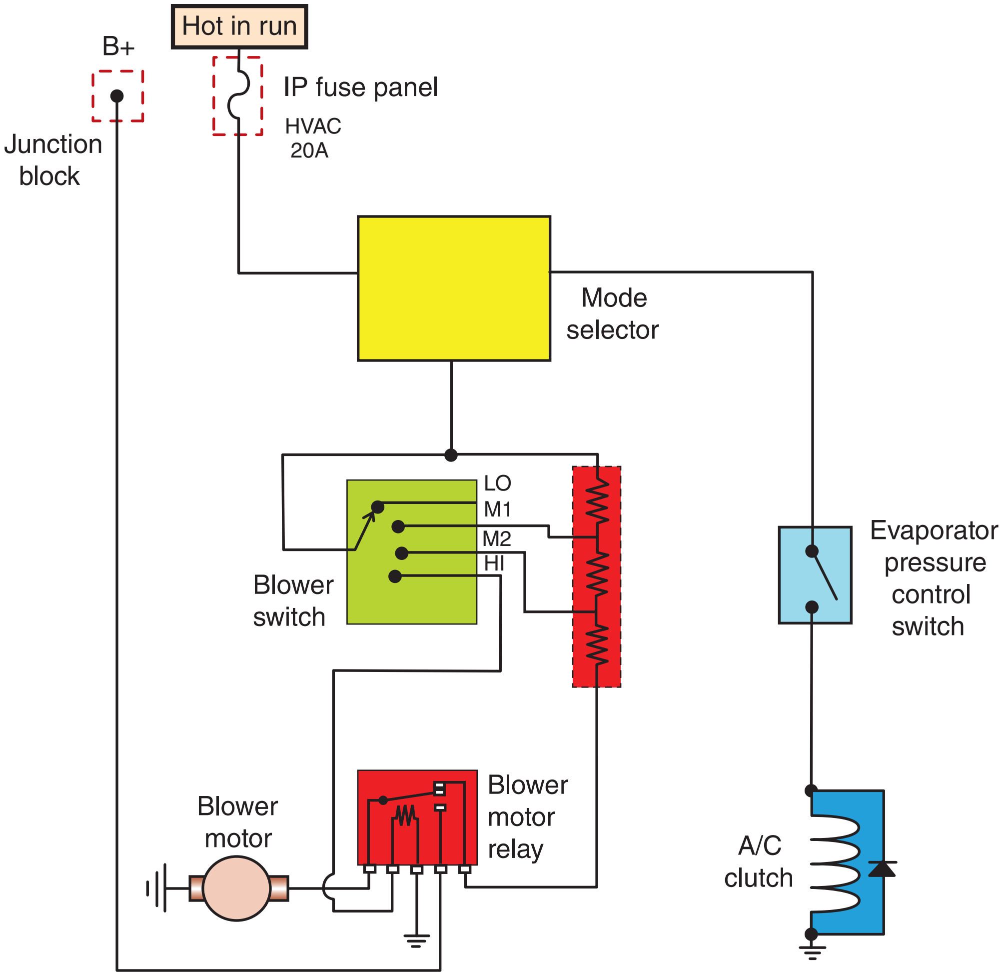


FIGURE 54-11 An example of a power-controlled blower motor circuit.

position of the temperature selector knob, sliding it from hot to cold. If you do not hear the sound of doors opening and closing, it means the control cables have slipped loose from the dash switch or door arm, which can sometimes occur, rendering the door inoperative. If this is the case, you will feel little or no resistance when sliding the temperature control knob. A kinked or rusted cable can also prevent a door from working. If this is the case, you will feel resistance when trying to move the control knob. In either case, it is necessary to get under the dash, find the cable, and then replace, reroute, or reconnect it. Doors can also be jammed by objects that have fallen down the defroster ducts. Remove the obstruction from the plenum by fishing through the heater outlet with a coat hanger or magnet, or remove the plenum. Be careful when fishing for the obstruction; some heater cores are easily pierced.

Most current HVAC systems use electric servomotors to move the various doors. Each motor is fitted with a potentiometer that sends a signal to the A/C control unit regarding the actual position of the door. If the actual position is not the same as the commanded position, most systems will set a DTC, indicating that the door is not working properly. Before proceeding with detailed diagnostics of the electrical system, make sure there are no linkage problems or that the door is not physically stuck. Normally, if the problem is electrical, the A/C control unit, servomotor, or wiring harness is faulty.

With vacuum-controlled doors, the most common causes of failure are leaky or loose vacuum hoses or defective diaphragms in the vacuum motors that move the doors. Check the vacuum by starting the engine and disconnecting the hose that goes to one of the door's vacuum motor. If you feel a vacuum or hear a hissing sound when trying different temperature settings, the vacuum source is good. Apply vacuum to the motor with a hand-held pump; if it moves and holds vacuum for about 1 minute then bleeds off, the problem is a bad vacuum motor. If it does not, check for leaky vacuum hose connections, a defective temperature control switch, or a leaky vacuum reservoir or check valve under the dash or in the engine compartment.

Theory of Automotive Air Conditioning

Air conditioning basically supplies cool air into the passenger compartment. It also removes moisture from the air. An A/C system cools the air by moving heat from the confined space of the passenger compartment to the atmosphere. The operation of all A/C systems is based on fundamental laws of nature.

GO TO Chapter 3 for a detailed discussion of these laws.

Heat Flow

An air-conditioning system is designed to pump heat from one point to another. All materials or substances, as cold as –459 °F (–273 °C), have heat in them. Below this temperature, called absolute zero, no heat energy remains. Heat always flows from a warmer object to a colder one. For example, if one object is at 30 °F (–1.1 °C) and another object is 80 °F (27 °C), heat flows from the warmer object (80 °F [27 °C]) to the colder one. The greater the temperature difference between the objects (30 °F [–1.1 °C]), the greater the amount of heat flow.

Heat Absorption

Objects can be in one of three forms: solid, liquid, or gas. When objects change from one state to another, large amounts of heat can be transferred. For example, when water temperature goes below 32 °F (0 °C), water changes from a liquid to a solid (ice). If the temperature of water is raised to 212 °F (100 °C), the liquid turns into a gas (steam). But an interesting thing occurs when water, or any matter, changes from a solid to a liquid and then from a liquid to a gas. Additional heat is necessary to change the state of the substance, even though this heat does not register on a thermometer. For example, ice at 32 °F (0 °C) requires heat to change into water, which will also be at 32 °F (0 °C). Additional heat raises the temperature of the water until it reaches the boiling point of 212 °F (100 °C). More heat is required to change water into steam. But if the temperature of the steam were measured, it would also be 212 °F (100 °C). The amount of heat necessary to change the state of a substance is called latent heat—or hidden heat—because it cannot be measured with a thermometer. This hidden heat is the basic principle behind all air-conditioning systems.

GO TO Chapter 3 for a discussion of heat and how it is measured.

Pressure and Boiling Points

Pressure also plays an important part in air conditioning. Pressure on a substance, such as a liquid, changes its boiling point. The greater the pressure on a liquid, the higher the boiling point. If pressure is placed on a vapor, the vapor condenses at a higher-than-normal temperature. In addition, as the pressure on a substance is reduced, the boiling point can also be reduced. For example, the boiling point of water is 212 °F (100 °C). The boiling point can be increased by increasing the pressure on the fluid. This is because as the pressure increases, the energy required for the water molecules to expand and turn to a gas also increases. It can also be decreased by reducing the pressure or placing the fluid in a vacuum. By reducing the pressure, the water molecules can change state at a lower temperature. If the pressure is reduced enough, water can boil at room temperature.

Relative Humidity

The amount of moisture that air can hold is directly related to the temperature of the air. The warmer the air, the more moisture it can hold. Therefore, lowering the temperature of the air extracts the moisture from the air and lowers the air's relative humidity. What we call relative humidity is the amount of moisture in the air compared to the amount the air can actually hold at that temperature. If the air cannot hold any more moisture, it condenses back into water. This is what causes dew and condensation on surfaces. For many people, low relative humidity is typically more comfortable than high humidity.

Refrigerants

An air-conditioning (A/C) system is designed to move heat from one point to another. In an automobile, heat is removed from the passenger compartment and moved to outside the vehicle. The substance used to move the heat is called the **refrigerant**.

Before 1994, most automotive A/C systems used a refrigerant called Refrigerant-12 (commonly referred to as R-12 and Freon). R-12 is dichlorodifluoromethane ($CC1_2F_2$). By law, R-12 is no longer used in A/C systems. This resulted from studies showing that the earth's ozone layer was being depleted by the **chlorofluorocarbons (CFCs)** found in R-12. The ozone layer is the earth's outermost shield of protection. This delicate layer protects against harmful effects of the sun's ultraviolet rays. Because A/C systems with R-12 are susceptible to leaks, further damage to the ozone layer could be avoided by not using R-12 in A/C units.

R-134a

Of the many chemicals that could have replaced R-12, automobile manufacturers decided to use R-134a, which contains no chlorine. This refrigerant may also be referred to as SUVA. R-134a is tetrafluoroethane (CH_3CF_3) and considered a **hydrofluorocarbon (HFC)** that causes less damage to the ozone layer when released to the atmosphere. Although R-134a air conditioners operate in the same way and with the same basic components as R-12 systems, the two refrigerants are not interchangeable.

R-134a systems operate at higher pressures and are designed to handle these pressures **(Figure 54–12)**. R-134a systems also require different service techniques and equipment. All R-134a systems are identified by an underhood decal **(Figure 54–13)** and by the hoses and fittings used in the system. Service equipment for R-134a is also different. Retrofit kits are available to convert older R-12 systems to R-134a.

Although R-134a is less likely to have an adverse effect on the ozone layer, it still has the capability of contributing to the "greenhouse effect" when released into the air. The recovery and recycling of R-12 and R-134a is mandatory by law.

In 1987, many countries worldwide agreed to the Montreal Protocol agreement. This agreement began the phasing out of R-12 refrigerant. This agreement was followed up by 1990 U.S. Clean Air Act that mandated that all refrigerants were to be recovered and recycled. Section 609 of the act requires that all service technicians who work on A/C systems must be certified in proper refrigerant recovery and recycling. This section also mandates that all recovery and recycling equipment must be certified. Section 609 is a United States requirement and is not valid in other countries. Some states have stricter laws regarding refrigerant and these must be followed. While Section 609 certification is not required for purchasing R-134a, it is necessary for those who recover R-134a.

The Kyoto Protocol, a worldwide environmental program, has set standards for the reduced use of greenhouse gases, including R-134a. While not every country has signed onto the Kyoto Protocol, standards set by the European Union (EU) and the U.S. EPA have mandated the transition to a new refrigerant, one with a reduced global warming potential (GWP). As a result, some European and Japanese manufacturers began to eliminate R-134a A/C systems in 2013. This means those companies will be shipping vehicles to the United States with an alternative refrigerant and U.S. service facilities will need to be equipped to service R-134a systems and its replacement, HFO-1234yf. Full adoption of 1234yf is proposed to occur by 2017.

HFO-1234yf

The replacement for R-134a is HFO-1234yf. HFO means the refrigerant is a hydrofluoro-olefin based chemical. 1234yf differs from R-134a in that it has a GWP of 4 compared to that of 1430 for R-134a. This provides a major reduction in the impact of the refrigerant on global warming if accidentally released into the atmosphere. Another benefit to changing to 1234yf is that it can be used in existing mobile air-conditioning systems with very little change to the system as operating pressures and temperatures are very similar to R-134a.

Ambient Temperature	High-Side PSIG, R-134a	Low-Side PSIG, R-134a	High-Side PSIG, R-12	Low-Side PSIG, R-12
60 °F (15.6 °C)	120–170	7–15	120–150	5–15
70 °F (21.1 °C)	150–250	8–16	140–180	8–16
80 °F (26.7 °C)	190–280	10–20	160–250	10–18
90 °F (32.2 °C)	220–330	15–25	200–280	12–25
100 °F (37.8 °C)	250–350	20–30	220–300	15–30

FIGURE 54–12 A chart comparing the pressures of R-134a and R-12 at various temperatures.

FIGURE 54-13 A typical decal informing the technician that the system uses R-134a.

One issue with 1234yf that has caused some debate and delay in its adoption has to do with its flammability. In 2012, Daimler announced it would not use 1234yf after crash tests of its vehicles equipped with 1234yf revealed flammability issues. A potential for the refrigerant to ignite exists when the refrigerant is released in a hot engine compartment.

Alternative Refrigerants

As part of the Clean Air Act, the EPA identifies and publishes a list of acceptable and unacceptable refrigerants. This is part of the significant new alternatives policy or SNAP. In addition to refrigerants, SNAP also applies to all ozone-depleting chemicals. The list of refrigerants listed by SNAP does not mean that the EPA approves refrigerants for use in specific vehicles; it means that the refrigerant, when used as directed, is safer for humans and the environment than the R-12 refrigerant it replaces. Currently, over a dozen different types of refrigerants are approved as SNAP refrigerants for mobile air-conditioning (MAC) systems.

There are different refrigerants that can be used in automotive A/C systems; these are typically called alternative refrigerants. The EPA has a list of approved alternative refrigerants; however, the OEMs say that only R-134a should be used when retrofitting an R-12 system. The use of any refrigerant that contains flammable substances, such as propane and butane, is illegal and dangerous. Installing R-134a into an R-12 system without first removing the old refrigerant is also illegal.

CO_2 Systems

To meet the standards set up by the Kyoto Protocol, auto manufacturers need to find an alternative to R-134a. BMW and other European manufacturers have chosen CO_2 as a possible refrigerant for their A/C systems in the future. CO_2 is nontoxic when used as a refrigerant. It is known as R-744 and has a GWP of 1. The extremely low GWP means there is little environmental concern with its use. In fact, this refrigerant will not need to be recovered and recycled. If CO_2 leaks from an A/C system, the effect on the environment is very small. CO_2 is abundantly available in our air; therefore, it does not need to be manufactured.

It is claimed that CO_2-based systems will be up to 25 percent more energy efficient than the best of today's R-134a systems. In addition, CO_2 can be used for heat pump systems. Heat pump systems can supply cool and warm air and can be used in hybrid vehicles. Also, CO_2 systems need a smaller amount of gas than conventional systems, which means the size of the system is substantially less than a conventional system.

The operation of a CO_2 system is the same as that of any other A/C system but the components are different due to the higher pressures. CO_2 systems operate at pressures that are nearly ten times that of an R-134a system. CO_2 also has a critical temperature that is much lower than R-134a. Critical temperature is the temperature above which a substance cannot exist in the liquid state regardless of the pressure. Therefore, these systems need an internal heat exchanger (IHX) and accumulator. The materials used for hoses and gaskets must also be slightly different. The IHX is located between the condenser and the evaporator. The accumulator is part of the IHX **(Figure 54–14)**.

One concern about using CO_2 systems is the consequence of a leak into the passenger compartment. If a leak occurred in the evaporator, the carbon dioxide could make the cabin air toxic. Just as a CO_2 fire extinguisher displaces oxygen to put out a fire, CO_2 leaking into the passenger compartment could significantly reduce the oxygen levels inside the car. Because of this issue, CO_2 systems may require sensors to monitor cabin air quality or the A/C system could be separated into primary and secondary cooling loops. Many commercial refrigeration systems use chillers **(Figure 53–15)** so that toxic chemicals, such as ammonia, are not present in the system where humans are present. A chiller is a secondary heat exchanger that uses a less dangerous refrigerant or even an antifreeze and water mixture to cool the interior. The A/C system is used to cool the primary evaporator, which then is used to cool the secondary evaporator.

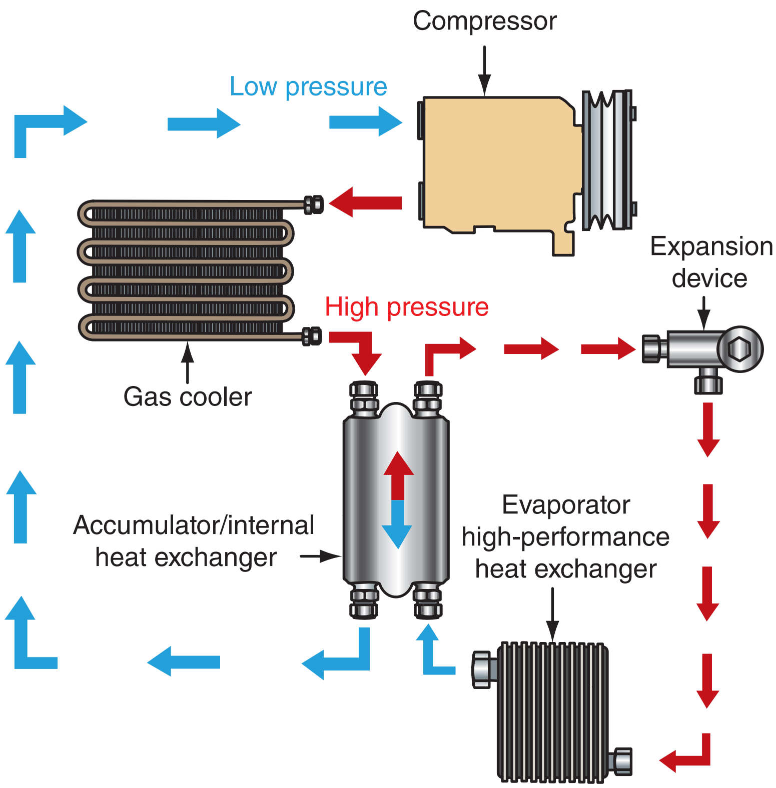


FIGURE 54-14 The layout of a CO_2 A/C system.

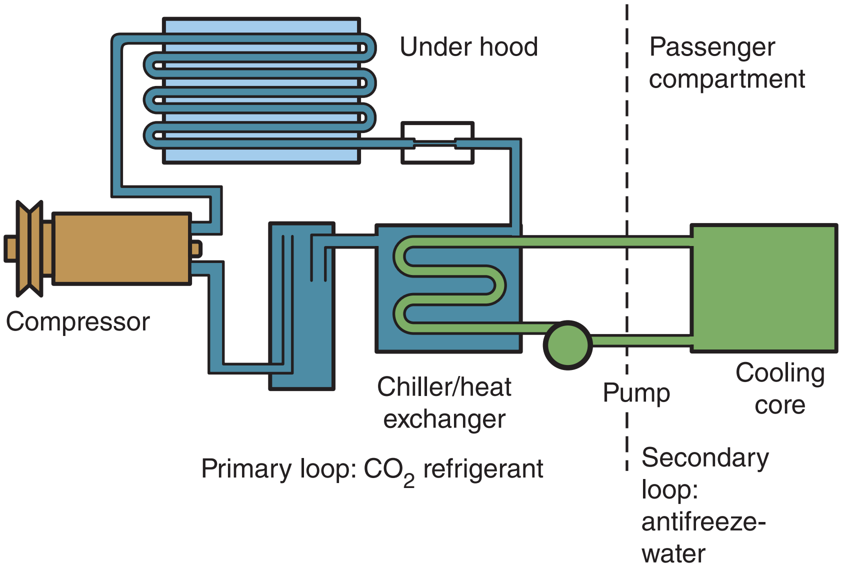


FIGURE 54-15 A primary and secondary loop may be required for CO_2 systems.

Basic Operation of an Air-Conditioning System

Refrigerants are used to carry heat from the inside of the vehicle to the outside of the vehicle. Automotive refrigerants have a low boiling point (the point at which **evaporation** occurs). For example, under atmospheric pressure, liquid R-134a boils at –15.34 °F (–26.3 °C), and becomes a vapor. As a refrigerant changes state, it absorbs a large amount of heat. Because the heat that it absorbs is from the inside of the vehicle, passengers are cooler.

To understand how a refrigerant is used to cool the interior of a vehicle, the effects of pressure and temperature must be understood first. If the pres-

sure of the refrigerant is high, so is its temperature. Likewise, if the pressure is low, so is its temperature. Therefore, the temperature of the refrigerant can be changed by changing its pressure. As the pressure on a liquid increases, its boiling point also increases. Likewise, as the pressure decreases, the boiling point of the liquid also decreases. **Figure 54–16** shows the pressures of R-134a at various temperatures.

To absorb heat, the temperature and pressure of the refrigerant are kept low. To dissipate heat, the temperature and pressure are high. As the refrigerant absorbs heat, it changes from a liquid to a vapor. As it dissipates heat, it changes from a vapor to a liquid. The change from a vapor to a liquid is called **condensation**. These two changes of state—evaporation and condensation—occur continuously as the refrigerant circulates through the system.

Refrigeration Cycle

In a basic A/C system, the heat is absorbed and transferred in the following steps **(Figure 54–17)**.

1. When the system is off, the refrigerant occupies the system as a vapor and its pressure is the same throughout the system.
2. When the A/C compressor is turned on, it increases pressure on the refrigerant and raises its temperature.
3. The refrigerant is pumped out of the compressor as a high-pressure, high-temperature vapor.
4. The high-pressure gas is sent to the condenser. Heat in the refrigerant is moved to the outside air by conduction and convection. The removal of the heat causes the refrigerant vapor to condense into a liquid under high pressure.
5. The high-pressure, high-temperature liquid leaves the bottom of the condenser and enters a receiver/dryer. The receiver/dryer removes moisture and contaminants and stores clean refrigerant until it is needed. On some systems, an accumulator is placed in line between the evaporator and compressor to capture any liquid refrigerant before it can enter the compressor.
6. The refrigerant then flows to the inlet side of the evaporator core orifice or expansion valve. These control the flow of refrigerant into the evaporator. The restriction causes the pressure and boiling point of the refrigerant to drop.
7. As the liquid refrigerant leaves the restriction, it is at its lowest pressure and temperature.

TEMPERATURE °F	TEMPERATURE °C	PRESSURE psig	PRESSURE kPa
10	–12.2	12.0	82.7
20	–6.67	18.4	127
30	–1.11	25.3	174
40	4.44	35.0	241
50	10.0	45.4	313
60	15.6	57.4	396
70	21.1	71.1	490
80	26.7	86.7	598
90	32.2	104.3	719
100	37.8	124.1	856
110	43.3	146.3	1009
120	48.9	171.1	1180
130	54.4	198.7	1370
140	60.0	229.2	1580
150	65.6	262.8	1812

FIGURE 54–16 A simple chart showing the relationship of temperature and pressure of R-134a.

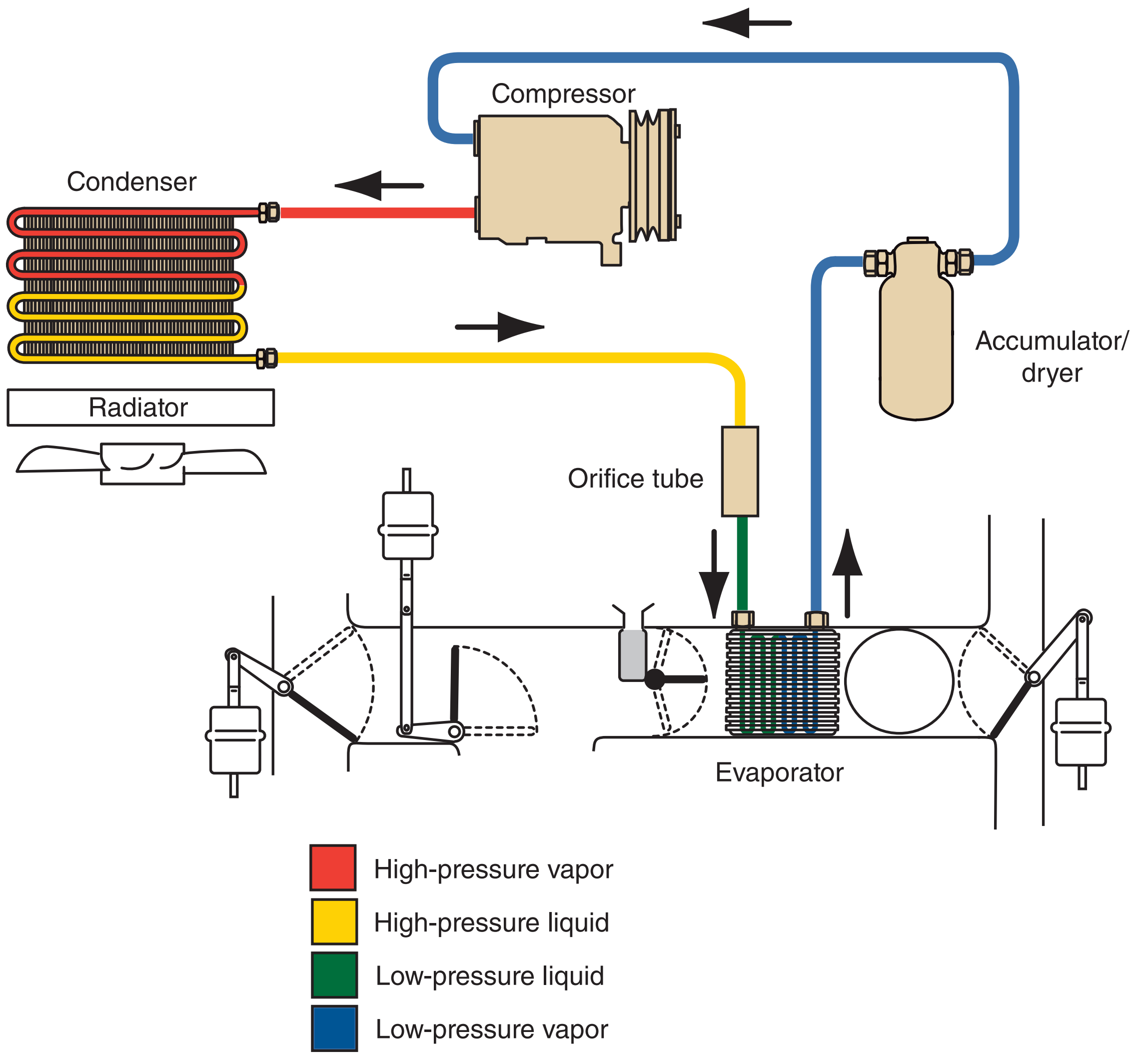


FIGURE 54-17 The basic refrigerant flow cycle.

8. The refrigerant then passes through the evaporator where it absorbs heat, through convection, from the air inside the passenger compartment. The additional heat causes the refrigerant to boil and change back to a vapor.
9. The refrigerant then returns to the compressor as a low-pressure, low-temperature vapor and the cycle continues.

An automotive A/C system is a closed, pressurized system. It consists of a compressor, condenser, receiver/dryer or accumulator, expansion valve or orifice tube, and an evaporator. To understand the operation of these components, remember that an A/C system is divided into two sides: the high side and the low side **(Figure 54–18)**. **High side** refers to the side of the system that is under high pressure and high temperature. **Low side** refers to the low-pressure, low-temperature side of the system.

Compressors

The compressor is the heart of the automotive A/C system. It separates the high and low sides of the system. The compressor is designed to pump only refrigerant vapor; liquid refrigerant will not compress and its presence in the compressor can damage it. Its primary purpose is to draw the low-pressure and low-temperature vapor from the evaporator and compress it into high-temperature, high-pressure vapor. The refrigerant then has a higher temperature than surrounding air and condenses back to a liquid form at the condenser. The secondary purpose of the compressor is to circulate or pump the refrigerant through the A/C system under the different pressures required for proper operation. The compressor is located on the engine and is typically driven

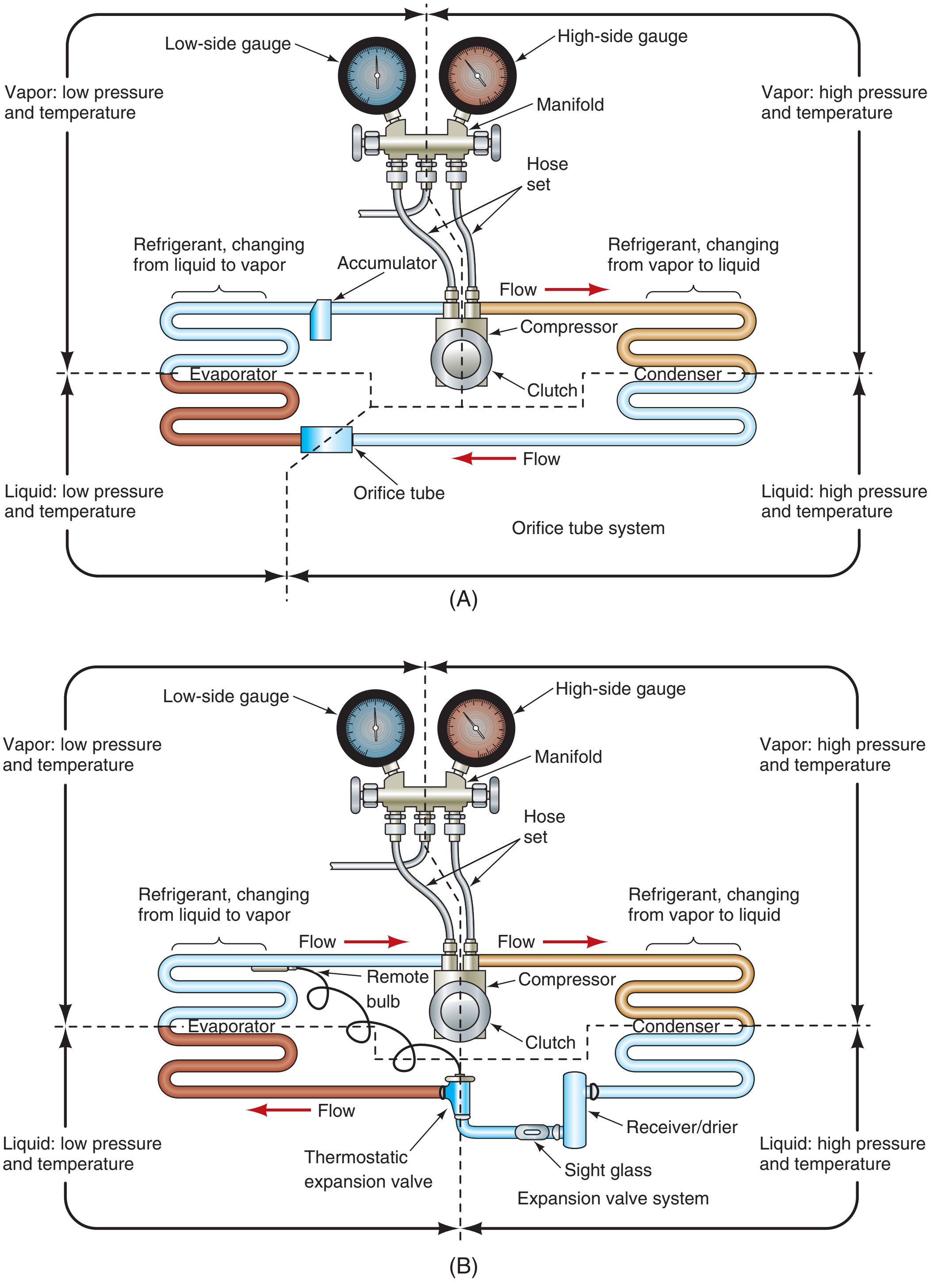


FIGURE 54–18 The low and high pressure sections of (A) an orifice tube system and (B) a system with a TXV.

by the engine's crankshaft via a drive belt. Hybrid and electric vehicles typically have a three-phase high-voltage motor in the compressor for when the engine is off.

Although there are numerous types of compressors in use today **(Figure 54–19)**, they are usually based on one of these designs.

Piston Compressor

This type of compressor **(Figure 54–20)** can have its pistons arranged in an inline, axial, radial, or V design. It is designed to have an intake stroke and a compression stroke for each cylinder. On the intake stroke, the refrigerant from the low side of the system

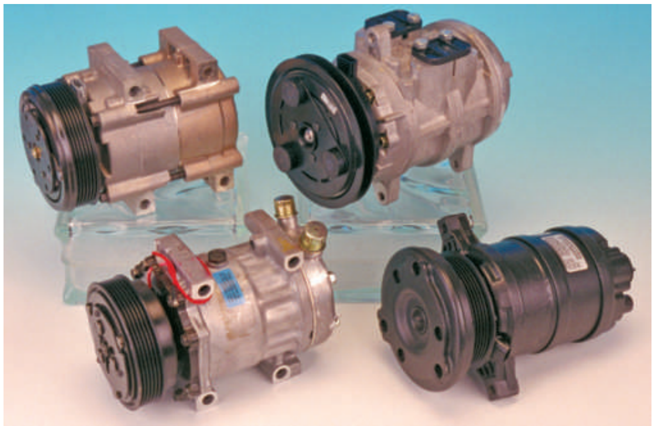


FIGURE 54–19 Various A/C compressors.

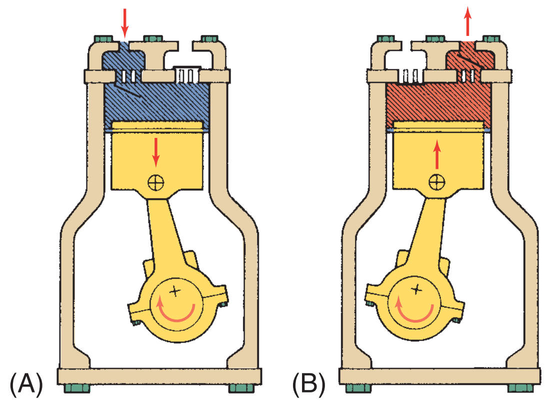
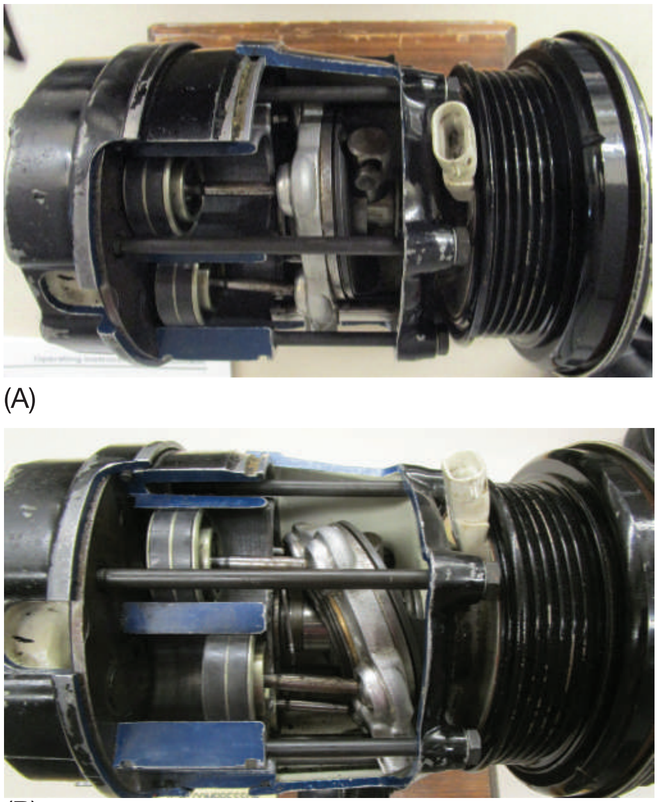


FIGURE 54–20 (A) A piston on the downstroke (intake) pulls low-pressure refrigerant into the cylinder's cavity. The intake (suction) valve is open, and the discharge valve is closed. (B) A piston on the upstroke (discharge) compresses refrigerant vapor and forces it out through the discharge valve. The intake (suction) valve is closed, and the discharge valve is open.

(evaporator) is drawn into the compressor. The intake of refrigerant occurs through intake reed valves **(Figure 54–21)**. These one-way valves control the flow of refrigerant vapors into the cylinder. During the compression stroke, the refrigerant vapor is compressed. This increases both the pressure and the temperature of the refrigerant. The outlet or **discharge side** reed valves then open to allow the refrigerant to move to the condenser. The outlet reed valves are the beginning of the high side of the system. Reed valves are made of spring steel, which can weaken or break if improper charging procedures are used, such as liquid charging with the engine running.

Variable Displacement Compressor Today nearly all manufacturers use variable displacement compressors **(Figure 54–22)**. These compressors are normally axial compressors, with the pistons

FIGURE 54–21 The reed valves for an A/C compressor.



(A)

(B)

FIGURE 54–22 A V5 variable displacement compressor. The swash plate and pistons are at the minimum stroke and displacement (A). At maximum displacement, the swash plate is angled and the stroke increased (B).

arranged around and parallel to the drive shaft. The pistons are driven by a wobble plate or a swash plate. When a wobble plate is used, short pushrods connect the pistons to the plate **(Figure 54–23)**. As the compressor's drive shaft rotates, the plate wobbles and the pistons move in their bores. When a swash plate is used, it is set at an angle to the drive shaft. As the shaft rotates, the pistons move back and forth in their bores.

The angle of the wobble plate or swash plate determines the stroke of the pistons. When the stroke of the pistons is increased, more refrigerant is being pumped and there is increased cooling.

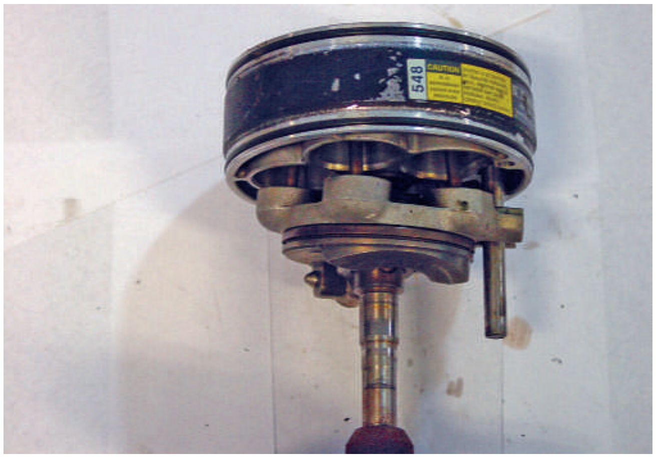


FIGURE 54–23 The pistons are driven by a short pushrod that connects the pistons to the wobble plate.

The angle is controlled by the difference in pressure between the outlet and inlet of the compressor. When the pressure inside the compressor increases, that pressure works on the bottom of the pistons and moves them closer to the cylinder head. This action shortens their stroke, thereby decreasing the displacement of the pump. As pressure inside the compressor decreases, spring tension overcomes the pressure and the pistons move down in their bores. This causes the plate angle to increase, resulting in increased stroke and displacement.

Some swash plate compressors use a solenoid control valve that opens and closes to adjust the inlet to the compressor. Controlling the suction side of the compressor changes the volume capacity and pressure. The change in pressure also affects the angle of the swash plate.

On some vehicles, the compressor does not have a clutch, which means the compressor runs constantly. These units have an electrically controlled rotary valve at the rear of the compressor to control the flow of refrigerant into a special chamber that changes the angle of the swash plate. This regulates the flow of refrigerant by changing the stroke of the pistons.

Rotary Vane Compressor

The rotary vane compressor does not have pistons. It has a rotor with several vanes and a carefully shaped housing. The sliding vanes seal against the housing at both ends. As the compressor shaft rotates, the vanes and housing form chambers. As the rotor turns, the size of the chambers changes.

The refrigerant is drawn into the chambers through the suction port. The discharge port is located at the point where the gas is completely compressed. No sealing rings are used in a vane compressor. The vanes are sealed against the housing by centrifugal force and lubricating oil. The oil sump is located on the discharge side, so the high pressure tends to force it around the vanes into the low-pressure side. This action ensures continuous lubrication. Because this type of compressor depends on a good oil supply, it is subject to damage if the system charge is lost. A protection device is used to disengage the clutch if pressure drops too low.

Scroll-Type Compressor

The scroll-type compressor has a movable scroll and a fixed or nonmovable scroll that provide an eccentric-like motion. As the compressor's crankshaft rotates, the movable scroll forces the refrigerant against the fixed scroll and toward the center of the compressor. This motion pressurizes the refrigerant. The action of a scroll-type compressor can be compared to that of a tornado. The pressure of air moving in a circular pattern increases as it moves toward the center of the circle **(Figure 54–24)**. A delivery port is positioned at the center of the compressor and allows the high-pressure refrigerant to flow into the A/C system. These compressors do not have a suction valve. They are smaller and operate more smoothly than other designs.

Compressor Clutches

Most compressors are equipped with an electromagnetic clutch as part of the compressor pulley assembly **(Figure 54–25)**. It is designed to engage the pulley to the compressor shaft when the clutch coil is energized. The purpose of the clutch is to transmit power from the engine to the compressor and to provide a means of engaging and disengaging the refrigeration system from engine operation. The clutch is driven by power from the engine's crankshaft, which is transmitted through one or more belts (a few use gears) to the pulley, which is in operation whenever the engine is running. When the clutch is engaged, power is transmitted from the pulley to the compressor shaft by the clutch drive plate. When the clutch is not engaged, the compressor shaft does not rotate, and the pulley freewheels.

The clutch allows the A/C system to be controlled by an electric circuit. The clutch relay is controlled by a temperature signal from the evaporator and a pressure switch in the refrigerant line. In most systems, the compressor clutch cycles on and off periodically

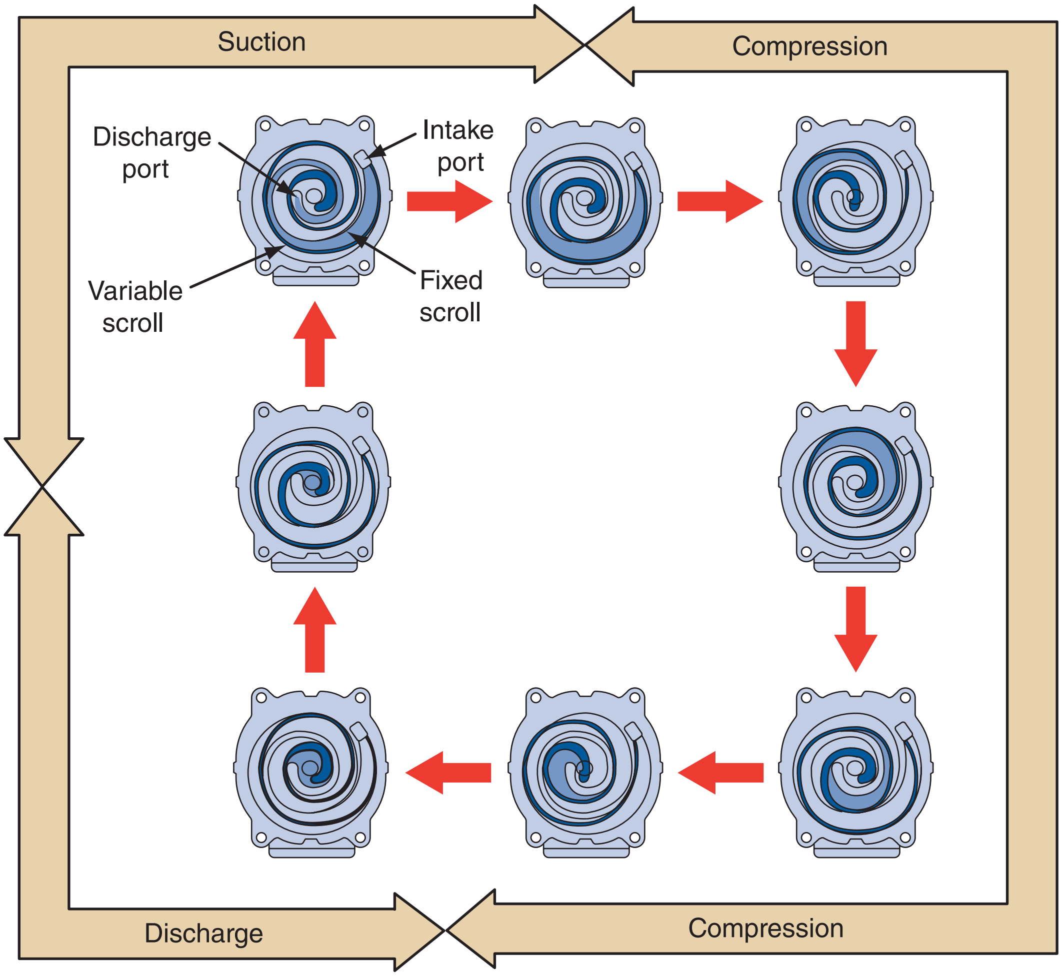


FIGURE 54–24 A scroll compressor passes through three distinct phases: suction, compression, and discharge.

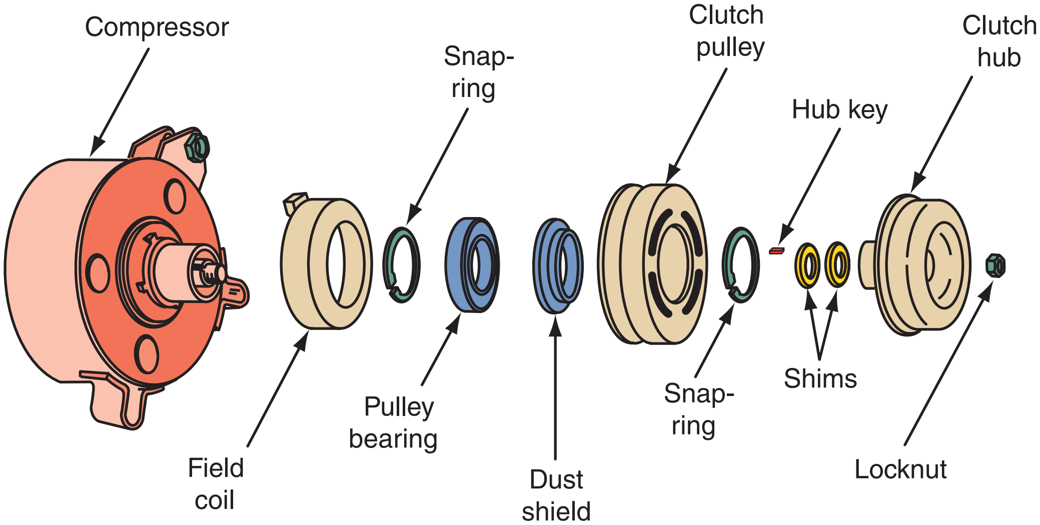


FIGURE 54–25 An A/C compressor clutch assembly.

to allow the evaporator to warm up during periods of high cooling demand.

The clutch is engaged by a magnetic field and disengaged by springs when the magnetic field is broken. When the controls call for compressor operation, the electrical circuit to the clutch is completed, the magnetic clutch is energized, and the clutch engages the compressor. When the electrical circuit is opened, the clutch disengages the compressor. Many systems use a diode wired in parallel with the compressor clutch to absorb voltage spikes when the clutch disengages. Voltage spikes are possible as the magnetic field that holds the clutch engaged collapses once the circuit is open. If left unchecked, the voltage spike could damage the electronics controlling clutch operation.

Modern clutches use a stationary clutch coil. When the system is turned on, the pulley assembly is magnetized by the stationary coil on the compressor body, thus engaging the clutch to the clutch hub attached to the compressor shaft. This activates the A/C system. Depending on the system, the magnetic clutch is usually pressure controlled to cycle the operation of the compressor (depending on system temperature or pressure). In some system designs, the clutch might operate continually when the system is turned on.

Clutchless Compressors

Some late-model A/C systems use clutchless or variable drive compressors. Clutchless systems control refrigerant flow through the compressor by varying swash plate angle with a pulse width modulated control solenoid. The climate control module uses input data such as cabin temperature, ambient temperature, evaporator temperature, engine speed, and system pressures to determine the required flow through the compressor. When the system is off or cooling is not needed, the solenoid limits swash plate angle from 2 to 3 percent. As cooling load increases, swash plate angle is increased up to 100 percent.

Electric Drive Compressors

One of the features of hybrid and other new vehicles is the idle-stop or stop-start system. When the vehicle is sitting at a light, the system shuts down the engine. This means there is no power to drive the A/C compressor. Therefore, most hybrid vehicles have an electric drive for the compressor. An electric motor is built into the compressor and is powered by the vehicle's high-voltage system **(Figure 54–26)**. This means the A/C system can operate when the engine is not running.

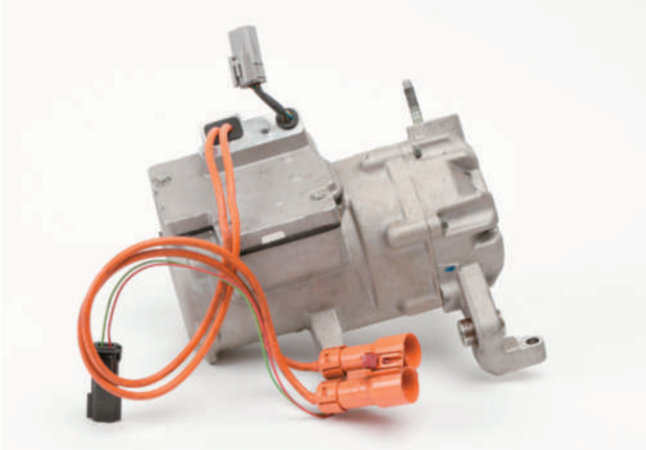


FIGURE 54–26 An electric A/C compressor.

A/C compressors in hybrid vehicles are typically identical to those used in a conventional vehicle, except for the portion that is actuated by the electric motor. Because the compressor is energized by electricity, the control module can control its speed. This enables the system to provide ideal cooling while using a minimum of energy to run the system.

In most cases, the compressor's motor is driven by AC voltage from the vehicle's inverter. The system controls the voltage to rotate the compressor at a desired speed. This speed is calculated by the control module and is based on a target evaporator temperature and the actual evaporator temperature.

The Accord hybrid is also equipped with a dual-scroll "hybrid" A/C compressor **(Figure 54–27)**. The A/C system uses two compressors built into a single housing; one compressor is driven by the engine and the other is driven by an electric motor powered by the high-voltage battery. A driver circuit in the control module provides switched high voltage to the motor. The action of the driver is determined by inputs from the climate control settings and the CAN bus. The mechanically driven side uses a normal electric clutch controlled by the climate control module. The electrically driven side uses a high-voltage, brushless, three-phase motor driven by a controller. When full cooling is needed, the A/C unit relies on both power sources to provide maximum cooling. During normal cooling, the A/C is powered by either the belt-driven compressor or the electric motor-driven compressor.

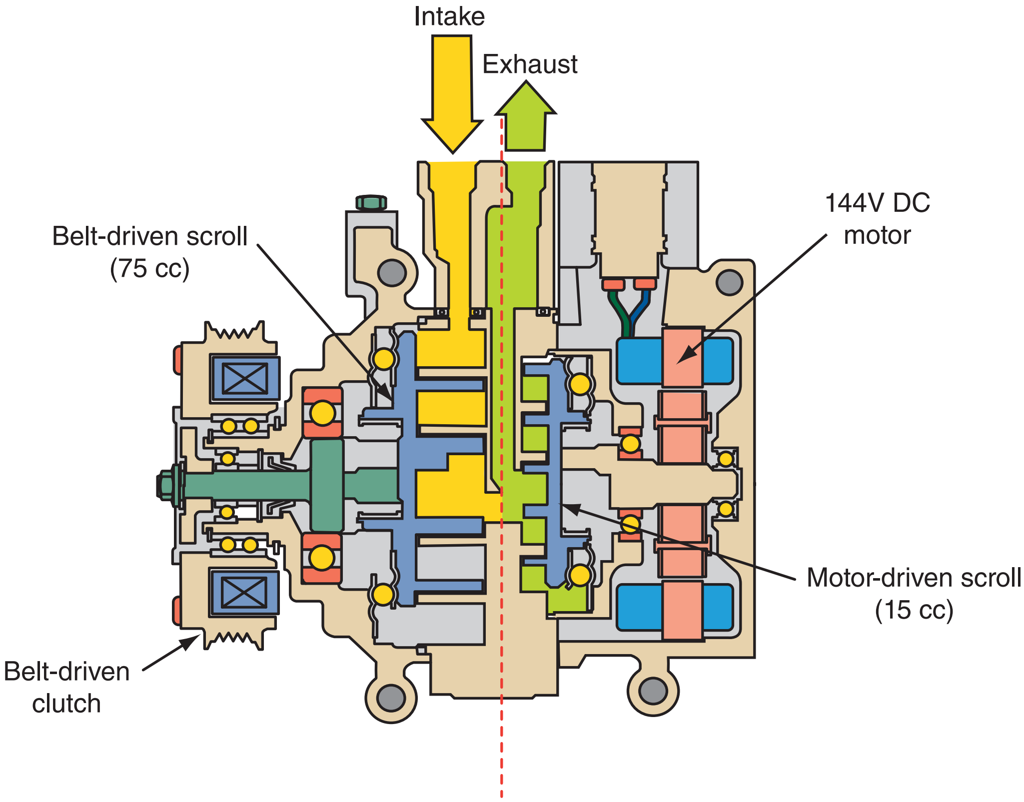


FIGURE 54–27 A dual-scroll A/C compressor powered by a drive belt and/or an electric motor.

Refrigerant Oils

Normally the only source of lubrication for a compressor is the oil mixed with the refrigerant. A/C systems carry oil through the system with the refrigerant to lubricate the parts of the system, including the compressor. Because of the loads and speeds at which the compressor operates, proper lubrication is a must for long compressor life.

The refrigerant oil required by the system depends on a number of things, but it is primarily dictated by the refrigerant used in the system. R-12 systems used a mineral oil. Mineral oil, however, cannot be used with R-134a. R-134a systems require a synthetic oil, polyalkaline glycol (PAG) or POE (polyester) oil. Most manufacturers use PAG oil in R-134a systems. Aftermarket companies, on the other hand, often choose ester oils for lubrication with R-134a because they tend to attract less moisture than PAG oils. Most often when a system has been converted from R-12 to R-134a, ester oil will be recommended. Ester oil mixes well with mineral oil because it is hydrocarbon based.

There are a number of different blends of refrigerant oil; always use the one recommended by the vehicle manufacturer or compressor manufacturer. Failure to use the correct oil will cause damage to the compressor.

Warning! Hybrid vehicles often have an electrically driven compressor. Because the electric motor is inside the compressor case and is in contact with the oil in the compressor, only the specified oil should be used in the compressor. This oil has electrical insulating qualities that protect you from dangerous electrical shocks. Also, if you use the wrong oil, the A/C unit will be contaminated and this may result in a need to replace the compressor, condenser, evaporator, and/or all of the refrigerant lines.

Condenser

The condenser **(Figure 54–28)** consists of coiled refrigerant tubing mounted in a series of thin cooling fins to provide maximum heat transfer in a minimum amount of space. The condenser is normally mounted just in front of the vehicle's radiator. It receives the full

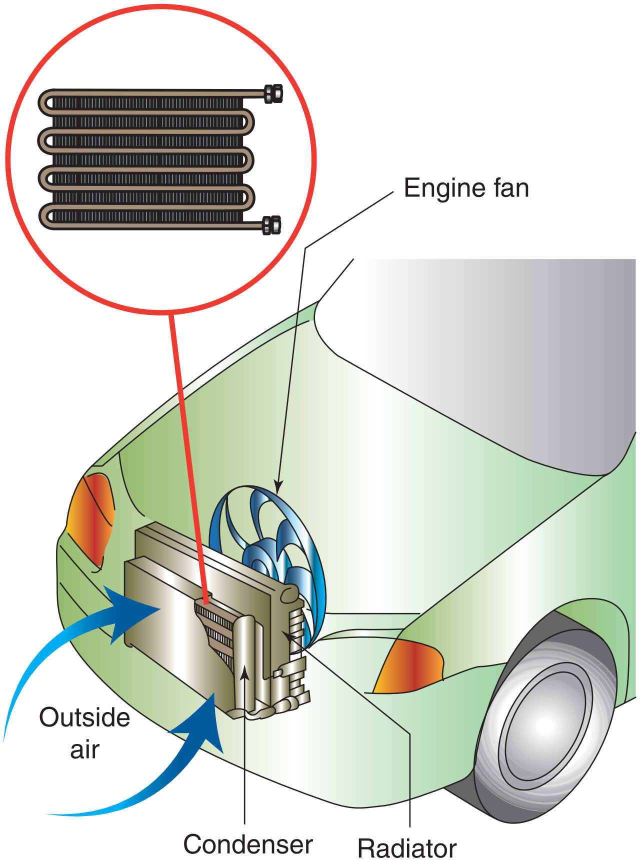


FIGURE 54–28 A typical condenser.

flow of ram air from the movement of the vehicle or airflow from the radiator fan or dedicated condenser fan when the vehicle is standing still.

The purpose of the condenser is to condense or liquefy the high-pressure, high-temperature vapor coming from the compressor. To do so, it must give up its heat. The condenser receives very hot (normally 200 to 400 °F), high-pressure refrigerant vapor from the compressor through its discharge hose. The refrigerant vapor enters the inlet at the top of the condenser and as the hot vapor passes down through the condenser coils, heat (following its natural tendencies) moves from the hot refrigerant into the cooler air as it flows across the condenser coils and fins. This process causes a large quantity of heat to be transferred to the outside air and the refrigerant to change from a high-pressure hot vapor to a high-pressure warm liquid. This high-pressure warm liquid flows from the outlet at the bottom of the condenser through a line to the receiver/dryer or to the refrigerant metering device if an accumulator is used instead of a dryer.

In an A/C system operating under an average heat load, the condenser has a combination of hot refrigerant vapor in the upper two-thirds of its coils. The lower third of the coils contains the warm liquid refrigerant, which has condensed. This high-pressure, liquid refrigerant flows from the condenser and on toward the evaporator. In effect, the condenser is a true heat exchanger.

Subcoolers and Internal Heat Exchangers

Some vehicles have a subcooler built into the condenser or have a separate subcooler. Subcooling is a process by which sensible heat is removed from liquid refrigerant, resulting in lower refrigerant temperatures. Sensible heat is heat that can be felt and measured and represents the energy required to change the temperature of a substance without causing a change in its state. The separate subcooler is located between the condenser and evaporator. A subcooler is a heat exchanger that allows the refrigerant to lose additional heat after it becomes a liquid. The subcooler increases the efficiency of the system by cooling the refrigerant and prevents premature vaporization or flash off as the refrigerant passes through the expansion valve and before it reaches the evaporator. Premature flash off can result in stopping some of the refrigerant from evaporating, and that part of the refrigerant would have no useful effect on the cooling of the vehicle. The heat exchanger causes the liquid to be subcooled to a level that ensures little or no flash gas on its way to the evaporator.

Many vehicles have a condenser with a subcool chamber **(Figure 54–29)**. In these condensers, refrigerant enters at the top as a high-pressure gas. It then passes through a receiver/dryer or modulator to separate the liquid from the gaseous refrigerant. The modulator contains a desiccant and filter to remove the moisture and foreign material from the refrigerant. After passing through the modulator, the refrigerant flows into the bottom subcooler chamber to further cool the liquid. This results in complete liquidization of the refrigerant and better A/C performance. These condensers have thin tubes and low fin height, which improve the heat exchange rate. Because of this two-step approach, the refrigerant sent to the evaporator is almost completely liquefied.

R-1234yf systems and some R-134a systems use an internal heat exchanger (IHX). The IHX is a liquid-to-vapor heat exchanger that looks like a pipe within a pipe **(Figure 54–30)**. Hot liquid refrigerant from the condenser flows through the inner pipe, which is surrounded by cool refrigerant from the outlet of the evaporator. Surrounding the hot liquid with the cooler gas removes heat from the liquid, subcooling it beyond what was achieved by the condenser. This improves overall system efficiency and improves performance.

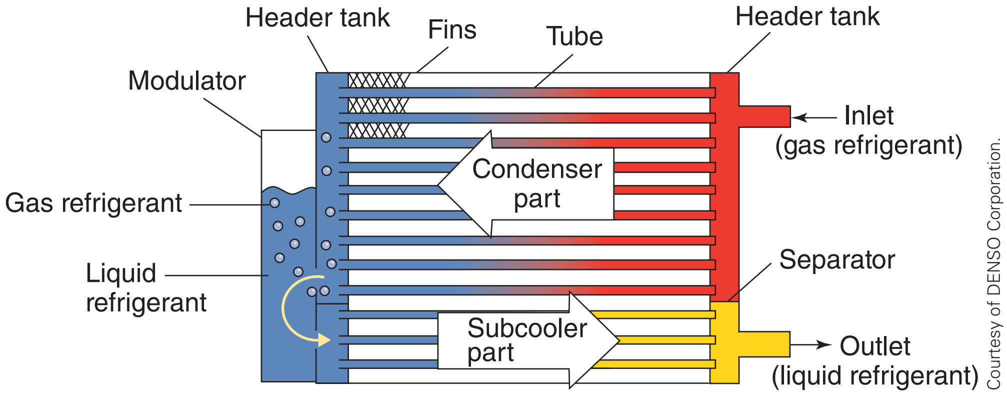


FIGURE 54–29 A condenser with a built-in subcooler.

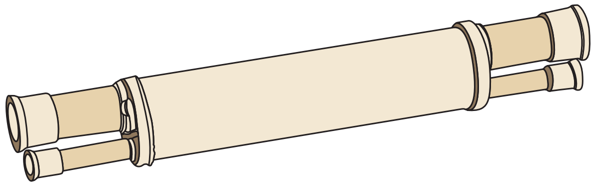


FIGURE 54–30 An internal heat exchanger.

FIGURE 54–31 Two different accumulator designs.

Receiver/Dryer

Used on many systems, the receiver/dryer is a storage tank for the liquid refrigerant from the condenser, which flows into the upper portion of the receiver tank containing a bag of desiccant (moisture-absorbing material such as silica alumina or silica gel). As the refrigerant flows through an opening in the lower portion of the receiver, it is filtered through a mesh screen attached to a baffle at the bottom of the receiver. The purpose of the desiccant in this assembly is to absorb any moisture present that might enter the system during assembly. These features of the assembly prevent obstruction to the valves or damage to the compressor.

Depending on the manufacturer, the receiver/dryer may be known by other names such as filter or dehydrator. Regardless of its name, the function is the same. Included in many receiver/dryers are additional features such as a high-pressure fitting, a pressure relief valve, and a sight glass for determining the state and condition of the refrigerant in the system.

Accumulator

Most late-model systems are not equipped with a receiver/dryer; rather, they use an accumulator to accomplish the same thing **(Figure 54–31)**. The accumulator is connected into the low side at the outlet of the evaporator. The accumulator also contains a desiccant and is designed to store excess refrigerant and to filter and dry the refrigerant **(Figure 54–32)**. If liquid refrigerant flows out of the evaporator, it will be collected by and stored in the accumulator. The main purpose of an accumulator is to prevent liquid from entering the compressor.

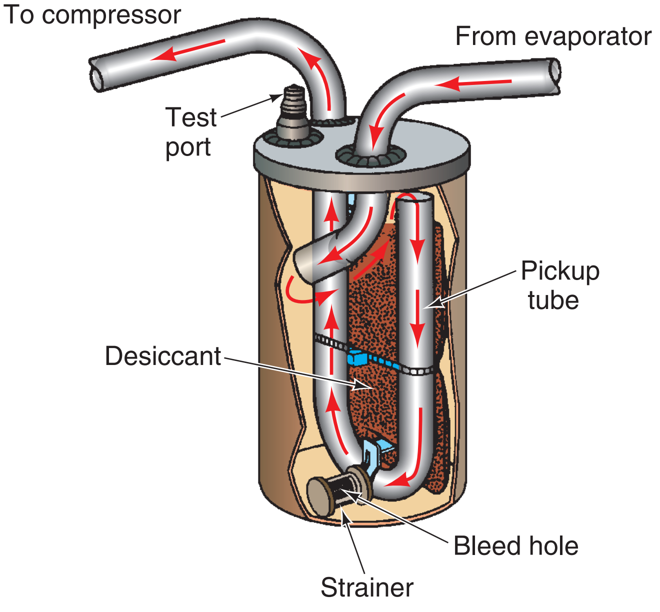


FIGURE 54–32 An accumulator/dryer.

Thermostatic Expansion Valve/ Orifice Tube

The refrigerant flow to the evaporator must be controlled to obtain maximum cooling while ensuring complete evaporation of the liquid refrigerant within the evaporator. This is accomplished by a thermostatic expansion valve (TEV or TXV) or a fixed orifice tube.

The TEV is mounted at the inlet to the evaporator and separates the high-pressure side of the system from the low-pressure side. The TEV regulates refrigerant flow to the evaporator to prevent evaporator flooding or starving. In operation, the TEV regulates the refrigerant flow to the evaporator by balancing the inlet flow to the outlet temperature.

Both externally and internally equalized TEVs are used in A/C systems. The only difference between the two valves is that the external TEV uses an equalizer line connected to the evaporator outlet line as a means of sensing evaporator outlet pressure. The internal TEV senses evaporator inlet pressure through an internal equalizer passage. Both valves have a capillary tube to sense evaporator outlet temperature. The tube is filled with a gas, which, if allowed to escape due to careless handling, will ruin the TXV.

During stabilized conditions, the pressure on the bottom of the expansion valve diaphragm becomes equal to the pressure on the top of the diaphragm. This allows the valve spring to close the valve. When the system is started, the pressure on the bottom of the diaphragm drops rapidly, allowing the valve to open and meter liquid refrigerant to the lower evaporator tubes where it begins to vaporize **(Figure 54–33)**.

Compressor suction draws the vaporized refrigerant out of the top of the evaporator at the top tube, where it passes by the sealed sensing bulb. The bottom of the valve diaphragm internally senses the evaporator pressure through the internal equalization passage around the sealed sensing bulb. As evaporator pressure is increased, the diaphragm flexes upward, pulling the pushrod away from the ball seat of the expansion valve. The expansion valve spring forces the ball onto the tapered seat and the liquid refrigerant flow is reduced.

As the pressure is reduced due to restricted refrigerant flow, the diaphragm flexes downward again, opening the expansion valve to provide the required controlled pressure and refrigerant flow condition. As the cool refrigerant passes by the body of the sensing bulb, the gas above the diaphragm contracts and allows the expansion valve spring to close the expansion valve. When heat from the passenger compartment is absorbed by the refrigerant, it causes the gas to expand. The pushrod again forces the expansion valve to open, allowing more refrigerant to flow so that more heat can be absorbed.

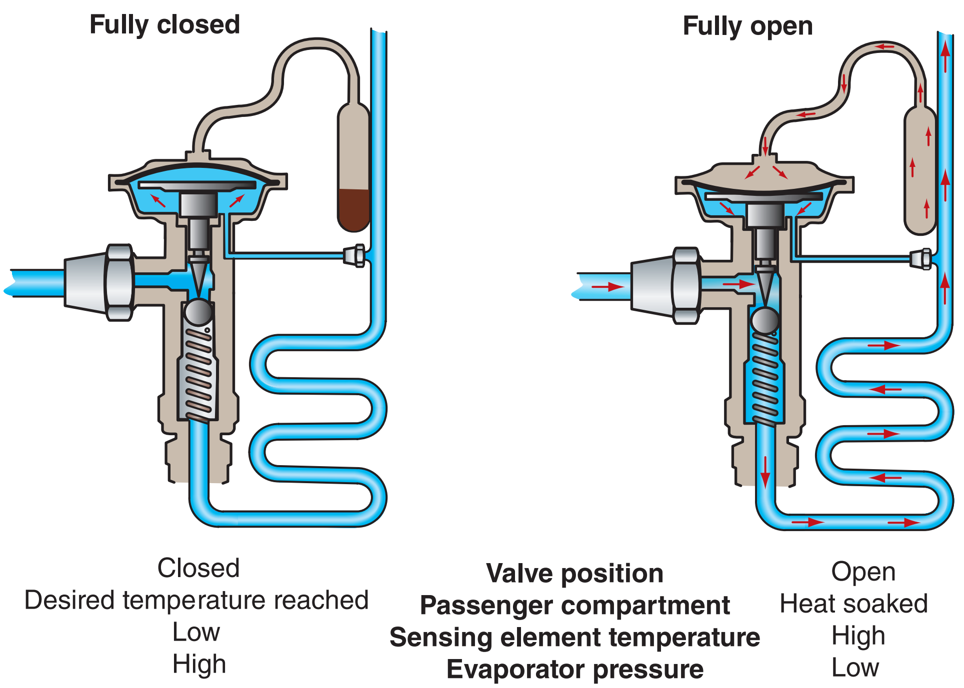


FIGURE 54–33 How a TXV regulates refrigerant flow through the evaporator.

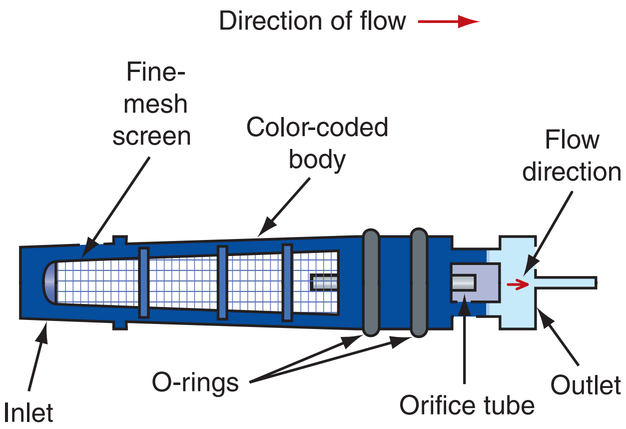


FIGURE 54–34 A typical orifice expansion tube.

Orifice Tube

Like the TEV, the orifice tube is the dividing point between the high- and low-pressure parts of the system. However, its metering or flow rate control does not depend on comparing evaporator pressure and temperature. It is a fixed orifice **(Figure 54–34)**. The flow rate is determined by pressure difference across the orifice and by subcooling at the bottom of the condenser. Because an orifice tube cannot vary the flow rate itself, it is used with a cycling clutch compressor. The compressor turns on and off to control flow through the system. Orifice tubes have been phased out in modern systems that use variable displacement compressors.

H-Block Thermal Expansion Valve

Many newer vehicles use an H-block TXV. The H-block is located near the firewall and close to the evaporator and has four separate line connections: one to and one from the evaporator, one that returns to the compressor, and one from the condenser **(Figure 54–35)**. The outlet from the evaporator passes over the sensing element in the H-block. If the outlet temperature is high, it causes the sensing element to allow more refrigerant flow to the evaporator. If the temperature of the outlet gas is low, flow is reduced.

Evaporator

The evaporator, like the condenser, consists of a refrigerant coil mounted in a series of thin cooling fins **(Figure 54–36)**. It provides a maximum amount of heat transfer in a minimum amount of space. The evaporator is usually located beneath the dashboard or instrument panel.

Upon receiving the low-pressure, low-temperature liquid refrigerant from the TEV or orifice tube in the form of an atomized (or droplet) spray, the evaporator serves as a boiler or vaporizer. This regulated flow of refrigerant boils immediately. Heat from the core surface is lost to the boiling and vaporizing refrigerant, which is cooler than the core, thereby

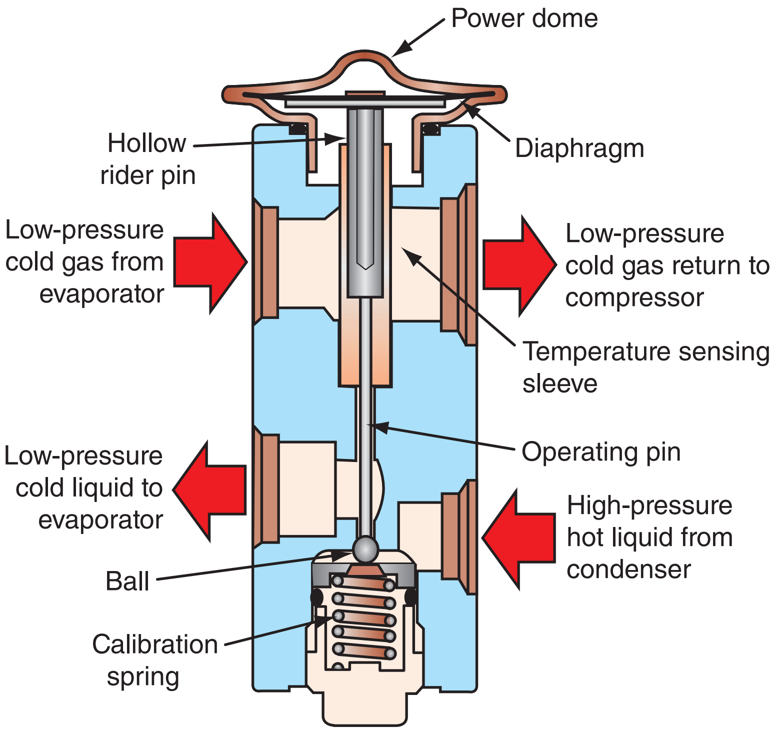


FIGURE 54–35 An H-block expansion valve.

FIGURE 54-36 A typical evaporator.

cooling the core. The air passing over the evaporator loses its heat to the cooler surface of the core, thereby cooling the air inside the car. As the process of heat loss from the air to the evaporator core surface is taking place, any moisture (humidity) in the air condenses on the outside of the evaporator core and is drained off as water. A drain tube in the bottom of the evaporator housing leads the water outside the vehicle **(Figure 54–37)**. This dehumidification of air is an added feature of the A/C system that adds to passenger comfort. It also is used as a means of controlling fogging of the vehicle windows. Under certain conditions, however, too much moisture can accumulate on the evaporator coils. An example would be when humidity is extremely high and the maximum cooling mode is selected. The evaporator temperature might become so low that moisture would freeze on the evaporator coils before it can drain off.

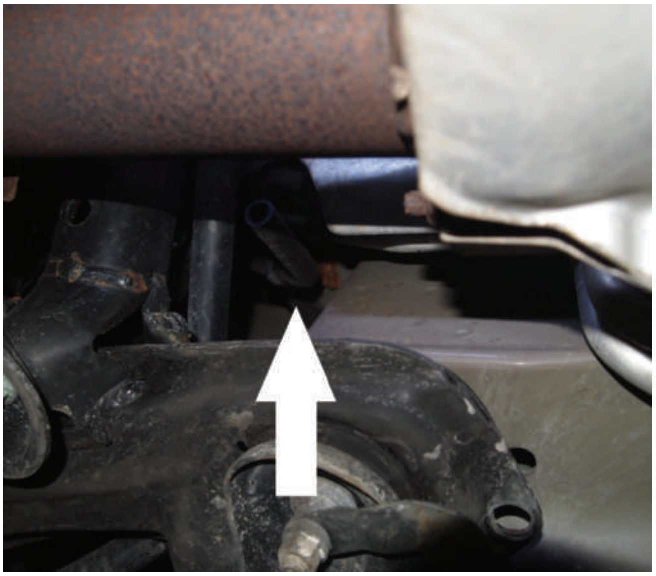


FIGURE 54-37 An evaporator drain.

Through the metering, or controlling, action of the TEV or orifice tube, greater or lesser amounts of refrigerant are provided in the evaporator to adequately cool the car under all heat load conditions. If too much refrigerant is allowed to enter, the evaporator floods. This results in poor cooling due to the higher pressure (and temperature) of the refrigerant. The refrigerant can neither boil away rapidly nor vaporize. On the other hand, if too little refrigerant is metered, the evaporator starves. Poor cooling again results because the refrigerant boils away or vaporizes too quickly before passing through the evaporator.

The temperature of the refrigerant vapor at the evaporator outlet will be approximately 4 to 16 °F higher than the temperature of the liquid refrigerant at the evaporator inlet. This temperature differential ensures that the vapor will not contain any droplets of liquid refrigerant that would be harmful to the compressor.

Blower Motor/Fan

The blower motor/fan assembly is located in the evaporator housing. Its purpose is to increase airflow in the passenger compartment. The blower motor, which is the same as those used in heater systems, draws warm air from the passenger compartment, forces it over the coils and fins of the evaporator, and blows the cooled, cleaned, and dehumidified air into the passenger compartment. The blower motor is controlled by a fan switch. On some systems, blower speed is regulated by the speed of the compressor.

Refrigerant Lines

All of the major components of the system have inlet and outlet connections that accommodate either flare or O-ring fittings. The refrigerant lines that connect between these units are made up of an appropriate length of hose or tubing with flare or O-ring fittings at each end as required **(Figure 54–38)**. In either case the hose or tube end of the fitting is constructed with sealing beads to accommodate a hose or tube clamp connection.

There are three major refrigerant lines. Suction lines are located between the outlet side of the evaporator and the inlet side or suction side of the

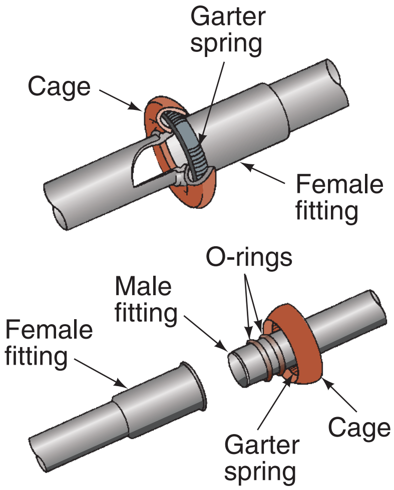


FIGURE 54–38 Spring-lock line coupler with O-rings.

compressor. They carry the low-pressure, low-temperature refrigerant vapor to the compressor where it again is recycled through the system. Suction lines are always distinguished from the discharge lines by touch and size. During operation, they are cold to the touch. The suction line is also larger in diameter than the discharge line.

Beginning at the discharge outlet on the compressor, the discharge or high-pressure line connects the compressor to the condenser. The liquid lines connect the condenser to the receiver/dryer and the receiver/dryer to the inlet side of the expansion valve. Through these lines, the refrigerant travels in its path from a gas state (compressor outlet) to a liquid state (condenser outlet) and then to the inlet side of the expansion valve, where it vaporizes on entry to the evaporator. Discharge and liquid lines are very warm to the touch when the system is operating and easily distinguishable from the suction lines.

Aluminum tubing is commonly used to connect A/C components where flexibility is not required. Where the line is subjected to vibrations, special rubber hoses are used. Typically the compressor outlet and inlet lines are rubber hoses with aluminum ends and fittings.

R-134a and R-1234yf systems must have quick-disconnect service fittings throughout the system **(Figure 54–39)**. The two systems have similar looking service fittings but they are different and not interchangeable. These also have hoses specially made for R-134a. They have an additional layer of rubber that serves as a barrier to prevent the refrigerant from escaping through the pores of the hose. Some late-model R-12 systems also use these barrier hoses to prevent the loss of refrigerant through the walls of the hoses.

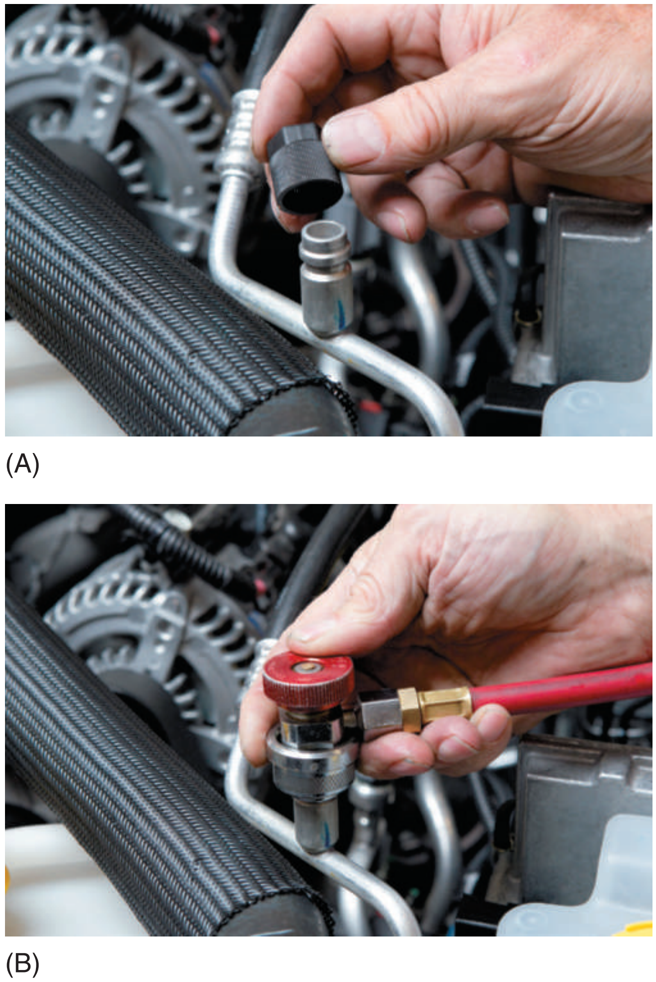


FIGURE 54–39 (A) A quick disconnect fitting on an A/C line, (B) connecting a pressure gauge to the fitting.

Air-Conditioning Systems and Controls

There are two basic types of automotive air-conditioning systems. They are classified according to the method used in obtaining temperature control and are known as cycling clutch systems or evaporator pressure or temperature control systems.

Evaporator Pressure Control System

Evaporator controls maintain a backpressure in the evaporator. Because of the refrigerant temperature/pressure relationship, the effect is to regulate evaporator temperature. The temperature is controlled to a point that provides effective air cooling but prevents the freezing of moisture that condenses on the evaporator.

In this type of system, the compressor operates continually when dash controls are in the air-conditioning position. Evaporator outlet air temperature is automatically controlled by an evaporator pressure control valve. This type of valve throttles the flow of refrigerant out of the evaporator as required to establish a minimum evaporator pressure and thereby prevent freezing of condensation on the evaporator core.

Cycling Clutch System

In every **cycling clutch** system, the compressor is run intermittently by means of controlling the application and release of its clutch through a thermostatic or pressure switch. The thermostatic switch senses the evaporator's outlet air temperature through a capillary tube that is part of the switch assembly. With a high sensing temperature, the thermostatic switch is closed and the compressor clutch is energized. As the evaporator outlet temperature drops to a preset level, the thermostatic switch opens the circuit to the compressor clutch. The compressor then ceases to operate until such time as the evaporator temperature rises above the switch setting. From this on-and-off operation is derived the term *cycling clutch*. In effect, the thermostatic switch is calibrated to allow the lowest possible evaporator outlet temperature that would prevent the freezing of condensation that might form on the evaporator.

Variations of the cycling clutch system include a system with a thermostatic expansion valve and a system with an orifice tube.

Cycling Clutch System with Thermostatic Expansion Valve Some factory installations utilize a cycling clutch system that incorporates a TEV and receiver/dryer, as do some add-on units. The evaporator and control components are either in the engine compartment or an integral part of the cowl. In such cases there is a common blower and duct work for both heating and air-conditioning purposes. Also in these installations, the thermostatic switch has no temperature control knob and is usually mounted on the evaporator or its case. Temperature control is accomplished by using fresh or recirculating air and by reheating the cooled air in the heater core. The clutch cycles only to prevent evaporator icing.

Cycling Clutch System with Orifice Tube (CCOT) A typical CCOT system is illustrated in **Figure 54–40**. The system is factory installed and can use a thermostatic clutch cycling switch mounted on the evaporator case or a pressure cycling switch located on the accumulator. An expansion (orifice) tube is used in place of the TEV. Also, the system has an accumulator in the evaporator outlet. The accumulator is used primarily to separate vapor from liquid refrigerant before it enters the compressor. It also contains a drying agent or desiccant to remove moisture. The CCOT system has no receiver/dryer or sight glass. This system does have a special orifice, the oil bleed orifice, that allows refrigerant oil to return to the compressor rather than to collect in the accumulator.

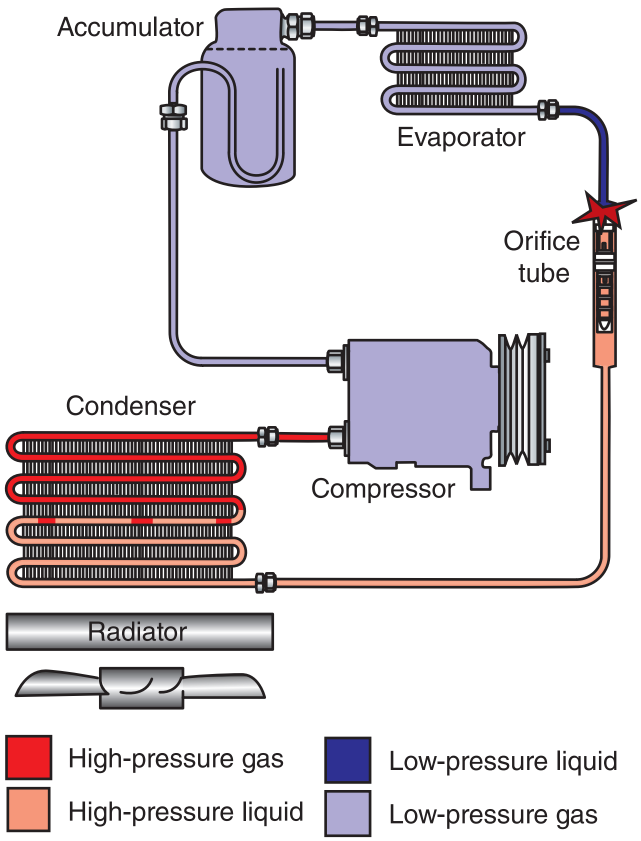


FIGURE 54–40 A typical cycling clutch system with an expansion (orifice) tube.

Compressor Controls

Many controls are used to monitor and trigger the compressor during its operational cycle. Each of these represents the most common protective control devices designed to ensure safe and reliable operation of the compressor.

Ambient Temperature Switch This switch senses outside air temperature and is designed to prevent compressor clutch engagement when air conditioning is not required or when compressor

operation might cause internal damage to seals and other parts.

The switch is in series with the compressor clutch electrical circuit and closes at about 37 °F (2.7 °C). At all lower temperatures, the switch is open, preventing clutch engagement.

On some vehicles, the ambient switch is located in the air inlet duct of air-conditioning systems regulated by evaporator pressure controls; other makes have it installed near the radiator. It is not required on systems with a thermostatic or pressure switch.

Thermostatic Switch In cycling clutch systems, the thermostatic switch is placed in series with the compressor clutch circuit so it can turn the clutch on or off. It has two purposes. It de-energizes the clutch and stops the compressor if the evaporator is at the freezing point **(Figure 54–41)**.

When the temperature of the evaporator approaches the freezing point (or the low setting of the switch), the thermostatic switch opens the circuit and disengages the compressor clutch. The compressor remains inoperative until the evaporator temperature rises to the preset temperature, at which time the switch closes and compressor operation resumes.

Evaporator Temperature Sensor

Many systems use temperature sensors or thermistors to determine evaporator temperature. This information is used to help control refrigerant flow to prevent freezing the evaporator.

Pressure Cycling Switch This switch is electrically connected in series with the compressor electromagnetic clutch. Like the thermostatic switch, the turning on and off of the pressure cycling switch controls the operation of the compressor.

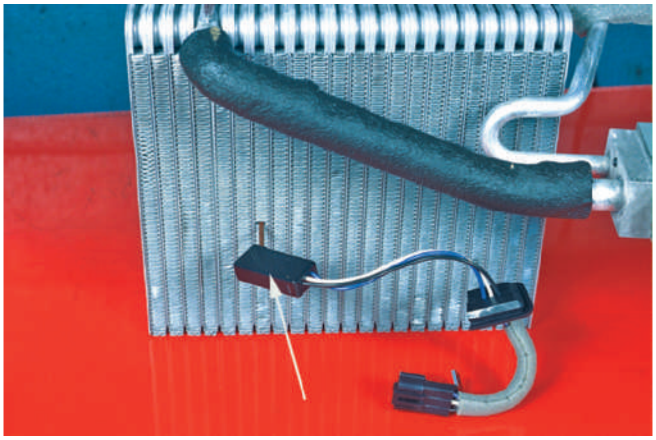


FIGURE 54-41 A temperature sensor mounted onto an evaporator.

Low-Pressure Cutoff or Discharge Pressure Switch This switch is located on the high side of the system and senses any low-pressure conditions. It is tied into the compressor clutch circuit, allowing it to immediately disengage the clutch when the pressure falls too low.

High-Pressure Cutout Switch This switch, normally located in the vicinity of the compressor or discharge (high side) muffler, is wired with the compressor clutch (in series). Designed to open (cut out) and disengage the clutch at 350 to 375 psi (2,400 to 2,600 kPa), it again closes and normally reengages the clutch when pressure returns to 250 psi (1,700 kPa) (higher if the system uses R-134a).

High-Pressure Relief Valve A high-pressure relief valve is incorporated into many air-conditioning systems. This valve may be installed on the receiver/dryer, compressor, or elsewhere in the high side of the system. It is a high-pressure protection device that opens (normally at 440 psi [3,033 kPa]) to bleed off excessive pressure that might occur in the system.

Compressor Control Valve This valve regulates the crankcase pressure in some compressors (commonly General Motors' V5 compressor). It has a pressure-sensitive bellows exposed to the suction side that acts on a ball and pin valve, which is exposed to high-side pressure. The bellows also controls a bleed port that is also exposed to the low side. The control valve is continuously modulating—changing the displacement of the compressor according to pressure or temperature.

Electronic Cycling Clutch Switch (ECCS) The ECCS prevents evaporator freeze-up by sending a signal to the engine control computer. The computer, in turn, cycles the compressor on and off by monitoring suction line temperature. If the temperature gets too low, the ECCS will open the input circuit to the computer, which causes the A/C clutch relay to open, disengaging the compressor clutch. Often this switch is the thermostatic switch at the evaporator.

Solar "Sunload" Sensor

More than half of the heat that is in a vehicle's passenger compartment comes from solar radiation. Many A/C systems have a solar sensor, also called the sunload sensor, that anticipates the amount of heat that will result from the sunlight. The solar sensor is usually located on top of the instrument

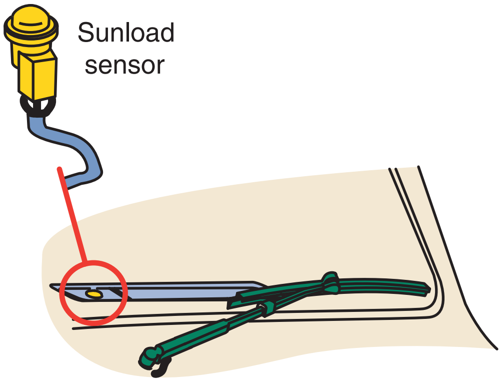


FIGURE 54–42 A solar (sunload) sensor.

panel **(Figure 54–42)**. The solar sensor is one of the main controls in many automatic climate control systems.

The solar sensor is a photo diode that receives a 5-volt reference signal from the control module. The diode normally blocks the flow of current in both directions except in the presence of light. The signal voltage from the solar sensor varies with the amount of sunlight on the sensor. When the sunlight increases, the output voltage increases, and as the sunlight decreases, the output voltage decreases. Bright sunlight causes the vehicle's interior temperature to increase; therefore, the system adds more cool air to the passenger compartment to overcome the increased heat.

Some vehicles have a solar sensor that measures sunlight at two separate angles. This allows the system to react differently on the driver and passenger sides of the vehicle. Other dual-zone systems have left and right solar sensors.

Some late-model vehicles are using infrared sensors inside the passenger compartment to measure the temperature of the passengers. Input from the sensors is used to direct airflow and control compressor operation. Other vehicles monitor which seat belts are being used so that airflow can be routed where passengers are seated to maintain a more comfortable environment for them.

Temperature Control Systems

Temperature control systems for air conditioners usually are connected with heater controls. Most heater and air-conditioning systems use the same plenum chamber for air distribution. Two types of air-conditioning controls are used: manual/semiautomatic and automatic.

Manual/Semiautomatic Temperature Controls

Air conditioner manual/semiautomatic temperature controls (MTC and SATC) operate in a manner similar to heater controls. Depending on the control setting, doors are opened and closed to direct airflow. The amount of cooling is controlled manually through the use of control settings and blower speed.

Automatic Temperature Control

An automatic or electronic temperature control system **(Figure 54–43)** maintains a specific temperature automatically inside the passenger compartment. To maintain a selected temperature, heat sensors send signals to a computer unit that controls compressor, heater valve, blower, and plenum door operation. A typical electronic control system might contain a coolant temperature sensor, in-car temperature sensor **(Figure 54–44)**, outside temperature sensor, high-side temperature switch, low-side temperature switch, low-pressure switch, vehicle speed sensor, throttle position sensor, sunload sensor, and power-steering cutout switch. Late-model vehicles are also incorporating GPS data and occupant detection via seat belt use and infrared sensors to determine where to direct airflow.

The control panel is found in the instrument panel at a convenient location for both driver and front-seat passenger access. Three types of control panels may be found: manual, push-button, or touch pad. All serve the same purpose. They provide operator input control for the air-conditioning and heating system. Some control panels have features that

FIGURE 54–43 Typical automatic climate control panel and selectors.

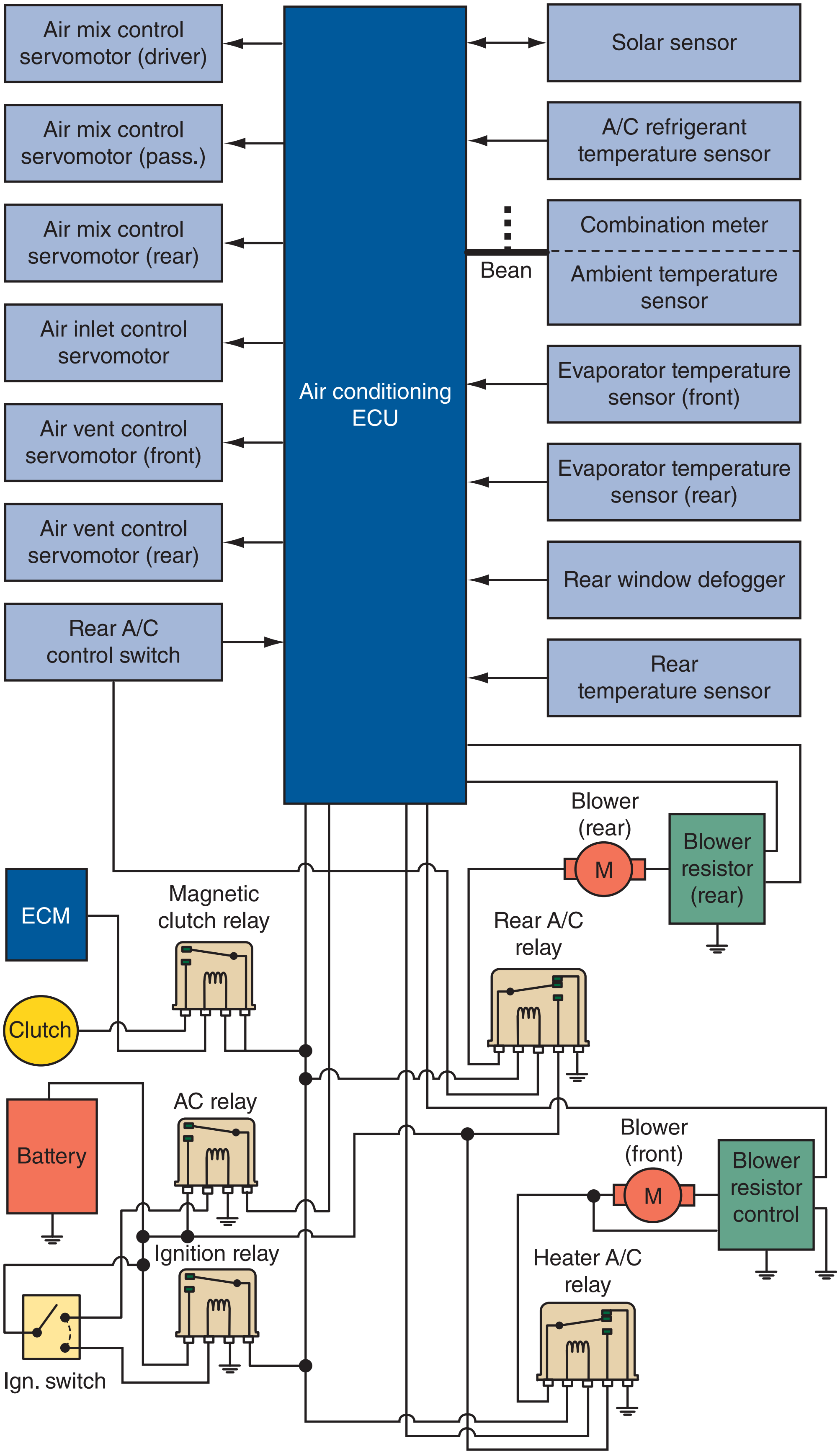


FIGURE 54-44 The layout of a computer-controlled automatic climate control system.

other panels do not have, such as provisions to display in-car and outside air temperature in degrees.

Provisions are made on the control panel for operator selection of an in-car temperature between 65 and 85 °F (18 and 29 °C) in one-degree increments. Some have an override feature that provides for a setting of either 60 or 90 °F (15 or 32 °C). Either of these two settings overrides all in-car temperature control circuits to provide maximum cooling or heating conditions.

Usually, a microprocessor is located in the control head to input data to the programmer, based on operator-selected conditions. When the ignition switch is turned off, a memory circuit remembers the previous setting. These conditions are restored the next time the ignition switch is turned on. If the battery is disconnected, however, the memory circuit is cleared and must be reprogrammed. Some vehicles are using smart-keys and individual personality settings for each key to pre-program the climate control system before the driver even enters the vehicle.

Many automotive electronic temperature control systems have self-diagnostic test provisions in which an on-board microprocessor-controlled subsystem displays a code. This code (number, letter, or alphanumeric) is displayed to tell the technician the cause of the malfunction. Some systems also display a code to indicate which computer detected the malfunction. Manufacturers' specifications must be followed to identify the malfunction display codes, because they differ from car to car.

Most late-model vehicles include the climate control part of the body control system **(Figure 54–45)**. This means that in addition to DTCs, scan data can be observed to help determine the cause of a complaint. Using the scan tool can allow you to determine if the systems inputs are being received and the information acted upon. In addition, the scan tool may have the ability to actively command the components of the system **(Figure 54–46)**. This can be very useful when testing stepper motors, blower motors, and the air-conditioning compressor clutch.

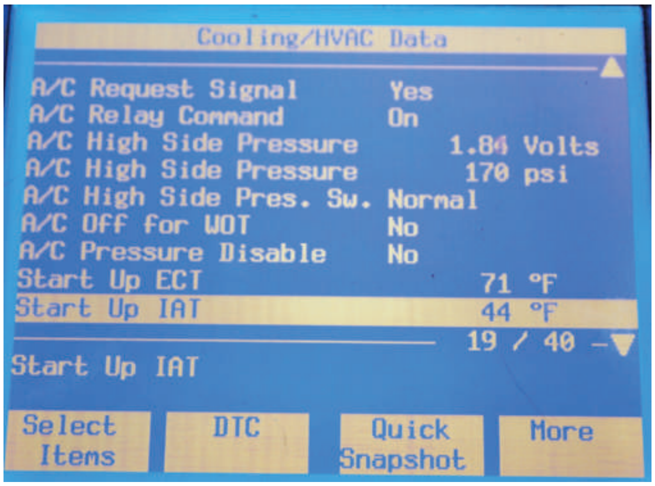


FIGURE 54–45 Using a scan tool to examine climate control data.

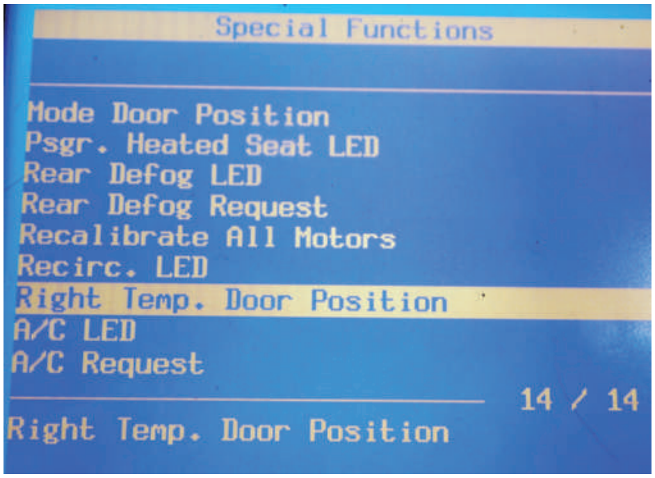


FIGURE 54–46 An example of active commands for a climate control system.

Case and Duct Systems

A typical automotive heater/air conditioner/case and duct system is shown in **Figure 54–47**. The purpose of the system is twofold: It is used to house the heater core and the air conditioner evaporator and to direct the selected supply air through these components into the passenger compartment of the vehicle. The supply air selected can be either fresh (outside) or recirculated air, depending on the system mode. After the air is heated or cooled, it is delivered to the floor outlet, dash panel outlets, or the defrost outlets.

In domestic vehicles, there are two basic duct systems employed. In the stacked-core-reheat system the basic control is in the water valve. For maximum air, the water valve is completely closed. All air enters the vehicle compartment through the heater core.

The access door, which is activated by a cable, controls only fresh or recirculated air. Recirculated air is used during maximum cold operation. The air-conditioning unit is not operative and the evaporator will not be cold. The evaporator is used only in the max air or maximum cold position. As the control level inside the car is moved, it controls the water valve by means of a vacuum or a cable to control the amount of hot water entering the heater core and the temperature of the air at the unit outlet.

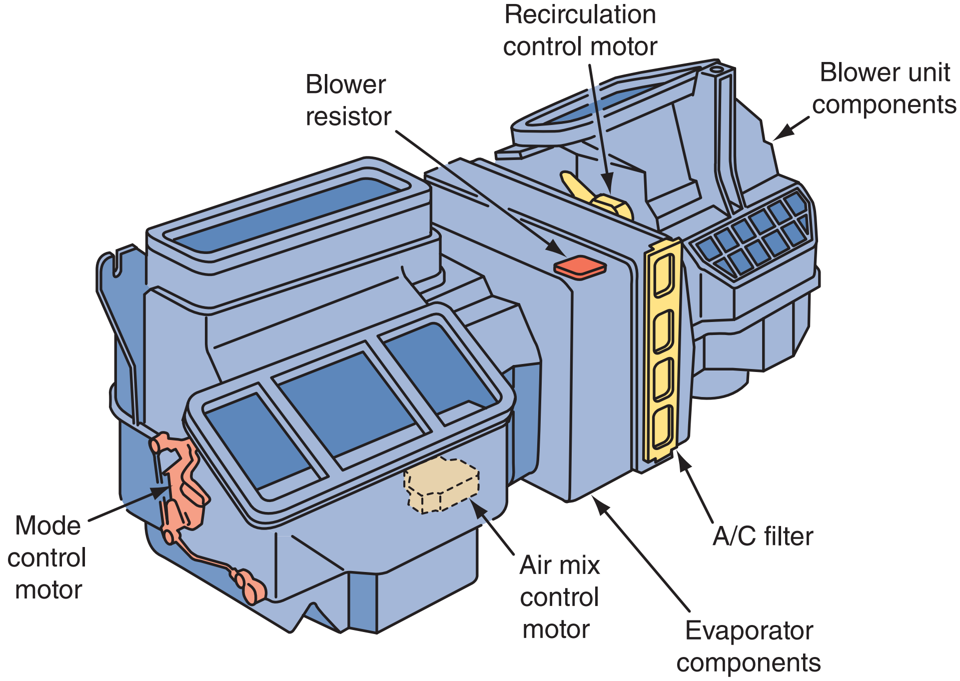


FIGURE 54–47 Typical heater/air conditioner ducts.

A blend-air-reheat mode door is found on General Motors and Ford vehicles and some truck units with factory-controlled heater system units. During heater-only operation, the air-conditioning unit is shut off, and the evaporator performs no function in air distribution or temperature control. During maximum air or extreme cold air, the air-conditioning system operates, the evaporator is cold, and the blend-air-door damper is completely closed. Only cold air enters the car.

As the control lever is moved in the vehicle from max air toward heat with the air conditioner on, the blend-air-door is moving. In maximum cold, it is completely shut. On maximum hot, it is completely open. The water valve on this unit is a vacuum on/off unit to regulate water flow. Normal position would be open. This type of blend-air system is extremely popular and can be used with or without a water valve.

To check the proper functioning of the ductwork, move the temperature control lever to see if any change occurs. If it does not, shut off the air conditioner and turn on the heater. Move the temperature control arm again to see if any change occurs. If not, check the cable and the flap door connected to the temperature control lever. You might be able to reach under the dash to reconnect the cable or free a stuck flap.

If no substantial airflow is coming out of the registers, check the fuses in the blower circuit. Remove the fan switch and test it. Check the blower motor by hot-wiring it directly to the battery with jumper cables.

Dual-Zone and Multiple-Zone Systems

Some climate control systems offer separate temperature settings for the driver's seat and passenger's seat **(Figure 54–48)** as well as for rear-seat passengers. On some BMW models, the temperature can even be adjusted separately for the driver's side upper and lower vents, focusing cooling on the upper body rather than the legs and feet. The temperature on each side of the vehicle is controlled by the doors in the ductwork for the heating and A/C system. Each side of the vehicle has its own air temperature actuator motor, controlling discharge air from the blower case. Each side also has an inside air temperature sensor and a solar sensor. The temperature setting for either side of the vehicle is made at

FIGURE 54–48 The control panel for a vehicle with dual zone and a rear heating and A/C system.

the control panel. If the passenger's control is turned off, the climate control system will maintain both sides of the vehicle according to the setting on the driver's side. When the passenger's control is turned on, the temperature on that side of the vehicle can be adjusted independently from the driver's setting.

On some systems, the climate control system is tied into the navigation system. In these cases, the A/C control module calculates the direction of the vehicle, the time, longitude, latitude, intensity of the sunlight, ambient temperature, and other information to determine the ideal amount of heat or cooling for each side of the vehicle. This system automatically controls the temperature in response to all of these inputs.

The automatic climate control also may be linked to the heated and ventilated seats. As the driver or passengers select their desired temperatures, the climate control system may heat, cool, or use a combination of heating and cooling based on temperature and humidity levels.

Rear Systems

Some vehicles, typically larger vans and SUVs, have a separate rear A/C system to provide comfort and temperature control for the passengers in the rear of the vehicle. These vehicles have a separate evaporator mounted in the rear of the vehicle **(Figure 54–49)**. A single conventional compressor is used to move refrigerant through the front and rear systems. There are also independent controls for the front and rear of the vehicle. Refrigerant lines connect the rear system to the compressor.

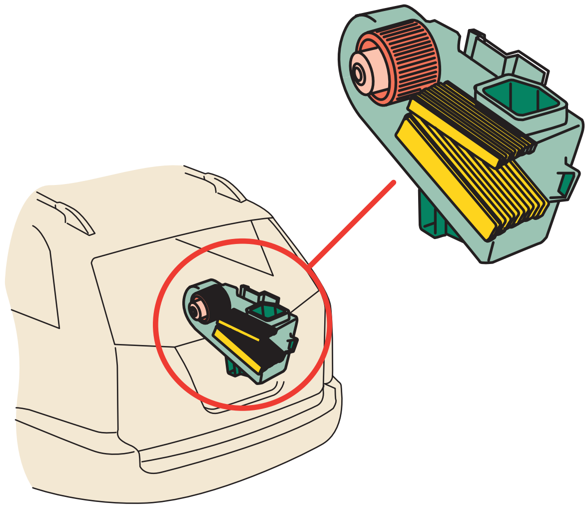


FIGURE 54–49 A rear A/C unit.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE		REPAIR ORDER		
Year: 1997	**Make:** Buick	**Model:** LeSabre	**Mileage:** 52,248	**RO:** 19268
Concern:	Customer states the passenger floor is wet.			
History:	Car had cooling system flushed and refilled 6 months ago.			
After confirming the complaint, the technician inspects the coolant level and finds that both radiator and overflow bottles are full. Next, he pressure tests the cooling system but finds no sign of a leak. Unsure why the interior is wet, he asks the customer for more information. He finds out the elderly woman who owns the car does not drive it much but has been driving and using the air conditioning. Suspecting a drain problem, the technician raises the car and inspects the evaporator drain.				
Cause:	Plugged evaporator drain.			
Correction:	Cleaned hose and verified drain is working properly.			

KEY TERMS

Chlorofluorocarbon (CFC)
Condensation
Cycling clutch
Discharge side
Evaporation
Heater control valve
Heater core
Hydrofluorocarbon (HFC)
High side
Low side
Refrigerant

SUMMARY

- Ventilation, heating, and air conditioning provide for the comfort of the vehicle's passengers.
- The ventilation system on most vehicles is designed to supply outside air to the passenger compartment through upper or lower vents or both. Several systems are used to vent air into the passenger compartment. The most common is the flow-through system. In this arrangement, a supply of outside air, called ram air, flows into the car when it is moving.
- Automotive heating systems have been designed to work with the cooling system to maintain proper temperature inside the car. The heating system's primary job is to provide a comfortable passenger compartment temperature and to keep car windows clear of fog or frost.
- The main components of an automotive heating system are the heater control valve, the heater core, the blower motor and fan, and heater and defroster ducts.
- All air-conditioning systems are based on three fundamental laws of nature: heat flow, heat absorption, and pressure and boiling points.
- The major components of an air-conditioning system are compressor, condenser, receiver/dryer or accumulator, expansion valve or orifice tube, and evaporator.
- The compressor is the heart of an automotive air-conditioning system. It separates the high-pressure and low-pressure sides of the system. The primary purpose of the unit is to draw the low-pressure vapor from the evaporator and compress this vapor into high-temperature, high-pressure vapor. This action results in the refrigerant having a higher temperature than surrounding air, enabling the condenser to condense the vapor back to liquid.
- The secondary purpose of the compressor is to circulate or pump the refrigerant through the condenser under the different pressures required for proper operation. The compressor is located in the engine compartment.
- The condenser consists of a refrigerant coil tube mounted in a series of thin cooling fins to provide maximum heat transfer in a minimum amount of space. The condenser is normally mounted just in front of the vehicle's radiator.
- The receiver/dryer is a storage tank for the liquid refrigerant.
- The refrigerant flow to the evaporator must be controlled to obtain maximum cooling, while ensuring complete evaporation of the liquid refrigerant within the evaporator. This is accomplished by a thermostatic expansion valve or a fixed orifice tube.
- The evaporator, like the condenser, consists of a refrigerant coil mounted in a series of thin cooling fins. The evaporator is usually located beneath the dashboard or instrument panel.
- Although R-134a air conditioners operate in the same way and with the same basic components as R-12 systems, the two refrigerants are not interchangeable. Because it is less efficient than R-12, R-134a operates at higher pressures to make up for the loss of performance and requires new service techniques and system component designs. Basically, the higher system pressures of R-134a mean the system must be designed for those higher pressures.
- There are two basic types of automotive air-conditioning systems. They are classified according to the method used in obtaining temperature control and are known as cycling clutch systems or evaporator pressure control systems.
- Evaporator controls maintain a backpressure in the evaporator. Because of the refrigerant temperature/pressure relationship, the effect is to regulate evaporator temperature.
- Temperature control systems for air conditioners are usually connected with heater controls. Most heater and air-conditioner systems use the same plenum chamber for air distribution.
- Two types of air conditioner controls are used: manual/semiautomatic and automatic.

REVIEW QUESTIONS

Short Answer

1. What is the amount of heat necessary to change the state of a substance called?
2. Explain how an electromagnetic compressor clutch operates.
3. Describe four ways in which the heater control valve may be controlled.
4. What is the purpose of the compressor clutch thermostatic switch?
5. What does "change of state" mean? And why is it important to air-conditioning units?
6. What state is the refrigerant in when it leaves the condenser?

7. What causes condensed water to leak from the air-conditioning system?
8. Explain why a diode may be wired into the compressor clutch circuit.

Multiple Choice

1. On which of the following laws of nature is the air-conditioning system based?
   a. Heat flow
   b. Heat absorption
   c. Pressure and boiling points
   d. All of the above
2. Which of the following statements is *true*?
   a. Refrigerant leaves the compressor as a high-pressure, high-temperature liquid.
   b. Refrigerant leaves the condenser as a low-pressure, low-temperature liquid.
   c. Refrigerant returns to the compressor as a low-pressure, high-temperature vapor.
   d. None of the above.
3. Which of the following statements is *false*?
   a. The condenser is normally mounted just in front of the radiator.
   b. The receiver/dryer is a storage tank for the liquid refrigerant from the condenser.
   c. An accumulator is not used in a system with a receiver/dryer.
   d. All of the above.
4. Which of the following statements about PTC heaters is *not* true?
   a. Some vehicles have a PTC heating element in the heater core.
   b. Some vehicles have a PTC element installed in an air duct from the blower housing to increase the air temperature in the ducts.
   c. PTC heaters are electronically controlled and work with the cooling system to provide hot coolant.
   d. PTC elements are small ceramic stones that react quickly to changes in current.
5. Which of the following is electrically connected in series with the compressor electromagnetic clutch?
   a. Ambient temperature switch
   b. Thermostatic switch
   c. Pressure cycling switch
   d. All of the above
6. Which of the following oils is used in an original equipment R-134a system?
   a. Mineral oil
   b. CCOT
   c. Ester oil
   d. PAG
7. A heating system includes all of the following parts except a ___.
   a. heater core
   b. ventilation system
   c. receiver/dryer
   d. distribution plenum

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that a great amount of heat is transferred when a liquid boils or a vapor condenses. Technician B says that a change in pressure does not change the boiling point of a substance. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Technician A says that suction lines become very warm during A/C operation. Technician B says that discharge lines connect the compressor to the condenser. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. While discussing the reasons the use of R-134a is being discontinued in some countries: Technician A says that the chemical composition of the refrigerant has been proven to be harmful to the earth's ozone layer. Technician B says that R-134a leaks contribute to the undesirable greenhouse effect. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

4. While discussing the reaction by a refrigerant to heat: Technician A says that to absorb heat, the temperature and pressure of the refrigerant are kept low. Technician B says that to dissipate heat, the temperature and pressure are kept high. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. While discussing solar sensors: Technician A says that a solar sensor is a photo diode that receives a 5-volt reference signal from the control module. Technician B says that when the intensity of sunlight increases, the output voltage increases, and as the sunlight decreases, the output voltage decreases. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
6. While discussing the future use of CO_2 as a refrigerant: Technician A says that CO_2 is nontoxic and presents little threat to the environment. Technician B says that only slight changes from conventional systems will be required because CO_2 systems operate at low pressures and temperatures. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. Technician A says that when the A/C system is off, the refrigerant occupies the system as a liquid and its pressure is the same throughout the system. Technician B says that refrigerant is pumped out of the compressor as a high-pressure, high-temperature vapor and is sent to the condenser. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. Technician A says that when the refrigerant is pumped out of the compressor and sent to the condenser, heat in the refrigerant is moved to the outside air by conduction and convection. Technician B says that the refrigerant leaves the bottom of the condenser as a high-pressure, high-temperature liquid. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. A heater does not supply enough heat and the coolant level and flow are correct: Technician A says that a misadjusted heater control could be the cause. Technician B says that a bad thermostat could be the cause. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. While discussing relative humidity: Technician A says that the amount of moisture that air can hold is directly related to the temperature of the air. Technician B says that the colder the air is, the more moisture it can hold. Who is correct?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 55

AIR-CONDITIONING DIAGNOSIS AND SERVICE

OBJECTIVES

- Understand the special handling procedures for automotive refrigerants.
- Describe how to connect a manifold gauge set and a recovery/recycling machine to a system.
- Describe methods used to check refrigerant leaks.
- Determine refrigerant type, test refrigerant type and check for sealants.
- Use approved methods and equipment to discharge, reclaim/recycle, evacuate, and recharge an automotive A/C system.
- Perform a performance test on an A/C system.
- Interpret pressure readings as an aid to diagnose A/C problems.
- Diagnose and repair A/C control systems.

Air-conditioning (A/C) service, in many ways, is different from service to other parts of the vehicle. Although there are few parts in the system **(Figure 55–1)**, each component has a specific purpose and service procedure. That by itself is not a big deal. The challenge with the A/C is how it operates. The system operates on changes of refrigerant pressure. There are many things that can cause the pressure to change; some are part of the system, some are part of the environment, and some of them are faults or bad components in the system.

Service Precautions

A/C systems are extremely sensitive to moisture and dirt. Therefore, clean working conditions are very important. The smallest particle of foreign matter in an A/C system contaminates the refrigerant, causing rust, ice, or damage to the compressor. For this reason, all replacement parts are sold in vacuum-sealed containers and should not be opened until they are ready to be

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2010	**Make:** Dodge	**Model:** Ram 1500	**Mileage:** 102,544	**RO:** 19301
Concern:	Customer states the air conditioning is not working properly. It sounds like the A/C turns on and off quickly.			
History:	Car had A/C system serviced and recharged 2 months ago.			
Given this customer concern, use what you learn in this chapter to determine possible causes for this concern, methods of diagnosing the concern, and what steps will be necessary to correct the concern.				

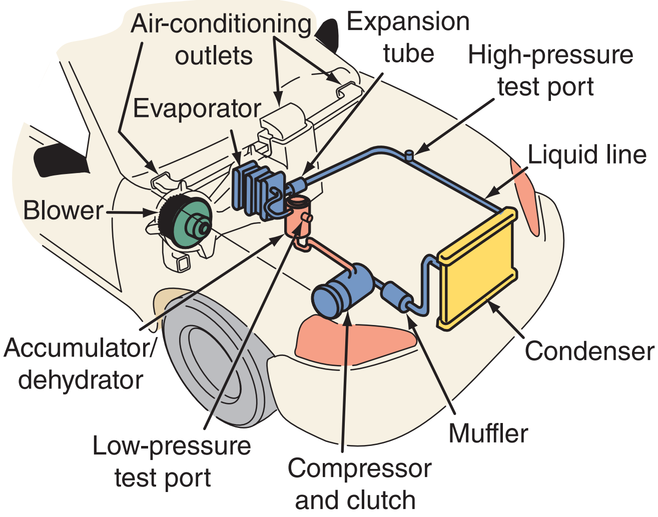


FIGURE 55–1 A late-model air-conditioning system.

installed in the system. If, for any reason, a part has been removed from its container for any length of time, the part must be completely flushed using only the recommended solvent to remove any dirt or moisture that might have accumulated during storage. If the system has been open for more than 2 minutes, the entire system must be completely evacuated and a new accumulator or desiccant bag must be installed.

Whenever it is necessary to disconnect a refrigerant line, wipe away any dirt or oil at and near the connection to eliminate the possibility of dirt entering the system. Both sides of the connection should be immediately capped or plugged to prevent the entrance of dirt, foreign material, and moisture. It must be remembered that all air contains moisture. Air that enters any part of the system carries moisture with it.

Keep all tools clean and dry. This includes the gauge set and replacement parts. Be careful not to overtighten any connection. Overtightening can result in distortion and a system leak.

When adding oil, the container and the transfer tube through which the oil will flow should be exceptionally clean and dry. Refrigerant oil quickly absorbs any moisture it contacts. For this reason, the oil container should not be opened until it is time to use it and should be capped immediately after use.

When it is necessary to open a system, have everything needed immediately available so as little time as possible is required to perform the operation. Do not leave the system open any longer than necessary.

Any time the system has been opened for repairs, it must be properly evacuated after the repair. Also, before disconnecting or removing any part, the refrigerant needs to be recovered and not allowed to escape the atmosphere.

SHOP TALK

It is important to remember that just one drop of water added to the refrigerant will start chemical changes that can result in corrosion and eventual breakdown of the chemicals in the system. The smallest amount of moist air in the refrigerant system might start reactions that can cause malfunctions.

Refrigerant Safety Precautions

- Always work in a well-ventilated and clean area. Refrigerants are colorless and invisible. Refrigerant is heavier than oxygen and will displace it in a confined area. Avoid breathing the refrigerant vapors. Exposure to refrigerant may irritate your eyes, nose, and throat.
- Refrigerant evaporates quickly when it is exposed to the atmosphere. It will freeze anything it contacts. If liquid refrigerant gets in your eyes or on your skin, it can cause frostbite. Never rub your eyes or skin if refrigerant has contacted these areas. Immediately flush the exposed areas with cool water for 15 minutes and seek medical help. Also check the SDS for the refrigerant to identify other safety-related procedures.
- An A/C system's high pressure can cause severe injury to your eyes and/or skin if a hose were to burst. Always wear eye protection when working around the A/C system and refrigerant. It is also advisable to wear protective gloves and clothing.
- Never use R-134a in combination with compressed air for leak testing. Pressurized R-134a in the presence of oxygen may form a combustible mixture. Never introduce compressed air into R-134a containers (empty or full ones), A/C systems, or A/C service equipment.
- Be careful when handling refrigerant containers. Never drop, strike, puncture, or burn the containers. Always use DOT-approved refrigerant containers.
- Never expose A/C system components to high temperatures. Heat will cause the refrigerant's pressure to increase. Never expose refrigerant to an open flame.

- Never overfill refrigerant containers. The filling level of the container should never exceed 60 percent of the container's gross weight rating. Always store refrigerant containers in temperatures below 125 °F (52 °C) and keep them out of direct sunlight.
- Refrigerant comes in 30- and 50-pound cylinders. Keep the drums in an upright position. Make sure that valves are protected by safety caps when the drums are not in use. Avoid dropping the drums. Handle them carefully.
- R-1234yf is stored and sold in white containers with red labeling or handles, whereas R-134a should be stored in light blue containers **(Figure 55–2)**. R-1234yf and R-134a should never be mixed. If the two refrigerants are mixed, contamination will occur and may result in A/C system failure. Separate service equipment must be used for the different refrigerants.
- To prevent cross-contamination, identify whether the A/C system being worked on uses R-1234yf or R-134a. Check the fittings in the system; all R-134a-based systems use ½-inch 16 ACME threaded fittings and quick-disconnect service couplings. R-1234yf systems can be identified by underhood labels clearly stating that R-1234yf is used **(Figure 55–3)**. Most manufacturers identify the type of refrigerant used by labeling the compressor. Also look for a label with the words, "CAUTION—SYSTEM TO BE SERVICED BY QUALIFIED PERSONNEL." This label or plate can be found under the hood near a component

FIGURE 55–2 R-12 should be stored and sold in white containers, whereas R-134a should be stored in light blue containers.

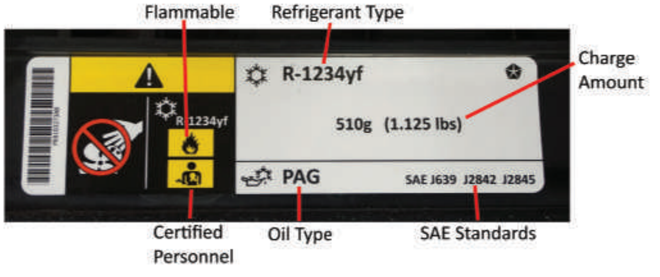


FIGURE 55–3 An underhood R-1234yf warning decal and what each item indicates.

of the system. This label also indicates what kind of refrigerant is used, the quantity required to fill the system, and the type of refrigerant oil.

- Before storing refrigerant in a tank, evacuate the tank before filling it. Tank pressure should never exceed the maximum allowable pressure as indicated on the tank.

Special Precautions for Hybrid Vehicles

Hybrid vehicles have high-voltage systems. Most often, the A/C compressor is powered by high voltage. Careless handling of some components can lead to serious injury, including death. Always follow and adhere to the precautions given by the manufacturer. These precautions are clearly labeled in their service information. All service procedures should be followed exactly as defined by the manufacturer. Being careless and/or not following the procedures can cause serious injury and can cause the battery to explode! Following is a list of commonsense items to consider when working on a hybrid vehicle:

- Because the A/C compressors are also electrically driven, special nonconducting refrigerant oils are used in HEV and EV systems **(Figure 55–4)**. Before attempting to service the A/C system, any gauge set or charging station that has been used with standard PAG oils must be purged and freed of any traces of PAG oil. Accidental contamination of the hybrid A/C system can cause electrical conduction within the compressor and potentially cause severe damage to the entire high-voltage system. Some shops keep separate equipment for working on hybrids to avoid contamination.
- Before doing any service on a hybrid vehicle, refer to the service information for that specific vehicle. All hybrids A/C systems operate in much the same way but have different systems and

FIGURE 55-4 Pay attention to all warning and service decals.

components; this is true for vehicles made by the same manufacturer.

- All high-voltage wires and harnesses are wrapped in yellow- or orange-colored insulation. Respect the color and stay away from it unless the system is depowered.
- Warning and/or caution labels are attached to all high-voltage parts. Be careful not to touch these cables and parts without the correct protective gear, such as safety gloves.
- Make sure that the high-voltage system is shut down and isolated from the vehicle before working near or with any high-voltage component.
- When working on or near the high-voltage system, even when it is depowered, always use insulated tools.
- Never leave tools or loose parts under the hood or close to the battery pack. These can easily cause a short.
- Never wear anything metallic, such as rings, necklaces, watches, and earrings, when working on a hybrid vehicle.

GO TO Chapter 35 for details on isolating the high-voltage system in a hybrid vehicle.

GO TO Chapter 6 for a complete description of the various tools used to diagnose and service A/C systems.

Warning! Under no circumstances, because of environmental and health concerns, should refrigerants or refrigerant oils be mixed. Never add one type of refrigerant to a system that has or has had another type refrigerant in it. Also make sure that the vehicle is clearly labeled as to the type of refrigerant it was converted to use.

SHOP TALK Under Section 609 of the Clean Air Act, you must be certified by an EPA-approved program to service and repair mobile air conditioning systems and buy bulk refrigerant. To become certified, a technician must have and use approved refrigerant recycling equipment and pass an exam on refrigerant recovery and recycling. A common test for this certification is administered by the ASE, MACS worldwide training/testing; some states also offer the test.

Initial System Checks

The first step in A/C diagnosis, as in all automotive diagnostic work, is to get the customer's story. Is the problem no cold air, the air from the ducts never gets cold enough, or the unit only cools at certain times of the day? The complaint could also be that the system does not work at all, or that the air blows out of the wrong ducts. An accurate description of the customer's problem helps pinpoint whether the problem is refrigerant, mechanical, vacuum, or electrical related. It also reduces diagnosis time and, most important, satisfies the customer.

Because of the many construction and operational variations that exist, there is no uniform or standard diagnostic procedure applicable to all automotive A/C systems except the performance test. For complete specific diagnostic information on a given air conditioner, check the manufacturer's service information.

A quick verification of the customer's concern can be done by starting the engine and allowing it to warm up. Move the temperature control to its full heat position. Check the amount of airflow and heat in each of the fan positions. The amount of air coming out the system should change with a change in blower speed. Also pay attention to all smells and noises. Turn the temperature control to the defrost mode. Make sure there is adequate airflow coming out of the defroster vents. Now turn the temperature control to cool or to the A/C position. Pay attention to how the engine reacts when the A/C compressor clutch engages. Also pay attention to any abnormal noises or smells. The air leaving the vents should be cool. While doing these checks, attempt to duplicate the customer's concerns and the conditions that exist when the problem occurs. If the system does not respond as expected, the system should be inspected and performance tested.

Inspection

A visual check of the A/C and cooling systems can result in an immediate diagnosis. Begin by checking the condition of the compressor's drive belt. Check the tension of the belt with a belt tension gauge (if the compressor is driven by a serpentine belt, check the belt tensioner markings). Carefully look at the compressor clutch for signs of oil leakage and belt slippage. Belt slippage may be evident by large amounts of black dust around the clutch plate. The presence of oil on or around the clutch normally indicates a bad compressor seal.

When the system is low on refrigerant charge, the performance of the system suffers. Low charge is typically the result of system leaks. The area of leakage can often be identified with a thorough inspection. Because refrigerant oil leaks out with the refrigerant, there will be an oily film at the point of leakage **(Figure 55–5)**. This film will collect dirt, and a buildup of dirt around a fitting is a good indication of a leak. Check the following refrigerant hoses and fittings for signs of leakage or damage and bends or distortion:

- Compressor to the condenser
- Condenser to the evaporator
- Evaporator to the compressor

While leaks from the metal lines are not very common, leaks from the rubber hoses and from around connections and fittings are. Make sure to check around electrical switches and any place a hose or line is secured or can contact another component.

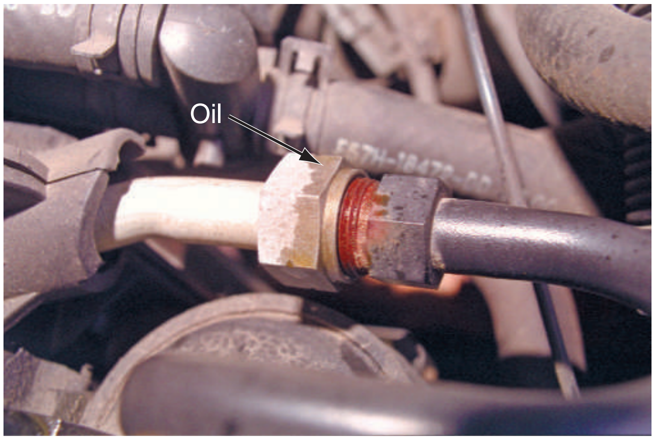


FIGURE 55–5 The oily film by this fitting is evidence of a refrigerant leak.

Visually check the condenser and the area between the condenser and radiator for a buildup of dirt, leaves, and other debris **(Figure 55–6)**. Also check the fins of the condenser for damage. If the airflow through the condenser is blocked, clean the condenser and the area around it. If the fins are damaged, they may be able to be straightened. In most cases, a damaged condenser is replaced.

A/C systems rely on many switches; these can be the cause of several operating problems. Look at the wiring and connectors to all sensors and switches carefully. Make sure all connections are secure and clean. Sometimes a bad connection or corrosion can cause intermittent problems.

In a well-ventilated area, start the engine, place the transmission in park (if the vehicle has a manual transmission, put it in neutral), set the parking brake, and turn on the A/C system to MAX cooling. On most vehicles, the electric engine cooling fan will turn on when the A/C system is turned on. Check to see if the fan(s) came on.

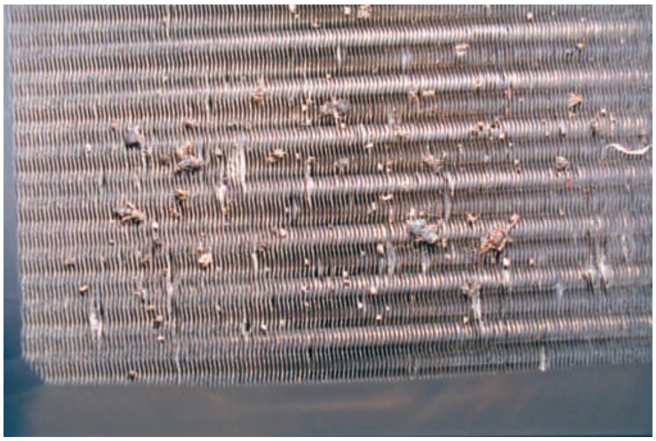


FIGURE 55–6 The condenser should be checked for damage and a buildup of debris that could cause a restriction to airflow.

Listen to the system and record any unusual sounds. Be sure to listen to the system while the compressor clutch cycles on and off. You should hear a click or a slight change in engine speed when the clutch engages. Of course, if the compressor runs at all times, the clutch will not engage or disengage with a change of the A/C controls.

Simple Checks Feel the air coming out of the vents. Cold or slightly cool air means the system has some cooling ability and the compressor is working. If the air is not cool, this means the compressor is not working or the system is not capable of providing conditioned air. If the air is warm or hot, there is probably a problem with the air duct system or the controls.

Move the temperature control from hot to cool. Feel the air from the vents. If the air temperature does not change or changes little, there is a problem with the blend door or doors in the air distribution case.

Operate the blower control through all of its speed positions; the amount of air should change. If not, there is a problem with the switch or the resistor block for the blower.

Carefully feel the discharge line from the compressor to the condenser. The line should be hot and the temperature should be the same along its full length. Any change is a sign of restriction, and the line should be flushed or replaced. Check the condenser by feeling up and down the face or along the return bends. There should be a gradual change from hot to warm as you move from the top to the bottom. Any abrupt change indicates a restriction, and the condenser has to be flushed or replaced.

If the system has a receiver/dryer, check the inlet and outlet lines. They should have the same temperature. Any temperature difference or frost on the lines or receiver tank are signs of a restriction. The receiver/dryer must be replaced. Also feel the liquid line from the receiver/dryer to the expansion valve. The entire length of the line should be warm. Typically the formation of frost on the outside of a line or component means there is a restriction to refrigerant flow. A restriction can cause the refrigerant to stay longer in the condenser. This is called condenser flooding and will cause a starved evaporator.

The expansion valve should be free of frost, and there should be a sharp temperature difference between its inlet and outlet. On vehicles equipped with the orifice tube, feel the liquid line from the condenser outlet to the evaporator inlet. A restriction is indicated by any temperature change in the liquid line before the orifice tube. Flush the line or replace the orifice tube if restricted.

FIGURE 55–7 Feeling the temperature of the pressure lines in an A/C system is part of a basic visual inspection of the system.

Carefully place your hand on the inlet line of the evaporator **(Figure 55–7)**. Do the same on the outlet. Both tubes should be colder than ambient temperature and both should be about the same temperature. If the inlet is significantly colder than the outlet, the system is probably low on refrigerant. If both lines are not colder than ambient temperature, the system needs further diagnosis.

The suction line to the compressor should be cool to the touch from the evaporator to the compressor. If it is covered with thick frost, this might indicate that the expansion valve is flooding the evaporator. The accumulator should also be cool to the touch.

Trouble Codes

Many late-model A/C systems have a self-diagnostic capability. An indicator lamp on the control panel may be used to flash codes. On most modern vehicles, part of the A/C system can be checked with a scan tool connected to the vehicle's BCM; this is especially true for those vehicles with automatic climate control. Normally the buttons on the control panel must be depressed in a certain sequence to activate the self-test.

Diagnosis

Often diagnosis of an A/C system can be done by observing the operation of the system, including listening for noises. When abnormal noises are heard, they can lead to the problem area.

PROCEDURE

To access DTCs from a system, follow these steps:

Using a Scan Tool

STEP 1 Using the service information, determine if and how to retrieve diagnostic information from the body control module (BCM).

STEP 2 Connect the scan tool.

STEP 3 Turn the ignition on.

STEP 4 Program the scan tool for that vehicle.

STEP 5 From the menu on the scan tool, select the BCM.

STEP 6 Retrieve and record all DTCs.

STEP 7 To observe the activity of the inputs and outputs, select DATA. Pay attention to any data that is outside its normal operating range, such as the ambient temperature, evaporator temperature, and low- and high-side pressures.

STEP 8 Diagnose any abnormal operating perimeters.

STEP 9 Turn the ignition off.

STEP 10 Disconnect the scan tool.

Noise

Often a customer's concern is the noise emitted by the A/C system. The following discussion covers the common abnormal noises and their causes.

Clutch Noises The clutch normally makes a clicking noise when it engages and disengages. This noise will become louder as the clutch wears. Once the clutch is severely worn, it will make a squealing noise when it is engaged. This noise can also result from oil on the clutch. A very loud screech or squeal can indicate a seized compressor. A bent drive pulley also can cause a growling or rubbing noise.

Hose Noise The change in pressures in the suction/discharge hoses can set up vibrations that cause sounds to appear from the inside of the vehicle. The noise is typically caused by a hose contacting another hose or part in the engine. Check the routing of the hoses to make sure they are not in contact. Also look for abrasions on the hoses. These can be caused by the contact.

Compressor Noise If the mounts for the compressor are loose or damaged, there will be a rattling or groaning noise. The noise is normally random. At times, loose mounts will also cause premature wear of the drive belt. Worn bearings and/or internal damage to the compressor can cause whining and growling noises when the compressor is engaged.

Hissing or Whistling This is a common and normal noise. When the A/C is turned off, a high-pitched whistle may be heard. This sound is caused by the pressures that are equalizing in the system. The high pressure moves to the low-pressure side through the metering device. This movement can result in a whistle or hiss.

Odors

A somewhat common concern of customers is a smell emitting from the A/C system. This moldy and musty smell is due to a buildup of moisture on the evaporator or the cabin filter. Moisture buildup is caused by the evaporator doing its job. As the temperature inside the vehicle is lowered, moisture is separated from the air; the moisture should be able to drain but sometimes the drain is plugged or dislocated. When a customer complains about the smell, check the evaporator drain. Also, the cabin air filter needs to be periodically changed; if it has not been changed, there will be odors that offend the passengers. Products are available to disinfect the evaporator and ductwork. These kill any odor-causing bacteria. Application of these products may require access to the evaporator, requiring disassembly of the HVAC system.

Cabin Filters Cabin air filters are designed to capture soot, dirt, pollen, and other pollutants that enter a vehicle through its heating, A/C, and defrost systems. Today more than 80 percent of all new vehicles sold in the United States have a cabin air

filter or a slot where one can be installed. Cabin air filters are typically located behind the glove compartment, under the dash, and under the hood **(Figure 55–8)**. Some cars have the filter in the HVAC case between the blower motor and evaporator core. A cabin filter is a critical part of the HVAC system. If the filter becomes dirty or clogged, less air will be able to pass through the filter. This will adversely affect the operation of the HVAC system.

Many Toyotas have an ion generator called the Plasmacluster generator **(Figure 55–9)** that improves interior air quality. It uses a high-voltage device that emits a slight sound. With these systems, dust will accumulate at the driver-side air vent. Clean it with a cloth; never spray solvent into the air vent.

FIGURE 55–8 A typical cabin air filter and housing.

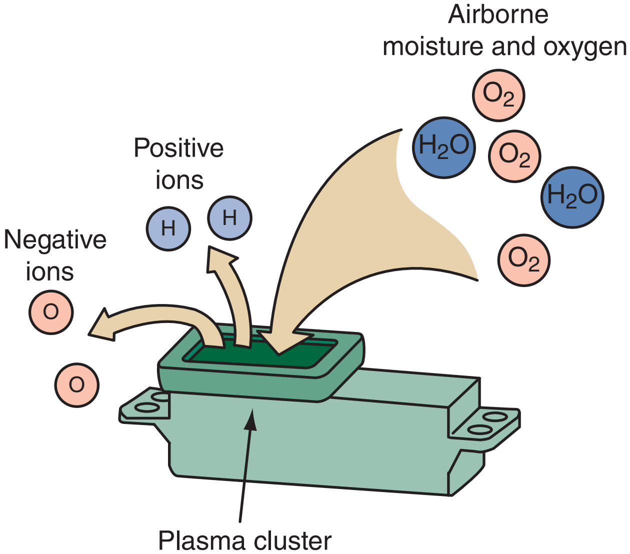


FIGURE 55–9 Many Toyotas have an ion generator called the Plasmacluster generator that improves interior air quality.

Replacement of the filters is part of a vehicle's PM program; normally a filter should be replaced every 12,000 to 15,000 miles (19,300 to 24,140 km) or at least once a year. This interval really depends on where the vehicle is typically driven. The procedure for replacing the filters varies with make and model; always check with the manufacturer.

There are two basic types of cabin air filters: particle-trapping and one that has an additional charcoal layer for odor absorption. Some particulate filters have a section that traps larger particles and another that is electrostatically charged to attract and hold smaller particles.

A charcoal type will hold a lot of odorant, and under some conditions it may release trapped odors. This is why these filters should be replaced on a regular basis. There are two alternatives to the charcoal filter: a filter element impregnated with baking soda and a filter with a biocidal cartridge. Both prevent the growth of bacteria, mold, mildew, algae, and yeast.

Some vehicles are also equipped with an air quality sensor in the main inlet duct of the HVAC system or in front of the condenser. The sensor detects the presence of undesirable gases in the incoming air, specifically carbon monoxide and nitrogen dioxide. Within seconds of detection, the ventilation system closes the outside air inlet and recirculates the air until the pollutants are no longer at an unacceptable level.

Performance Testing

Performance testing provides a measure of A/C system operating efficiency. A manifold pressure gauge set is used to determine both high and low pressures in the refrigeration system. The desired pressure readings will vary according to temperature. Use temperature/pressure charts as a guide to determine the proper pressures. At the same time, a thermometer is used to determine air discharge temperature in the passenger compartment **(Figure 55–10)**.

Service Valves and Quick-Connect Fittings

System service valves provide the attachment point for the manifold pressure gauge set. They are located in the low and high sides of most A/C systems. Both

FIGURE 55–10 A thermometer is used to determine air discharge temperature in the passenger compartment.

R-134a **(Figure 55–11A)** and R-1234yf systems have quick-connect fittings though each is different and not interchangeable **(Figure 55–11B)**. The service valve caps on R-1234yf systems are also tethered to the line to help prevent losing the caps when removed. Both systems use two different sized quick-connect fittings; the low-pressure fitting being the smaller of the two. This prevents incorrect connection of the service hoses. The service hose fittings should have a manual valve that threads through the fitting and down to open the service port connection. Once finished, loosening the valve retracts the pin and allows the system to seal before removing the fittings. This is to reduce the amount of refrigerant released when the service hoses are disconnected from the system.

Stem Valves The stem valve was sometimes used on older two-cylinder reciprocating-piston compressors. The service valves are mounted on the compressor head. These valves can be used to isolate the rest of the A/C system from the compressor when the compressor is being serviced. These valves have a stem under a cap with the hose connection directly opposite it.

Purity Test

When you are not sure of the refrigerant used in a system or if you suspect that a mixing of refrigerants has occurred, you should run a purity test and/or use a refrigerant identifier **(Figure 55–12)**. In addition

> **Caution!** Always wear safety goggles when working on or around A/C systems.

(A)

(B)

FIGURE 55–11 (A) A Schrader service valve for a R-134a system and (B) for a R-1234yf system.

to determine what is in the system, identification is also important because several refrigerants that are on the market are flammable. Knowing what refrigerant is in the system, or what condition it is in, will help you protect your equipment from damage and

FIGURE 55–12 A refrigerant identifier.

determine what steps you need to take to properly service the system.

It is recommended that the system be tested for sealant identification and/or contamination before conducting the purity test. Many of the A/C recharge products available over the counter contain some type of sealant. Reclaiming the refrigerant and sealant can cause damage to your equipment. It is recommended that shops have sealant ID kits **(Figure 55–13A)** and special filters installed on their charging stations to help prevent contamination. A small sample of refrigerant is drawn into the test kit; this acts like a leak in the system **(Figure 55–13B)**. If sealant is present it will react with the moisture in the air and solidify in the small disposable detection cartridge. Systems that contain sealant can still be reclaimed but special filters are used to trap the sealant, dyes, and any other contaminants that are present.

Manifold Pressure Gauge

The manifold gauge set is one of the most important A/C tools. It is used when discharging, charging, and evacuating the system; it also is used for diagnosing the system. With the new legislation on handling refrigerants, all gauge sets are required to

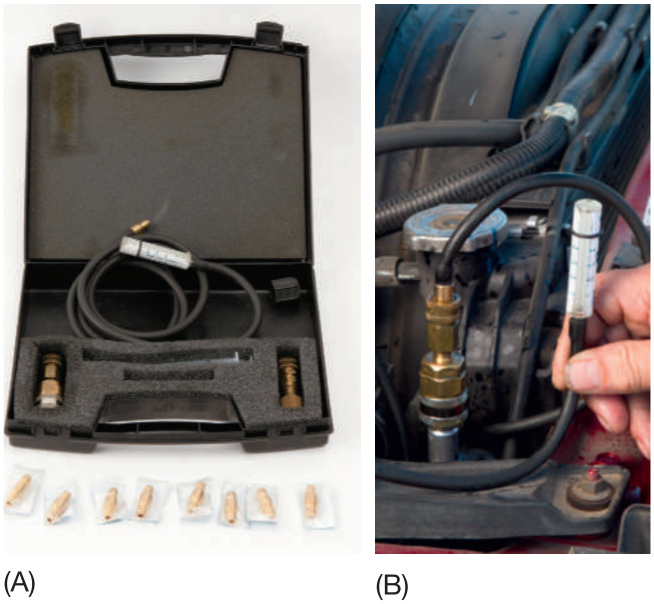


FIGURE 55–13 (A) A typical refrigerant identification kit. (B) Taking a sample of the refrigerant.

FIGURE 55–14 The test connectors with shutoff valves for an R-134a system.

have a valve device to close off the end of the hose so that the fitting not in use is automatically shut **(Figure 55–14)**.

The low-pressure gauge is graduated into pounds of pressure from 1 to 120 (with cushion to 250) in 1-pound graduations, and, in the opposite direction, in inches of vacuum from 0 to 30. This is the gauge that should always be used in checking pressure on the low-pressure side of the system. The gauge at the right is graduated from 0 to 500 pounds pressure in 10-pound graduations. This is the high-pressure gauge that is used for checking pressure on the high-pressure side of the system.

The center manifold fitting is common to both the low and the high sides and is for removing or adding refrigerant to the system. When this fitting is not being used, it should be capped. A test hose connected to the fitting directly under the low-side gauge is used to connect the low side of the test

manifold to the low side of the system. A similar connection is found on the high side.

The gauge set has hand valves that isolate the low and high sides from the central portion of the manifold. During all tests, both the low- and high-side hand valves are in the closed position (turned inward until the valve is seated).

Because R-134a is not interchangeable with R-1234yf, separate sets of hoses, gauges, and other equipment are required to service newer vehicles. Manifold gauge sets for R-134a can be identified by one or all of the following: Labeled "FOR USE WITH R-134a," labeled "HFC-134" or "R-134a," and/or have a light blue color on the face of the gauges. Also, R-134a service hoses have a black stripe along their length and are clearly labeled "SAE J2196/R-134a." The low-pressure hose is blue with a black stripe. The high-pressure hose is red with black stripe, and the center service hose is yellow with a black stripe. Service hoses for one type of refrigerant will not connect into the wrong system, because the fittings for an R-134a system are different from those used in an R-1234yf system. The operating pressures and temperatures of R-1234yf systems are similar to that of R-134a systems.

Connecting the Gauge Set Identify the type of refrigerant used in the systems and obtain the appropriate gauge set. Locate the high- and low-side service valves. Make sure the valves on the gauge set are fully closed. Remove the protective cap from the low-side service valve and connect the low-side service hose to the service valve. Then remove the protective cap from the high-side service valve and connect the high-side service hose to the valve.

FIGURE 55–15 Measure the temperature of the air entering the condenser.

Testing Procedures

PROCEDURE

To conduct a performance test, follow these steps:

STEP 1 With the manifold gauge set connected, start the engine in neutral or park with the parking brake on and allow the engine to run for about 5 minutes.

STEP 2 Increase engine speed from 1,500 to 2,000 rpm.

STEP 3 Keeping your hands away from the cooling fan, measure and record the temperature and humidity of the air in front of the condenser **(Figure 55–15)**.

STEP 4 Place a high-volume fan in front of the radiator grille to ensure an adequate supply of airflow across the condenser.

STEP 5 Adjust the A/C controls to maximum cooling and high blower position.

STEP 6 Place the thermometer in the center air duct in the dash. Measure and record the temperature.

STEP 7 Read the high and low pressures. If the vehicle uses a cycling clutch system, note the pressures at which the clutch engages and disengages.

STEP 8 Compare your readings to specifications.

STEP 9 Return the engine to a normal idle speed.

STEP 10 Close the service hose valves, if so equipped.

STEP 11 Disconnect the service hoses.

STEP 12 After disconnecting the gauge lines, check the valve areas to be sure that the service valves are correctly seated and that the Schrader valves are not leaking.

STEP 13 Reinstall the protective caps on the service valves.

STEP 14 Turn off the A/C and the engine.

Always refer to the manufacturer's pressure charts when using observed pressures for diagnostics **(Figure 55–16)**. It is normal for the gauge readings to fluctuate as the clutch cycles and the heat load

Ambient Air Temperature	Relative Humidity	Low-Side Pressure	High-Side Pressure
55–65 °F (13–18 °C)	0–100%	22–49 psi (51–337 kPa)	112–167 psi (771–1,150 kPa)
66–75 °F (19–24 °C)	Below 40%	22–34 psi (151–234 kPa)	107–160 psi (737–1,102 kPa)
	Above 40%	24–37 psi (165–254 kPa)	128–173 psi (881–1,191 kPa)
76–85 °F (25–29 °C)	Below 35%	24–37 psi (165–254 kPa)	120–176 psi (826–1,212 kPa)
	35–50%	28–38 psi (192–261 kPa)	127–177 psi (875–1,219 kPa)
	Above 50%	26–40 psi (179–275 kPa)	132–179 psi (909–1,233 kPa)
86–95 °F (30–35 °C)	Below 30%	26–41 psi (179–282 kPa)	152–199 psi (1,047–1,371 kPa)
	30–50%	31–42 psi (213–289 kPa)	164–193 psi (1,129–1,329 kPa)
	Above 50%	32–44 psi (220–303 kPa)	165–186 psi (1,136–1,281 kPa)
96–105 °F (36–41 °C)	Below 20%	35–46 psi (241–316 kPa)	193–228 psi (1,329–1,570 kPa)
	20–40%	35–46 psi (241–316 kPa)	190–216 psi (1,309–1,488 kPa)
	Above 40%	36–47 psi (248–323 kPa)	184–205 psi (1,267–1,412 kPa)
106–115 °F (42–46 °C)	Below 20%	40–50 psi (275–344 kPa)	224–251 psi (1,543–1,729 kPa)
	Above 20%	40–50 psi (275–344 kPa)	216–255 psi (1,488–1,743 kPa)
116–120 °F (47–49 °C)	Below 30%	44–54 psi (303–372 kPa)	239–285 psi (1,646–1,963 kPa)

FIGURE 55–16 A typical pressure chart.

changes, but they should not greatly fluctuate. Operating pressures will vary with humidity as well as with outside air temperature. Accordingly, on more humid days, operating pressures will be on the high side of the acceptable pressure range. On less humid days, the operating pressures will read toward the lower side. If operating pressures are found to be within the normal range, the refrigeration portion of the A/C system is functioning properly. This is further confirmed with a check of evaporator outlet air temperatures.

Here are some guidelines to help you interpret abnormal readings:

- If the observed pressures are below the normal ranges, this indicates an undercharged system.
- If both pressures are above normal pressures, the system is overcharged or there is insufficient air flowing through the condenser.
- If there is normal low-side pressure but higher-than-normal high-side pressure, this indicates there is air in the system.

- If both gauges show equally low pressures but a medium amount of pressure, this indicates a fully charged system with an inoperative compressor.
- If the high-side pressure is too high, suspect air in the system, too much refrigerant in the system, a restriction in the high-side of the system, and poor airflow across the condenser.
- If the high-side pressure is too low, suspect a low refrigerant level or defective compressor.
- If the low-side pressure is higher than normal, suspect refrigerant overcharge, a defective compressor, or a faulty metering device.
- If the low-side pressure is lower than normal, suspect a faulty metering device, poor airflow across the evaporator, a restriction in the low side of the system, or a system that is undercharged with refrigerant.

Evaporator Outlet Temperature Evaporator outlet air temperature also varies according to outside (ambient) air and humidity conditions. Further variations depend on whether the system is controlled by a cycling clutch compressor or an evaporator pressure control valve. Because of these variations, it is difficult to pinpoint what the evaporator outlet air temperature should be for all applications. In general, with low air temperatures and humidity, the evaporator outlet air temperature should be from 35 to 40 °F (1.7 to 4.4 °C). On the other extreme of high temperatures and humidity, the evaporator air outlet temperature might be in the 55 to 60 °F (12.8 to 15.6 °C) range.

Leak Testing

Testing the refrigerant system for leaks is one of the most important phases of troubleshooting. Over a period of time, the A/C systems may lose or leak some refrigerant. Modern systems that are in good condition should have nearly zero refrigerant loss per year. Current infrared leak detectors can find leaks as small as 0.15 oz/year or about 4 grams per year. Higher loss rates signal a need to locate and repair the leaks.

Leaks are often evident by low-pressure gauge readings. Normally, if there is some pressure in the system, the leak is a small one. Large leaks typically will empty the system.

Leaks are most often found at the compressor hose connections and at the various fittings and joints in the system. Refrigerant can be lost through hose permeation. Leaks can also be traced to pinholes in the evaporator caused by acid, which forms when water and refrigerant mix. Because oil and refrigerant leak out together, oily spots on hoses, fittings, and components mean there is a leak.

When the source of leakage is not obvious, a leak detector can be used to locate it. However, to use a leak detector, there must be some refrigerant in the system. Most manufacturers say that a leak detector will only work if the high-side pressure is above 60 psig. If the pressure is below this, add no more than 1 pound (453.6 grams) of refrigerant to the system and then check for leaks.

Be sure to check the entire system, including inside the passenger compartment around the evaporator. If a leak is found at a connection, tighten the connection carefully and recheck. If the leak is still apparent, the affected components should be replaced. After leak testing, and before opening the system for repairs, use the recovery station to remove all refrigerant from the system.

Stop Leak Products Products that can be added to seal leaks in the system are sold. Many OEMs do not recommend their use. Sealants may cause buildups in the system, causing unwanted restrictions. They may also cause compressor clutch problems if there is a leak around the compressor shaft. These manufacturers also will void the warranty on the system if a sealant has been installed. Always check with the manufacturer before adding a sealant to the system.

Electronic Leak Detector

This is the preferred method of leak detection; it is safe, effective, and can be used with all types of refrigerants. The hand-held battery-operated electronic leak detector **(Figure 55–17)** contains a test probe that is moved under the areas of suspected leaks. (Remember that refrigerant gas is heavier than air, so

FIGURE 55–17 An electronic leak detector.

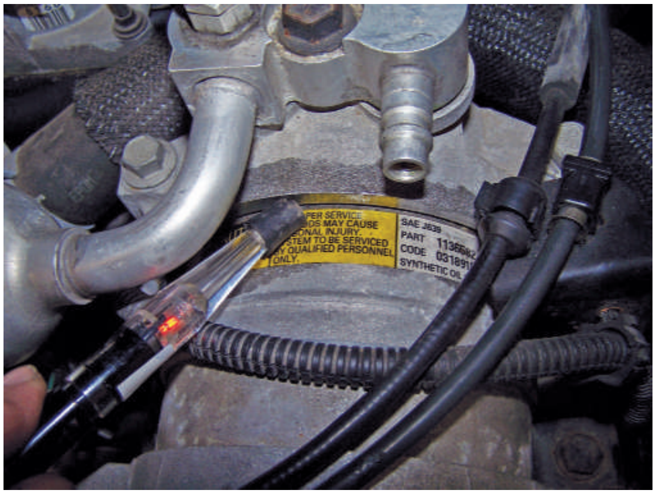


FIGURE 55–18 When the probe of the leak detector is near the area of a leak, its light will flash.

the probe should be positioned below the test point.) An alarm or a buzzer on the detector indicates the presence of a leak **(Figure 55–18)**. On some models, a light flashes to establish the leak.

Electronic (halogen) leak detectors are common because of their accuracy and ability to detect several types of refrigerants. This type of detector must be capable of measuring a leak as small as 0.15 ounces or 4 grams per year. When selecting a leak detector, make sure the unit meets the SAE J2791 performance standard for refrigerant leak detection. J2791 sets standards for leak detection capabilities as well as how quickly and from what distance the leak can be found.

When using an electronic leak detector, keep the following in mind:

- Many leak detectors have the sensing unit inside the tool and not at the tip.
- When checking the system, move slowly, about an inch per second, to allow the detector to get a sample of the air.
- Normally, small leaks can only be found when the A/C and engine are turned off and there are no cooling fans operating.
- Low-side leaks may be easier to find when the system is turned off.
- High-side leaks may be easier to find when the system is running.

Fluorescent Dye Leak Detection

A common method of leak detection is using a fluorescent dye. The dye can be injected into the system for testing. Many new vehicles have R-134a fluorescent dye installed in the refrigerant system when the vehicle is produced. The fluorescent dye mixes and flows with the PAG oil throughout the A/C system. In these systems, additional dye should not added unless more than 50 percent of the refrigerant oil has been lost because of bad fittings, hose rupture, or other major leakage. There is no need to add dye to the system after the system has been flushed. Part of the flushing process is the replacement of the accumulator or receiver/dryer. New accumulators or receiver/dryers for these systems have a fluorescent dye element in the desiccant bag. The element will dissolve while the system runs, adding the correct amount of dye to the system.

Fluorescent dye may need to be added to a system that was produced with dye in the system or added to other systems for leak detection. This can be done by injecting it into the system or by pouring it directly into a removed component. Normally to do this, a UV leak detection kit **(Figure 55–19)** is used to

FIGURE 55–19 The parts included with a UV leak detection tester.

find the source of any leakage. This kit includes the fluorescent dye, dye injector, high intensity UV lamp, and tinted protective safety glasses or goggles. To begin the detection process, the dye must be injected into the system. It is important to note that all fluorescent dyes are not compatible with PAG oil. Before adding dye to the system, make sure it is the right type. Make sure the right quantity of dye is installed; never overcharge the system with dye. And always follow the instructions for the detector and do not install too much dye.

There are two basic ways to inject dye into the system. One uses an A/C charging station and a manifold gauge set. This should only be used when the system is not fully charged. A small tank of dye and an injector is attached to the center hose on the gauge set. The dye is added with some refrigerant to the low side of the system.

When the system is fully charged, a special kit must be used. The kit contains a reservoir for the dye and is connected between the high-pressure and low-pressure service valves. With the A/C turned on, the high-side valve is opened and remains open until the dye has left the reservoir. This method does not add refrigerant to the system.

Run the A/C system for several minutes to distribute the dye evenly. Put on the tinted goggles and examine the system with the UV lamp. System leaks will be apparent by a luminous yellow-green **(Figure 55–20)** trace. When checking for leaks, inspect all components, lines, and fittings of the refrigerant system. This includes the evaporator and its drain tube. If a leak is found, continue checking the rest of the system because there may be more than one leak. It is important to remember that PAG oil is water soluble. Therefore, condensation on the evaporator or the refrigerant lines may wash the oil and fluorescent dye away from where the leak is.

If a leak is found, recover the refrigerant. Then correct the problem. Next, evacuate and charge the system. Thoroughly clean all traces of fluorescent dye from any area where leaks were found. Run the system for a short time and recheck the system for leaks to verify the repair.

FIGURE 55-20 When the system is checked with a UV leak detection kit, system leaks will be apparent by a luminous yellow-green trace.

Leak Detector Fluid Leaks can also be located by applying leak detector fluid around areas to be tested. Detection fluids are available for R-12 and R-134a systems; make sure you use the correct one for the refrigerant you are looking for. If a leak is present, it will form clusters of bubbles around the source **(Figure 55–21)**. A very small leak will cause white foam to form around the leak source within several seconds to a minute. Adequate lighting over the entire surface being tested is necessary for an accurate diagnosis.

SHOP TALK

Some OEMs, such as Toyota, do not recommend the use of leak-detecting dyes. Always check the manufacturer's recommendations before adding dyes to the A/C system.

Adding Fluorescent Dye Dye may need to be added to a system that was produced with dye in the system or added to other systems for leak detection. This can be done by injecting it into the system or by pouring it directly into a removed component. It is important to note that all fluorescent dyes are not compatible with PAG oil. Before adding dye to the system, make sure it is the right type. Make sure the right quantity of dye is installed; never overcharge the system with dye. Also, the dye needs time to

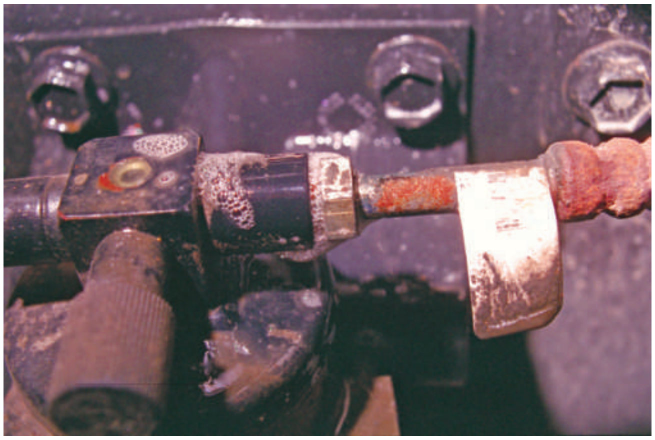


FIGURE 55–21 The bubbles show the location of a leak.

properly circulate through the system before it can be useful. This can be anywhere from 15 minutes to several days, depending on the size of the leak.

There are two basic ways to inject dye into the system. One uses an A/C charging station and a manifold gauge set. This should only be used when the system is not fully charged. A small tank of dye and injector is attached to the center hose on the gauge set. The dye is added with some refrigerant to the low side of the system.

When the system is fully charged, a special kit must be used. The kit contains a reservoir for the dye and is connected between the high-pressure and low-pressure service valves. With the A/C turned on, the high-side valve is opened and remains open until the dye has left the reservoir. This method does not add refrigerant to the system.

Emptying the System

Before the system is opened for service, all refrigerant in the system needs to be recovered. However, prior to doing this, the refrigerant needs to be positively identified. This is necessary to prevent mixing of refrigerants. Although the system may be clearly marked as using a particular refrigerant, there are many different refrigerants available that may have been added to the system. Some of these are blends and not pure. Any refrigerant that is not pure is considered contaminated. Also, the passage of a refrigerant that the recovery machine is not designed for will contaminate the machine and the storage containers. Identifying refrigerant should also take place before using a container of recycled refrigerant just to be safe.

The composition of refrigerant is analyzed by a refrigerant identifier. This tool takes a sample of the refrigerant from the low side of the system and analyzes it. The amount of R-12 or R-134a is displayed on the tool. All refrigerants that are less than 98 percent pure will fail the tests and should not be recycled. This should be recovered into a storage container labeled as contaminated. This container should only be used for contaminated refrigerant.

There are many different identifiers available; always follow the specific instructions for the tool you will be using.

Recovery

There are currently two types of refrigerant recovery/recycling machines: the single pass and the multipass. Both have the ability to draw the refrigerant from the vehicle, filter and separate the oil from it, remove moisture and air from it, and store the refrigerant until it is reused.

In a single-pass system, the refrigerant goes through each stage before being stored. In multipass systems, the refrigerant goes through all stages of oil separation and drying before being stored. When set to recycle, the refrigerant then passes back through the dryer until all moisture is removed. Either system is acceptable if it has the UL-approved label.

Recovery of R-1234yf

With the new refrigerant also comes new regulations and service procedures. SAE Standard J2843 for flammable refrigerants requires a dedicated recovery/recycle/recharge (RRR) machine to service R-1234yf systems. The new machine standards include the following:

- Recover 95 percent of the refrigerant in the system.
- Recharge the system within ½ ounce of the specification.
- A required filter change after 150 pounds of recovered refrigerant.
- A built-in refrigerant identifier or have a USB port to connect one.
- Prevents the recovery of contaminated refrigerant (must be more than 98 percent pure).
- Will not recharge the system if there's a leak detected.
- Has ventilation fans and nonsparking motors, switches, relays, and other components that could ignite the refrigerant.

Some machines, particularly those at new car dealerships, may have specific information that needs to be input before the machine will work, such as the vehicle VIN, repair order information, and technician ID.

To minimize the amount of refrigerant released to the atmosphere when A/C systems are serviced, always follow these steps.

1. The recovery/recycling equipment **(Figure 55–22)** must have shutoff valves within 12 inches of the hoses' service ends. With the valves closed, connect the hoses to the vehicle's A/C service fittings.
2. Always follow the equipment manufacturer's procedures for use. Recover the refrigerant from the vehicle and continue the process until the vehicle's system shows vacuum instead of pressure.

FIGURE 55–22 A R-1234yf refrigerant management center that is capable of doing all necessary refrigerant services.

Turn off the recovery/recycling unit for at least 5 minutes. The unit may default to a longer time, such as 10 minutes, for leak detection. If the system still has pressure, repeat the recovery process to remove any remaining refrigerant. Continue until the A/C system holds a stable vacuum for 2 minutes.

3. Close the valves in the recovery/recycling unit's service lines and disconnect them from the system's service fittings. On recovery/recycling stations with automatic shutoff valves, make sure they work properly.
4. You may now make repairs and/or replace parts in the system.

Recycling

Recycling collects old refrigerant from the system being serviced and cleans it up and prepares it to be used in the future. If recycled refrigerant is sent to a reclamation site, the EPA requires documentation of the name and address of the facility to which the refrigerant is sent. All recycled refrigerant must be safely stored in DOT CFR Title 49 or UL-approved containers. Containers specifically made for R-134a should be so marked. Before any container of recycled refrigerant can be used, it must be checked for noncondensable gases.

The SAE has set standards for recycled R-134a and R-1234yf to make sure the refrigerants provide proper system performance and longevity. J1991 and J2099 are purity standards for recycled refrigerant and specifies a limit in parts per million (ppm) by weight. These limits are placed on three potential contaminants. There can be no more than 15 ppm of moisture in recycled R-134a and 10 ppm for new R-134a. The limit for the amount of refrigerant oil in R-134a is 500 ppm. The additional contaminant looked at by the SAE is air or noncondensable gases. There should be no more than 1.5 percent by volume in R-134a or R-1234yf.

Because the A/C service equipment may recycle in addition to recover and recharge, periodic maintenance (such as filter changes) are necessary to keep the unit operating properly. Before using the A/C equipment, you should read and understand its operation and ensure that it is in proper working condition. Refer to the manual that came with the equipment to determine what type of maintenance is required and how often.

General Service

All refrigerant must be discharged from the system before repair or replacement of any component (except for compressors with stem service valves). The refrigerant must be recovered and recycled. This means the refrigerant cannot be released into the atmosphere. According to Section 609 of the Federal Clean Air Act, no one repairing or servicing a motor vehicle's A/C system can do so without the proper refrigerant recovery recycling equipment. It further states that no one can do this service unless that person is properly trained and certified.

Before replacing any part in the system, recover the refrigerant first. When replacing a part in an A/C system make sure it is the correct replacement part. Also make sure it is properly installed and the line connections are secure. After a component has been replaced it may be necessary to add refrigerant oil to the system to replace the oil that settled in the replaced component. Typically the amount of oil can be estimated by considering the component replaced. Some parts, such as an orifice tube, require special tools for removal and installation.

Refrigerant Oil

Normally the only source of lubrication for a compressor and other moving parts in the A/C system is the oil mixed with the refrigerant. The oil required for the system depends on the refrigerant used in it and if the vehicle is a hybrid or electric vehicle.

Generally, compressor oil level is checked only where there is evidence of a major loss of system oil that could be caused by a broken refrigerant hose, severe hose fitting leak, badly leaking compressor seal, or collision damage to the system's components.

When replacing refrigerant oil, it is important to use the specific type and quantity of oil recommended by the manufacturer. If there is a surplus of oil in the system, too much will circulate with the refrigerant, causing the cooling capacity of the system to be reduced. Too little oil results in poor lubrication. When there has been excessive leakage or it is necessary to replace a part of the A/C system, certain procedures must be followed to ensure that the total oil charge in the system is correct after the repair. Most A/C recovery/recycling equipment will display how much oil has been removed with the refrigerant **(Figure 55–23)**.

When the compressor is running, oil gradually leaves the compressor and is circulated through the system with the refrigerant. Eventually a balanced condition is reached in which a certain amount of oil is retained in the compressor and a certain amount is continually circulated. If a component of the system is replaced after the system has been operated, some oil goes with it. Always add the specific amount and the correct type of oil when replacing a part **(Figure 55–24)** and do so according to the manufacturer's recommendations.

GO TO Chapter 54 for a discussion on the various oils used in A/C systems.

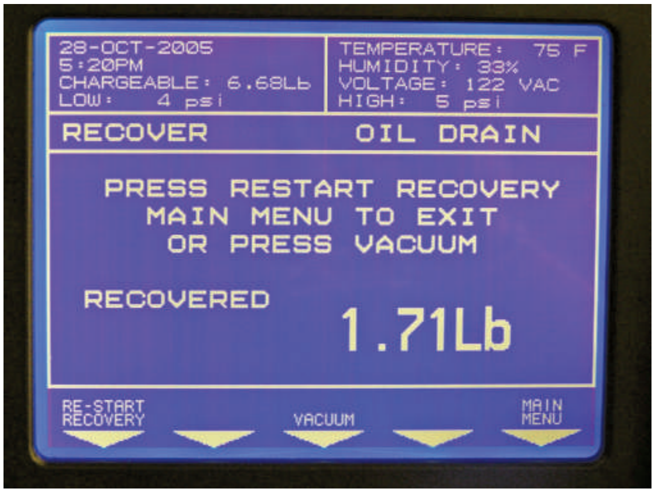


FIGURE 55–23 Most A/C recovery/recycling equipment will display how much oil has been removed with the refrigerant.

FIGURE 55–24 When a part is replaced, make sure to add the correct amount and type of refrigerant oil for that part to the system.

Clutch Service

The compressor clutch is engaged by a magnetic field and disengaged by springs when the magnetic field is broken. When the controls call for compressor operation, the electrical circuit to the clutch is completed, the magnetic clutch is energized, and the clutch engages the compressor. When the electrical circuit is opened, the clutch disengages the compressor.

The clutch assembly should be carefully inspected for discoloration, peeling, or other damage. If there is damage, replace the clutch assembly. Also check the play and drag of the compressor pulley bearing by rotating the pulley by hand. Replace the clutch assembly if it is noisy or has excessive play or drag. The field coil for the clutch can be checked with an ohmmeter **(Figure 55–25)**. The exact testing points and acceptable resistance readings are given in the vehicle's service information. If resistance is not within specifications, replace the field coil. Also, check the clutch clamping diode.

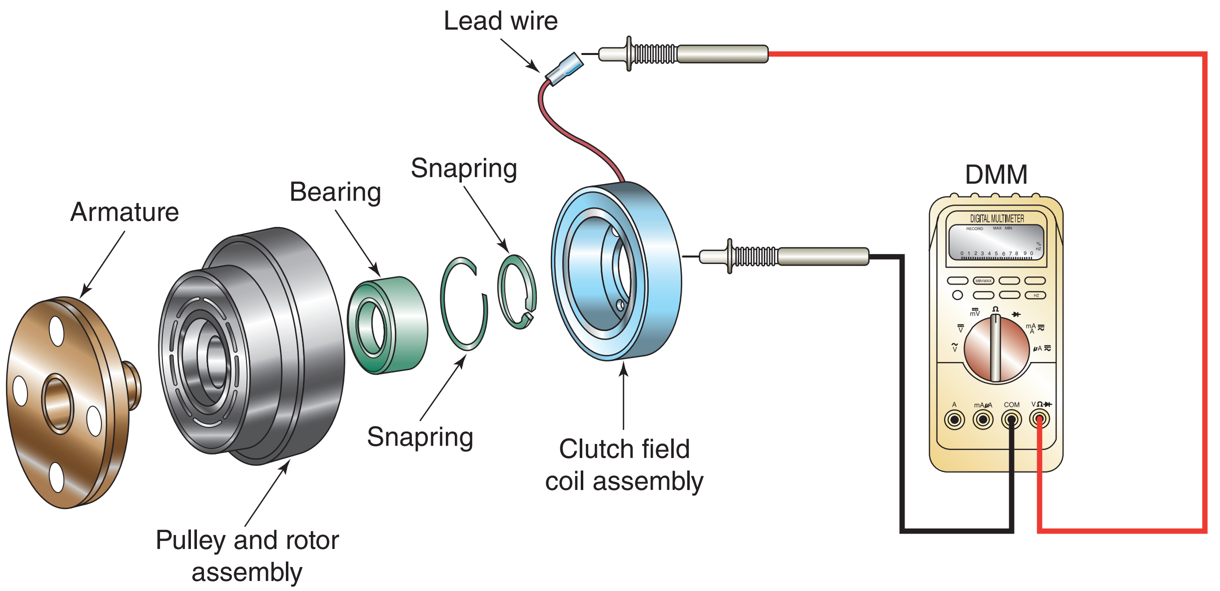


FIGURE 55–25 Testing a compressor clutch with an ohmmeter.

If the clutch is not operating, check the electrical connections to it. Make sure they are secure and corrosion free. Then, check for power to the clutch with a testlight or DMM. If there is no power, locate and repair the problem. If there is power to the clutch, check the ground circuit with a DMM. If there is power and a good ground, the clutch is defective and must be replaced.

Clutch Clearance Nearly all clutch assemblies have a clearance spec for the distance between the clutch and the pressure plate. This clearance is measured with a feeler gauge. If the clearance is too great, the clutch may slip and cause a scraping or squealing noise. If the clearance is insufficient, the compressor may run when not electrically activated and the clutch may chatter at all times. As the clutch assembly wears, the clearance increases and therefore should be checked and adjusted whenever symptoms suggest doing so. Always follow the specific procedures given by the manufacturer for measuring and correcting the gap.

Measure the clearance between the rotor pulley and the armature plate **(Figure 55–26)**. Do this at more than one location. If the clearance is not within the specified limits, remove the armature plate and add or remove shims as needed to increase or decrease the clearance. The shims are available in different thickness and it is recommended that no more three shims be installed to correct the clearance.

Some clutches are press-fit to the compressor shaft. The gap of these clutches is adjusted by tightening the retaining bolt. With a feeler gauge placed between the clutch plate and pulley, tighten the bolt until the feeler gauge of the specified size has a slight drag.

FIGURE 55–26 Check the gap between the armature plate and the pulley with a feeler gauge.

Clutch and Pulley Replacement On some vehicles, the clutch can be serviced on the vehicle. On others, the compressor assembly must be removed to service the clutch. Refer to the service information on your specific vehicle to determine what must be done.

Normally, to remove the clutch assembly, the magnetic clutch hub must be held while the retaining bolt is loosened. After the bolt is removed, the clutch hub and shims can be removed. This will give access to a snapring around the compressor shaft. Using

snapring pliers, expand and remove the snapring and then remove the rotor of the magnetic clutch. Be careful not to damage the compressor seals while doing this. Now, remove the snapring for the clutch stator and then the stator.

When installing a new clutch assembly, begin by aligning the protrusion on the stator with the notch on the compressor. Then install a new snapring with its chamfered side facing up. Install the clutch rotor with a new snapring. Now install the clutch shims and hub. Hold the hub while tightening the center bolt to specifications. While installing the clutch assembly, make sure all parts are kept clean and free of oil or grease.

Clutch Pulley Bearing Replacement The clutch pulley can be a source of unwanted noise and can be replaced on most systems. To replace the bearing, remove the pulley. Use a bearing driver or press to push the bearing out of the front of the pulley. To install a new bearing, align the pulley and press it into place.

Compressor Service

Compressors are normally replaced, rather than rebuilt, when they are faulty or damaged. The following procedure is typical for a non-electric compressor.

PROCEDURE

To remove and install a compressor, follow these steps:

STEP 1 Identify and disconnect all electrical connections to the compressor.

STEP 2 Discharge the system using a recovery/recycling machine.

STEP 3 Disconnect the refrigerant lines at the compressor. Immediately cap or seal the ends of the lines or hoses.

STEP 4 Remove the drive belt for the compressor.

STEP 5 Loosen and remove the compressor mounting brackets. Note the location of the bolts because they are typically of a different length.

STEP 6 Remove the compressor.

STEP 7 To install a compressor, reverse the removal procedure. Make sure the drive belt is tightened to the proper tension.

Shaft Seal Replacement The seal at the compressor shaft is a common source of leaks. To replace the seal, remove the clutch assembly. Then remove the internal snapring that holds the seal in place. Install the special seal remover/installer tool against the face of the seal. Twist it to expand the jaws of the tool on the seal. With a gentle twisting and pulling motion, remove the seal. Then remove and discard the O-ring seal that is located between the housing and the shaft seal.

Lubricate and install a new O-ring into its groove. Coat the new shaft seal with refrigerant oil. Then place the seal into the jaws of the seal remover/installer tool. Install a seal protector over the threads of the compressor's shaft **(Figure 55–27)**. With a gentle twisting motion, slide the seal over the protector and into the groove in the compressor. Release the installer from the seal. Then reinstall the snapring and clutch assembly. The system will need to be evacuated before it is recharged.

Flushing Compressor failure causes foreign material to pass into the system. The condenser must be flushed and the receiver/dryer or accumulator replaced. Filter screens are sometimes located in the suction side of the compressor and in the receiver/dryer. The compressor inlet screen should be replaced whenever the compressor is replaced. These screens confine foreign material to the compressor, condenser, receiver/dryer, and connecting hoses. If a screen becomes clogged, it will block the flow of refrigerant. Use only recommended flushing solvents. Never use CFCs or methylchloroform for flushing. Some manufacturers recommend replacing

FIGURE 55–27 Install the protector over the threads of the compressor shaft. Place the new seal on the installer and install the seal with a gentle twisting motion.

FIGURE 55–28 An inline filter.

the clogged components and installing a liquid line (inline) filter just ahead of the expansion valve or orifice tube instead of flushing the system. If flushing is recommended by the manufacturer, use only the recommended flushing agent and follow the specified procedures. After the system has been flushed, be sure to oil all components that require it.

Inline Filters The most effective way to collect debris that may be in the system is to install an inline filter **(Figure 55–28)**. These filters should be installed whenever the compressor seizes or has severe damage and needs to be replaced. A filter should also be installed if the expansion valve or orifice tube is plugged with debris. Filters can contain an orifice and these should be installed in a different location than filters without an orifice. If the filter does not have an orifice, it should be installed in the liquid line between the condenser outlet and the evaporator inlet. If the filter has an orifice, it is installed between the low-pressure side of the system beyond the expansion tube. If the filter has a built-in orifice, remove the original expansion tube. In either case, the filter should be inserted at a point where the refrigerant line is straight.

To install the filter, cut the line at the desired filter location. Make sure the cut is smooth and straight. Slide the ferrules, cones, and seals for the filter onto each end of the cut line. Lubricate the seals and insert the filter and tighten the ferrules. Make sure the lines are properly sealed, and then evacuate and charge the system. When finished, check the installation for leaks.

Compressor Controls

The ambient temperature sensor or the engine's IAT measures outside air temperature to prevent compressor clutch engagement when A/C is not required or when compressor operation might cause internal damage to the seals and other parts. The switch is in series with the compressor clutch electrical circuit and closes at about 37 °F (2.8 °C). At all lower temperatures, the switch is open preventing clutch engagement.

In cycling clutch systems, a thermostatic switch is placed in series with the compressor clutch circuit so it can turn the clutch on or off. It de-energizes the clutch and stops the compressor if the evaporator is at the freezing point. When the temperature of the evaporator approaches the freezing point, the thermostatic switch opens the circuit and disengages the compressor clutch. The compressor remains inoperative until the evaporator temperature rises to the preset temperature, at which time the switch closes and compressor operation resumes.

A pressure cycling switch is electrically connected in series with the compressor electromagnetic clutch. Like the thermostatic switch, the turning on and off of the pressure cycling switch controls the operation of the compressor.

The low-pressure cutoff or discharge pressure switch is located on the low side of the system and senses any low-pressure conditions. It is tied into the compressor clutch circuit, allowing it to immediately disengage the clutch when the pressure falls too low.

The electronic cycling clutch switch (ECCS) prevents evaporator freeze-up by sending a signal to the engine control computer. The computer, in turn, cycles the compressor on and off by monitoring suction line temperature. If the temperature gets too low, the ECCS will open the input circuit to the computer, which causes the A/C clutch relay to open, which disengages the compressor clutch. Often this switch is the thermostatic switch at the evaporator.

The high-pressure relief valve is used to keep system pressures from reaching a point that may cause compressor lockup or other component damage because of excessive high pressures. When system pressures exceed a predetermined point, the pressure relief valve opens, reducing the system's pressure.

The A/C high-pressure switch is used for additional A/C system pressure control. It is normally closed and its high-pressure contacts open at a predetermined A/C pressure. This results in the A/C turning off, preventing the A/C pressure from rising to a level that would open the A/C high-pressure relief valve. The A/C pressure transducer sensor is located in the high-pressure (discharge) side of the A/C system. The ACP transducer sensor provides a voltage signal to the PCM that is proportional to the A/C pressure. The PCM uses this information for A/C clutch control, fan control, and idle speed control.

The evaporator temperature sensor measures the temperature of the cool air immediately after the evaporator. This input to the A/C control module is used to detect evaporator freeze-up.

Hoses and Fittings

Although total hose replacement is the preferred way to correct for a hose leak, there are several accepted ways to repair refrigerant hoses and fittings. Using insert barb fittings and a length of replacement hose, you can fabricate an acceptable replacement for an original equipment hose. Insert barb fittings can also be used to replace bad original fittings or to replace a section of a hose.

When using an insert barb fitting **(Figure 55–31)** to replace a bad original fitting, the original fitting must be removed without damaging too much of the hose. Remove the hose from the vehicle. Set the

PROCEDURE

To check the various control devices, follow these steps:

STEP 1 Using the service information, locate the various pressure and temperature sensors in the system that controls the operation of the compressor.

STEP 2 Check the information to determine if each of these is normally closed or normally open.

STEP 3 Checking one sensor at a time, complete the following steps:

a. Disconnect the wires at the sensor or switch.

b. Connect the DMM across the switch terminals **(Figure 55–29)**.

c. Set the meter for resistance or continuity checks. If the switch is normally closed, the reading should be 0 ohms. If the switch is normally open, you should get an infinite reading. Any reading other than these is an indication of a faulty switch.

STEP 4 If a switch needs to be replaced, the system may need to be discharged. Check the service information before proceeding. Some systems have a Schrader-type disconnect below the switch. Switch replacement in these systems does not require system evacuation.

STEP 5 To remove the defective switch, loosen it and remove it.

STEP 6 To install the new switch, carefully thread it into place and tighten it. Then reconnect the wires leading to the switches.

FIGURE 55–29 All sensors and switches can be checked with an ohmmeter.

PROCEDURE

To fabricate a replacement A/C pressure hose, follow these steps:

STEP 1 Measure and mark the required length of replacement high-pressure hose.

STEP 2 Using the razor blade, cut the hose to the desired length. Make sure the cut is square and flat.

STEP 3 Apply clean refrigerant oil to the inside of the hose.

STEP 4 Install the correct ferrule onto the end of the hose.

STEP 5 Carefully inspect the new fitting to make sure it is free of nicks and other damage.

STEP 6 Coat the fitting with refrigerant oil and insert it into the hose.

STEP 7 Using the crimping tool designed for the ferrule, crimp the ferrule **(Figure 55–30)**.

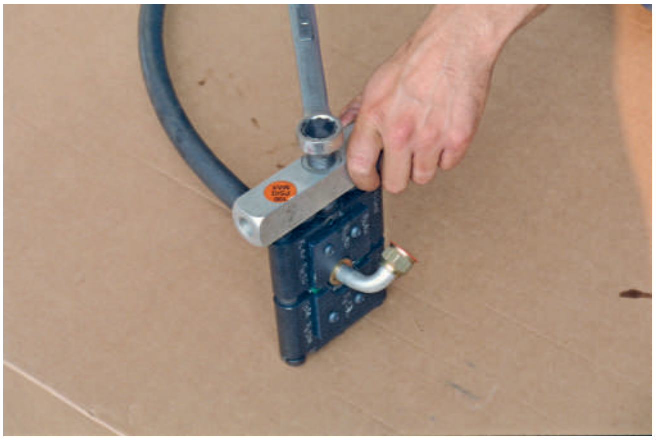


FIGURE 55–30 The ferrule is crimped with a special crimping tool.

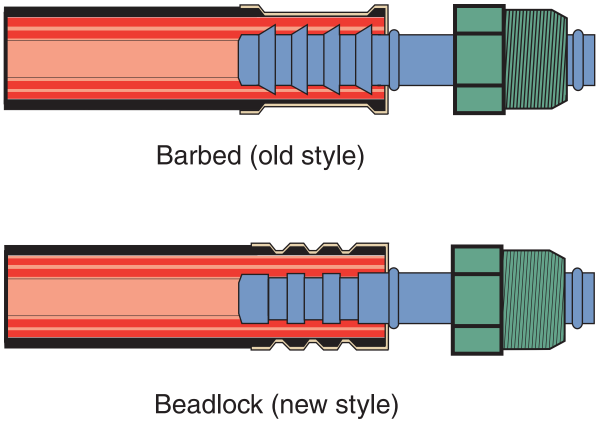


FIGURE 55–31 A comparison of a barbed fitting and the new-style beadlock fitting.

hose in a vise while cutting through the fitting's ferrule with a hacksaw. Make this cut in the direction of the hose, not through the hose. With the ferrule cut, use pliers to peel or pull the ferrule off. Cut the hose at a point just beyond the insert of the original fitting. Make sure the cut is square and flat. Apply clean refrigerant oil to the inside of the hose and to the fitting's insert. Insert the fitting into the hose. Position the hose clamp over the barb closest to the fitting before tightening it.

If the hose or line has spring lock fittings, a special tool is required to separate the sections. Put the tool over the coupling. Close the tool and push the lines into the tool to release the female fitting from the garter spring of the coupling. Then pull the male and female fittings apart. Remove the tool. When joining two fittings with a spring lock coupling, lubricate new O-rings and put them in their proper location on the male fitting. Insert the male fitting into the female fitting. Firmly push them together until they are secured by the spring lock coupling.

Rigid Line Repair Like pressure hoses, solid or rigid refrigeration lines are replaced rather than repaired if they leak. However, repairs can be made with special collars **(Figure 55–32)** inserted into the line to correct a kink or leak. The damaged section of the tube is cleanly cut out. The collar or fitting is inserted into the line after sealant has been applied to it. Using a special tool, the collar is pressed into the ends of the existing line **(Figure 55–33)**. The line is then crimped around the insert. This provides for a permanent seal.

Receiver-Dryer/Accumulator

The receiver-dryer/accumulator is often neglected when the A/C system is serviced or repaired. Failure to replace it can lead to poor system performance or replacement part failure. It is recommended that the receiver-dryer/accumulator and/or its desiccant be changed whenever a component is replaced, the system has lost the refrigerant charge, or the system has been open to the atmosphere for any length of time.

The desiccant draws moisture like a magnet and it can become contaminated in less than 5 minutes

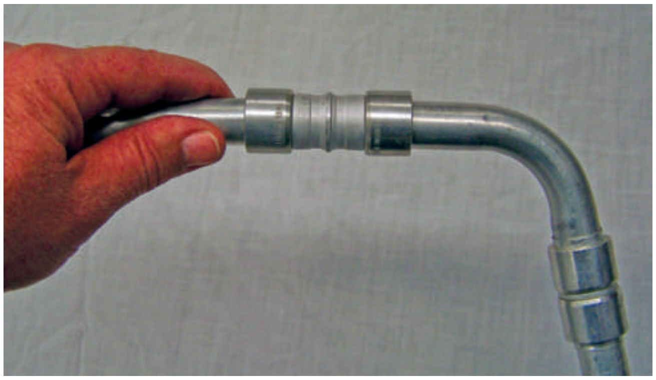


FIGURE 55–32 Repairs to rigid lines can be made with special collars.

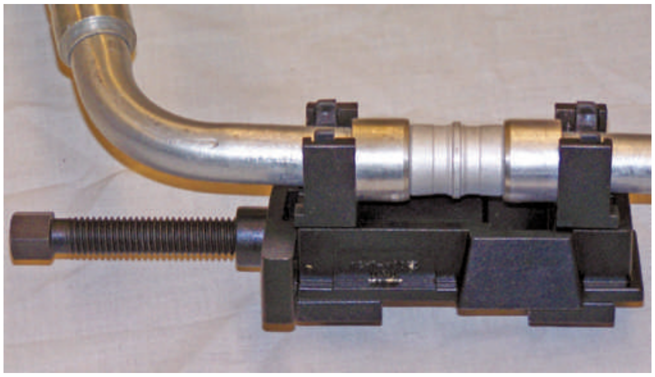


FIGURE 55–33 A designated tool is used to press the collar into the tube.

if it is exposed to the atmosphere. Keep it sealed. To replace a receiver-dryer/accumulator, disconnect the electrical connector to the low-pressure switch, if there is one. Then disconnect the inlet and outlet hoses or lines at the receiver-dryer/accumulator. Remove the mounting bolts and brackets from the receiver-dryer/accumulator and lift it out. The procedure for installation is the reverse of removal.

Accumulator Most late-model systems do not have a receiver/dryer; rather, they use an accumulator. The accumulator is connected to the low side at the outlet of the evaporator. The accumulator also contains a desiccant and is designed to store excess refrigerant and to filter and dry the refrigerant. If liquid refrigerant flows out of the evaporator, it will be collected by and stored in the accumulator. An accumulator/dryer should be replaced if there is excessive moisture or debris in the A/C system or when the accumulator leaks. To replace an accumulator, disconnect the lines at the accumulator's inlet and outlet fittings. Then loosen and/or remove the accumulator mounting bolts or screws. Lift the accumulator out. The procedure for installation is the reverse of removal. As soon as the accumulator is installed, immediately evacuate the system.

Evaporator

The evaporator and its controls often need service. If the evaporator is clogged, leaking, or damaged, it should be replaced. As vehicles make the switch from R-134a to R-1234yf, some vehicles from a manufacturer may use one refrigerant while other vehicles from the same manufacturer use the other. For R-1234yf vehicles, the evaporators are reinforced and stronger than those used in R-134a systems, but may not look any different. It is important that if replacing an evaporator on a R-1234yf vehicle that the correct part is installed.

Evaporator Water Drain Because the evaporator is also responsible for controlling the humidity in the vehicle, a check of its drain is necessary. This is especially true if the customer had concerns about odor or water on the carpet. To check the drain, raise the vehicle on a lift. Locate the evaporator case drain tube. Place the drain pan under the evaporator case. Disconnect the tube from the case. If no water comes out, carefully clean out the drain hole and tube at the evaporator case. You may need to insert a rod through the tube to clean it out; do this carefully because the

PROCEDURE

To remove an evaporator and install a new one, follow these steps:

STEP 1 Recover the refrigerant using an approved recovery/recycling equipment.

STEP 2 Disconnect the negative battery cable, if specified in the service information.

STEP 3 If the evaporator and heater core are a combined unit, drain the engine's coolant.

STEP 4 Disconnect and label all electrical connectors, cables, and vacuum hoses that are connected to the evaporator.

STEP 5 Disconnect the refrigerant hoses at the evaporator and plug or cap the hose ends to prevent dirt and moisture from entering the system.

STEP 6 Unbolt and remove the evaporator.

STEP 7 Drain the oil from the evaporator into a graduated container. Record the amount of oil removed.

STEP 8 Check the oil for dirt. If the oil is contaminated, replace the accumulator or receiver/dryer.

STEP 9 Add the same amount of new refrigerant oil as was drained out or the amount specified in the service information to the new evaporator.

STEP 10 Coat the new O-rings for the evaporator and the line fittings on the evaporator with clean refrigerant oil.

STEP 11 Install the new evaporator and tighten the fittings. Also install a new receiver-dryer/accumulator or its desiccant bag.

STEP 12 Immediately evacuate the system.

STEP 13 Reinstall and reconnect all parts, wires, cables, and vacuum hoses that were disconnected during removal. Add coolant if needed.

STEP 14 Connect the negative battery cable.

STEP 15 Evacuate and recharge the system.

STEP 16 Perform a leak test and correct any problems.

tube is accordion shaped and one of its bends may feel like a restriction. If no water comes out while trying to clear the tube, the entire evaporator case must be cleared. If water comes out of the case, the outside drain tube should be cleared by inserting the air nozzle into an end of the tube. Low air pressure should remove any restrictions in the tube.

Odor Control

Because the evaporator becomes wet from condensed water vapor, odor from mildew buildup in the evaporator case or on the evaporator itself is a common concern. To reduce odors, manufacturers and the aftermarket supply disinfecting kits to clean the evaporator. When performing a cleaning of the evaporator, refer to the manufacturer's service information for the proper disinfectant and procedures. In general, you will need to apply the disinfectant directly onto the evaporator and allow the chemicals to work on the surface and then rinse it with clean water.

Expansion Devices Basically there are two types of expansion devices. To replace an orifice tube assembly, always use the tools and procedures recommended by the manufacturer. Begin by disconnecting the inlet line at the evaporator. Then pour a small amount of clean refrigerant oil into the orifice tube. Insert the orifice removal tool. Turn the handle of the tool just enough for it to engage onto the tabs of the orifice tube. Hold the handle of the tool in position while turning the tool's outer sleeve clockwise to remove the orifice tube **(Figure 55–34)**. Coat the new orifice tube with clean refrigerant oil. Place

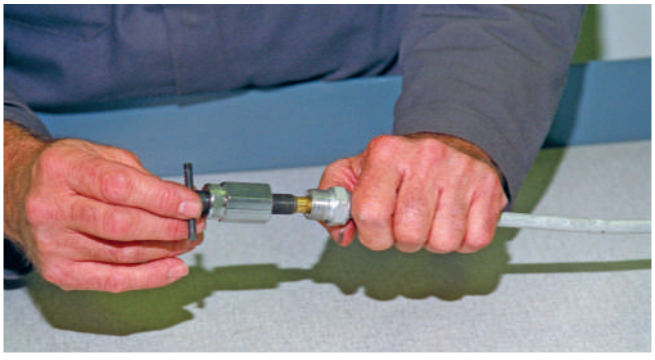


FIGURE 55–34 The tool designed to remove and replace an orifice tube.

Caution! Always wear safety goggles when working with refrigerant containers or servicing A/C systems.

FIGURE 55–35 Always install a new O-ring when replacing an orifice tube.

it into the evaporator line inlet. Push it in until it stops. Install a new O-ring on the refrigerant line **(Figure 55–35)** and reconnect it.

To replace a thermostatic expansion valve or H-block, disconnect the inlet and outlet lines at the TXV. Then remove whatever is used to keep the remote sensing bulb secure. Loosen and/or remove the mounting clamp for the TXV and remove the TXV from the evaporator. The procedure for installation is the reverse of removal.

Condenser

The condenser is quite reliable and only needs replacement when there are leaks due to damage. On many vehicles, the radiator, cooling fan, and/or shroud must be removed to gain access to the condenser. If the radiator must be removed, drain the coolant. Disconnect and label all electrical connectors that are connected to the condenser and all those that may be in the way. Disconnect the refrigerant hoses at the condenser and plug or cap the hose ends to prevent dirt and moisture from entering the system. Unbolt and remove the condenser. If the receiver-dryer/accumulator mounts to the condenser, disconnect it and remove it with the condenser. Drain and measure the oil from the condenser into a graduated container. Check the oil for dirt and debris. If the oil is contaminated with moisture, replace the accumulator or receiver/dryer. Add the above amount of new refrigerant oil or the amount specified in the service information to the new condenser. Install the new condenser and loosely tighten the mounting bolts. Coat the new O-rings for the condenser and the line fittings on the condenser with clean refrigerant oil. Tighten the fittings, and then tighten the mounting bolts. Then immediately

evacuate the system. Reinstall and reconnect all parts, wires, cables, and vacuum hoses that were disconnected or removed during removal. Connect the negative battery cable. Check for coolant and refrigerant leaks.

Recharging the System

All of the refrigerant in the system must be recovered prior to evacuation. Evacuation is the name given to the process that pulls all traces of air and moisture from the system. This is done by creating a vacuum in the system **(Figure 55–36)**. A vacuum pump is connected to the system to do this. The vacuum pump should remain on and connected to the system for at least 30 minutes after 26 to 29 inches of mercury (in. Hg) is reached.

Any air or moisture that is left inside an A/C system reduces the system's efficiency and eventually leads to major problems, such as compressor failure.

Air causes excessive pressure within the system, restricting the refrigerant's ability to change its state from gas to liquid within the refrigeration cycle, which drastically reduces its heat absorbing and transferring ability. Moisture, on the other hand, can cause freeze-up at the orifice tube or expansion valve, which restricts refrigerant flow or blocks it completely. Both of these problems result in intermittent cooling or no cooling at all. Moisture mixed with R-134a forms hydrochloric acid, causing internal corrosion, which is especially dangerous to the compressor. The vacuum pump reduces system pressure, vaporizes the moisture, and then exhausts it with the air.

The main responsibility of the vacuum pump is to remove the contaminating air and moisture from the system. The vacuum pump reduces system pressure in order to vaporize the moisture and then exhausts the vapor along with all remaining air. The pump's ability to clean the system is directly related to its ability to reduce pressure—create a vacuum—low enough to boil off all the contaminating moisture. As the vacuum (negative pressure) in the system reaches 29 in. Hg, the boiling point of the moisture in the system approaches room temperature. As the pressure is further reduced, the moisture will boil at even lower temperatures. Between 29 and 29.8 in. Hg, the boiling point drops to about 32 °F (0 °C).

An electronic thermistor vacuum gauge is designed to work with the vacuum pump to measure the last, most critical inch of mercury during evacuation. It constantly monitors and visually indicates the vacuum level so you know when the system has a full vacuum and will be moisture free. After the system is evacuated, it can be recharged. If the system will not pull down to a good vacuum, there is probably a leak somewhere in the system. Photo Sequence 51 goes through a common way to evacuate and recharge a system.

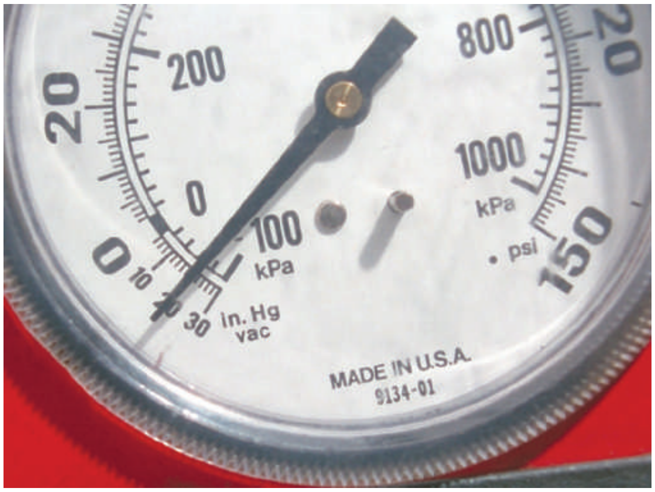


FIGURE 55–36 The reading on a low-pressure gauge with a vacuum pump connected to an A/C system through a gauge set.

Caution! Always wear safety goggles and protective gloves when handling disinfectants and cleaning the system.

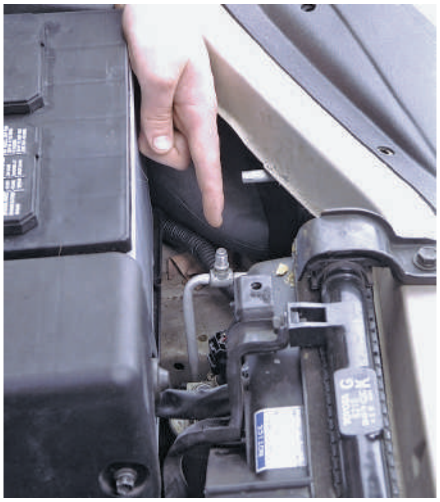
Charging

Refilling the system with refrigerant is called charging the system. Refrigerant is added through the system's service ports **(Figure 55–37)**. Depending on the method and source of new refrigerant, refrigerant is introduced through the low or high side of the system. When the system is operating, refrigerant is charged through the low side. On some vehicles with the system off, charging is done through the high side. Always refer to the service information for the correct procedure.

Currently, the only approved way to charge R-1234yf systems is by a Section 609 certified technician using a R-1234yf RRR unit. Because R-1234yf poses a flammability hazard, even a slight one, the proper equipment must be used. In addition, as of late 2017, the cost of R-1234yf is quite high, around $100 per pound. Shops need to closely track the

PHOTO SEQUENCE 51

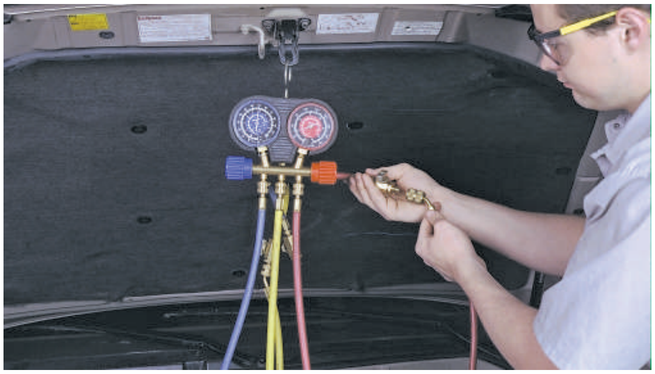
Evacuating and Recharging an A/C System with a Recycling and Charging Station



P51-1 Physically locate the pressure fittings of the system. Make sure you have the proper adapters for the fittings prior to starting any service work on air-conditioning system.

P51-2 Connect a gauge set to the system.

P51-3 Typical refrigerant recovery/reclaiming/recycling machine.



P51-4 Connect the reclaiming unit to the gauge set.

P51-5 Activate the reclaimer to discharge the system, then begin evacuation. Allow enough time for the machine to draw a good vacuum (at least 29 in. Hg) in the system. Observe the gauge set to determine when a vacuum is created.

P51-6 Close the valves at the gauge set and disconnect the reclaiming machine. Connect the charging station and open the gauge set valves. Set the unit to deliver the required amount of refrigerant for that system.

P51-7 After the system has been recharged, check the gauge readings while the system is in operation to make sure it is working properly.

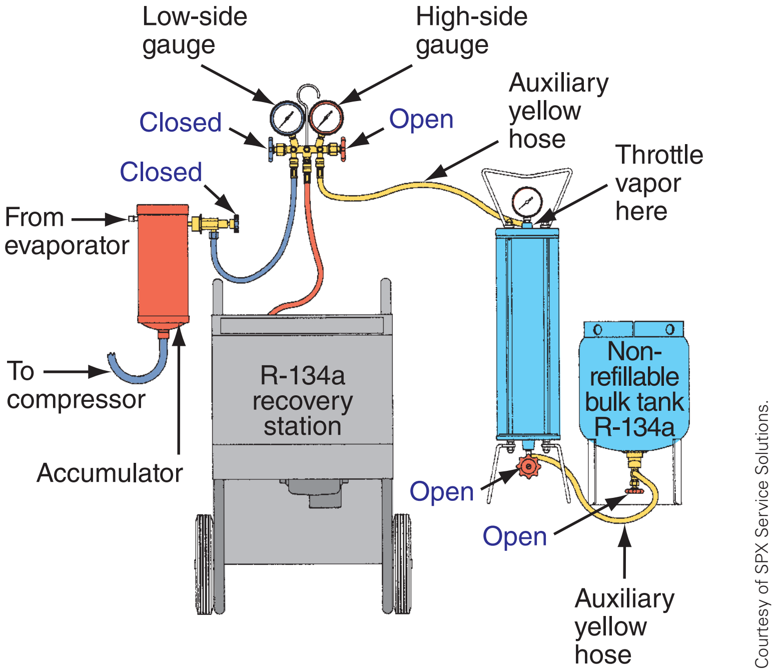


FIGURE 55–37 The connections for filling a system with refrigerant using a charging cylinder.

use of the refrigerant since if even small amounts escape, the cost can quickly be significant.

Because late-model vehicles require less refrigerant than in the past, modern recharging equipment must be more accurate in dispensing the amount of charge. New charging stations must meet the SAE J2788 standard, which requires an accuracy of 0.5 oz. This helps prevent overcharging, which can degrade system performance and cause damage to the system.

Always use the same type of refrigerant and refrigerant oil for the system. The importance of the correct charge cannot be stressed enough. The efficient operation of the A/C system greatly depends on the correct amount of refrigerant in the system. A low charge results in inadequate cooling under high heat loads due to a lack of reserve refrigerant and can cause the clutch cycling switch to cycle faster than normal. An overcharge can cause inadequate cooling because of a high liquid refrigerant level in the condenser. Refrigerant controls will not operate properly and compressor damage can result. In general, an overcharge of refrigerant will cause higher-than-normal gauge readings and noisy compressor operation.

The charging cylinder is designed to meter out a desired amount of a specific refrigerant by weight. Compensation for temperature variations is accomplished by reading the pressure on the gauge of the cylinder and dialing the plastic shroud. The calibrated chart on the shroud contains corresponding pressure readings for the refrigerant being used.

When charging an A/C system with refrigerant, the pressure in the system often reaches a point at which it is equal to the pressure in the cylinder from which the system is being charged. To get more refrigerant into the system to complete the charge, heat must be applied to the cylinder.

The A/C system may only be charged through the high side with the system off **(Figure 55–38)**. Inverting the refrigerant container disperses liquid refrigerant. As a general practice, the system is vapor charged through the low side while the system is running. If the system is charged through the high side (with the system off), the compressor should be turned a few times by hand afterward to ensure there is no liquid refrigerant on top of the piston. If liquid refrigerant enters the compressor, this component may be damaged. The vehicle should always be charged from the low-pressure side if the engine is on. If the engine is off, it can be charged from the high-pressure side.

Never open the high-side hand valve with the system operating and a refrigerant can connected to the center hose. The refrigerant will flow out of the system under high pressure into the can. High-side pressure is between 150 and 300 psi and will cause the refrigerant tank to burst. The only occasion for opening both hand valves at the same time would be when evacuating the system or when reclaiming refrigerant with the system off.

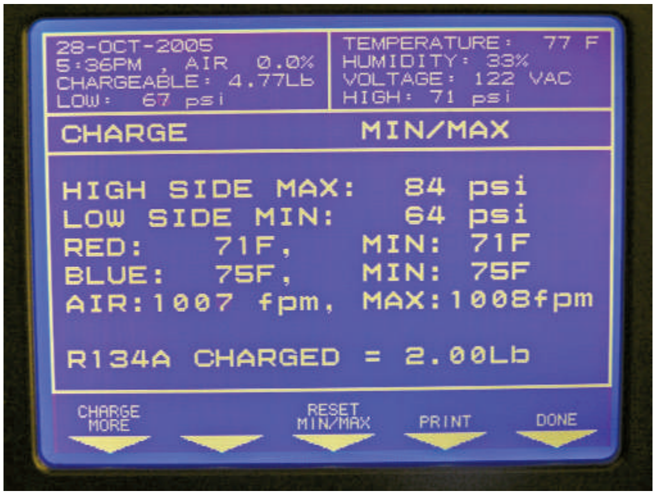


FIGURE 55-38 The recharging equipment will display how much refrigerant was added to the system.

Charging Cylinder

With an increase in temperature in any cylinder filled with refrigerant, there is a corresponding increase in pressure and a change in the volume of liquid refrigerant in the cylinder. To measure an accurate charge according to the weight of a cylinder, it is absolutely necessary to compensate for liquid volume variations caused by temperature variations. These temperature variations are directly related to pressure variations and accurate measurements by weight can be calibrated in relation to pressure.

The charging cylinder is designed to meter out a desired amount of a specific refrigerant by weight. Compensation for temperature variations is accomplished by reading the pressure on the gauge of the cylinder. A calibrated chart on the machine contains the corresponding pressure readings for the refrigerant being used.

When charging an A/C system with refrigerant, the pressure in the system often reaches a point at which it is equal to the pressure in the cylinder from which the system is being charged. To get more refrigerant into the system to complete the charge, the cylinder can be placed on a heating plate.

Testing for Noncondensable Gases Whenever using recycled refrigerant, it should be checked for noncondensable gases. Install a calibrated pressure gauge on the container and measure the pressure in the container. Measure the temperature of the air 4 inches away from the container's surface. Compare the measured pressure and temperature to the manufacturer's pressure/temperature chart. Determine if the recycled refrigerant has excessive noncondensable gases. If the refrigerant has excessive noncondensable gases, it should be recycled again and then retested before it is used.

Recover/Recycling/Recharging Station Maintenance

Even though modern charging stations are very dependable, most require some routine maintenance to keep in good working condition. Most systems have replaceable filters that need to be changed after a certain amount of refrigerant filtration, often after 220–331 pounds (100–150 kg). Place the machine into Filter Service mode or equivalent to evacuate the internal hoses. Remove the filter(s) **(Figure 55–39)** and replace with ones specified by the manufacturer of the unit. If the machine has a refrigerant identifier, there is likely a separate filter, oxygen sensor, and sample hose that needs to be replaced. Replace these items as per the machine's maintenance schedule or when changing the refrigerant filter.

To check the calibration of the tank scale, put the machine into Scale Calibration mode. Next, place the calibration weight on the scale and the machine will self-calibrate. This helps to ensure the machine is charging using the correct amount of refrigerant.

To keep the vacuum pump operating correctly, the pump oil should be changed after a certain number of hours of use. Locate the pump drain plug and drain the oil into a suitable container. Dispose of the oil with other waste refrigerant oil products. Pour in the specified amount of new pump oil. Contaminated pump oil can shorten the life of the pump and cause permanent damage if not maintained.

FIGURE 55-39 Filters for protecting RRR equipment.

Climate Control Systems

When diagnosing climate control systems, it is essential to have accurate information about the system before beginning. This information can be obtained from a number of sources: manufacturer service manuals, manufacturer service information, websites, Internet-based information systems, technical service bulletins, and aftermarket electronic and printed manuals.

Self-Diagnosis

Most climate control systems are computer controlled and have a self-diagnostic feature. Manufacturers' specifications must be followed to identify the malfunction display codes, because they differ from car to car. To check the system, refer to the service information and determine if the automatic climate control system relies on the PCM, BCM, or a separate computer for control. Modern systems are part of CAN therefore DTCs and other data are available through a scan tool. Typically, system pressures and input and output data are also available **(Figure 55–40)**. In addition, active command of system operation, such as blend doors and blower speed is often possible. By using active commands or bidirectional control, you can determine if a component and its circuit are functioning.

If the unit is part of the PCM/BCM system, connect the scan tool and retrieve any codes that may be present. If the unit is controlled by its own computer system, use your service information and the procedure for retrieving trouble codes. If the system is a semiautomatic system, check the service information for the proper diagnostic procedures for checking evaporator and heating controls. Test the components or subsystems identified by the trouble codes.

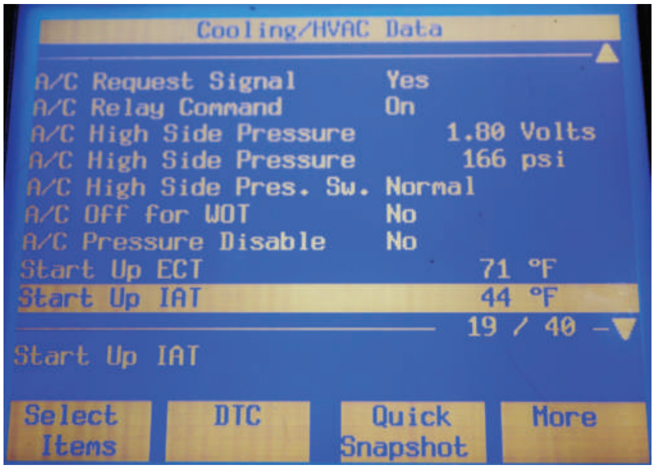


FIGURE 55–40 Using scanner data to monitor A/C system operation.

The DTCs from the system can lead a technician to the following problems:

- An open or short in the air mix control motor circuit
- A problem with the air mix control linkage, door, or motor circuit
- An open or short in the mode control circuit
- A problem with the mode control linkage, doors, or motor circuit
- A problem in the blower motor circuit
- A problem with the HVAC control unit
- An open or short in the evaporator temperature sensor circuit
- A problem with temperature and sunload sensors

Some automatic temperature control systems allow for testing through the control panel. By pressing and holding two buttons, such as the AUTO and Recirc buttons at the same time, the control panel will enter a self-diagnostic mode. During this mode, the system will move through different output modes, such as full heating to full cooling. Once completed, trouble codes are displayed on the control panel. Because each system is different, you will need to refer to the manufacturer's service information for procedures specific to the vehicle.

Blower Motor

The blower motor is usually located in the heater housing assembly. It ensures that air is circulated through the system. Its speed is controlled by a multi-position switch in the control panel. The switch works in connection with a resistor block that is usually located on the heater housing. Vehicles with automatic climate control typically use a blower speed control module, which uses pulse-width modulation to control motor speed.

On some vehicles, when the engine is running, the blower motor is in constant operation at low speed. On automatic temperature control systems, the blower motor is activated only when the engine reaches a predetermined temperature. The blower motor circuit is protected by a fuse located in the fuse panel. The fuse rating is usually 20 to 30 amperes.

The blower motor resistor block is used to control the blower motor speed. The typical resistor block is composed of three- or four-resistors in

series with the blower motor, which control its voltage and current. The speed of the motor is determined by the control panel switch, which puts the resistors in series. Increasing the resistance in the system slows the blower speed.

If the blower does not operate, use a testlight to make sure there is voltage on both sides of the fuse. Check the wiring diagram and identify whether the blower circuit is controlled by a ground side switch or an insulated (power side) switch. If the ground side of the circuit is controlled, check to see if voltage is arriving at the motor. On cars where the blower motor is behind the inner fender shell, hunt out the wiring and check for voltage. If the blower motor is getting voltage, the problem is either a burned-out blower motor or an open ground in the motor circuit. In situations where no voltage is available at the motor, backtrack to check for an open. Check also for burned or corroded connections in the blower relays and connectors. An open blower motor ground would cause the motor not to run at all. If the correct amount of voltage is available to the motor and the ground is good, suspect a bad motor.

If the blower works at some speeds but not all, check the voltage to the blower motor at the various switch positions. If the voltage does not change when a new position is selected, check the circuit from the switch to the resistor block. If there was zero voltage in a switch position, check for an open in the resistor block. Refer to **Table 55–1** for blower motor diagnosis.

If the motor runs when it should not, there is probably a short in the circuit. If a ground side switch controls the circuit, check for a short to ground in the control circuit. The exact problem can be isolated by disconnecting portions of the circuit until the motor stops. The short is in that part of the circuit that was disconnected last. If the circuit is controlled by an insulated switch, check for a wire-to-wire short. Check other circuits of the vehicle to identify what circuit is involved in this problem. That circuit will also experience a lack of control, or when that circuit is turned off, the blower motor will turn off. The exact problem can be isolated by disconnecting portions of the circuit until the motor stops. The short is in that part of the circuit that was disconnected last.

To diagnose PWM blower motor control systems, begin by setting the system to where the blower should operate. If the blower does not work at all, refer to the manufacturer's service information to determine how to access the self-diagnostics for the ATC system. In general, diagnosis of an ATC blower motor concern is similar to a non-ATC system. Determine if the motor is power or ground circuit controlled and test for power and ground at the motor. Verify which constant, either power or ground, is present. If the blower control circuit is intact, the motor is faulty.

If the PWM signal is not present at the motor you need to determine the cause. Using either the self-diagnostic function or a scan tool, determine whether a blower motor request is received and if the control module is attempting to control blower motor speed. If the inputs are present and correct and the blower is commanded on but does not operate, look for an open in the wiring between the blower control and the motor.

Doors and Ductwork

To check the proper functioning of the ductwork, move the temperature control lever to see if any change occurs. If it does not, shut off the air conditioner and turn on the heater. Move the temperature control arm again to see if any change occurs. If not, check the cable and the flap door connected to the temperature control lever. You might be able to reach under the dash to reconnect the cable or free a stuck flap.

If no substantial airflow is coming out of the registers, check the fuses in the blower circuit. Remove

TABLE 55–1 BLOWER MOTOR DIAGNOSIS

Problem	Possible cause
Blower inoperative all speeds	Open fuse, defective relay, faulty blower motor, open ground circuit, faulty switch
Works on high speed only	Open fuse, defective relay, open blower resistor
High speed inoperative	Open high speed fuse, defective high speed relay, faulty blower switch, open in high speed circuit
Inoperative on various speeds	Open in blower resistor, faulty blower switch

the fan switch and test it. Check the blower motor by hot-wiring it directly to the battery with jumper wires.

Controls

Most systems use electric motors to control the blend and mode doors; however, some use vacuum. To check these systems, identify and inspect the hoses and components for vacuum motors and doors. Look for disconnected or broken hoses, broken connectors, misrouted vacuum lines, and loose or disconnected electrical connectors at vacuum switches and controls. Identify the vacuum source for the various doors and switches of the duct system and make sure vacuum is available when the engine is running. Disconnect that vacuum source. Connect a vacuum gauge to the inlet for the defroster door motor(s) and record the vacuum available there when the master control switch is in the following positions: max, norm, bilevel, vent, heat, blend, defrost, and off.

If they do not move with the engine's vacuum, use a hand-operated vacuum pump to check the component's activity and its ability to hold a vacuum. Use the vacuum pump to check all one-way check valves. Also, check all mechanical or cable linkages and controls. Make sure the cables are properly attached to the levers of the control switch. If the cable(s) is equipped with an automatic adjuster, make sure the adjusting mechanism operates freely and is not damaged.

Control Panel At times the control unit is the root of problems **(Figure 55–41)**. Inspect the connectors to the control unit, look for damage and corrosion. For systems with mechanical switches, use an ohmmeter to check for continuity through the blower motor switch in all of its positions. Compare your results with the wiring diagram for the switch. Check the resistance across the temperature control switch. If the mode selector switch is electrical, check for continuity across the terminals as you move the switch through the various mode selections. If the mode selector switch is a vacuum switch, apply a vacuum to the inlet of the switch and feel for a vacuum at the various tube connectors on the switch while you move the selector through its various positions. Compare your results to the information in the service manual.

For systems with ATC or electronic controls, connect a scan tool to monitor the operation of the input switches **(Figure 55–42)**. ATC control panels are not repaired; rather, they are replaced as a unit. Care needs to be taken when handling and replacing these units. Like the other electronic circuits on a vehicle, the control panel may be part of the BCM circuit. Follow all precautions to eliminate static and voltage spikes at the BCM.

Solar Sensor

The solar sensor detects sunlight. It controls the climate control system on many vehicles. The output voltage from the sensor varies with the amount of sunlight. When the sunlight increases, the output voltage increases. As the sunlight decreases, the output voltage decreases. The sensor is monitored by the A/C control module. DTCs will indicate a perceived problem. The systems typically look for an open or short in the solar sensor circuit.

FIGURE 55–41 The control unit must be removed to test it and what it controls.

FIGURE 55–42 Scan data for an automatic HVAC system.

Three Cs: Concern, Cause, Correction

ALL TECH AUTOMOTIVE				REPAIR ORDER
Year: 2010	**Make:** Dodge	**Model:** Ram 1500	**Mileage:** 102,544	**RO:** 19301
Concern:	Customer states the air conditioning is not working properly. It sounds like the A/C turns on and off quickly.			
History:	Car had A/C system serviced and recharged 2 months ago.			
Upon starting the engine and turning on the A/C, the technician notices that the compressor turns on and off again rapidly. Thinking the system may be low on refrigerant, causing the low-pressure switch to open and turn the compressor off, she connects a gauge set to the system. With the compressor off, pressure is around 90 psi on the low and high sides, indicating normal pressure. Since the pressure indicates the system is not low on refrigerant, she turns the compressor on and watches the gauges. She immediately notices that the low-side pressure drops and the high-side pressure increases beyond normal to well over 400 psi before the compressor shuts off.				
Cause:	Inoperative A/C condenser fan allowing the A/C pressure to increase enough to open the high pressure cutoff switch.			
Correction:	Replaced fan and system operates normally.			

SUMMARY

- Air-conditioning (A/C) systems are extremely sensitive to moisture and dirt. Therefore, clean working conditions are extremely important. The smallest particle of foreign matter in an A/C system contaminates the refrigerant, causing rust, ice, or damage to the compressor.
- Air conditioner testing and servicing equipment includes a manifold gauge set, service valves, vacuum pumps, charging station, charging cylinder, recovery/recycling systems, and leak-detecting devices.
- Refrigerant evaporates quickly when it is exposed to the atmosphere. It will freeze anything it contacts. If liquid refrigerant gets in your eyes or on your skin, it can cause frostbite. Never rub your eyes or skin if refrigerant has contacted you. Immediately flush the exposed areas with cool water for 15 minutes and seek medical help.
- Never expose A/C system components to high temperatures. Heat will cause the refrigerant's pressure to increase. Never expose refrigerant to an open flame.
- Refrigerants should never be mixed. Their oils and desiccants are not compatible. If refrigerants are mixed, contamination will occur and may result in A/C system failure. Separate service equipment, including recovery/recycling machines and service gauges, should be used for the different refrigerants.
- The manifold gauge set is used when discharging, charging, and evacuating the system; it is also used for diagnosing trouble in the system. Because R-134a is not interchangeable with R-12, separate sets of hoses, gauges, and other equipment are required to service vehicles.
- Performance testing provides a measure of A/C system operating efficiency.
- A manifold pressure gauge set is used to determine both high and low pressures in the refrigeration system. The desired pressure readings will vary according to temperature.
- Using an electronic leak detector is the preferred method of leak detection.
- A common leak detection method includes a fluorescent dye and a black light glow gun to locate the source of leaks.
- All refrigerant must be discharged from the system before repair or replacement of any component, except for compressors with stem service valves.
- Recycling collects old refrigerant from the system being serviced and cleans it up and prepares it to be used in the future.

- R-12-based systems use mineral oil, whereas R-134a systems use synthetic polyalkylene glycol (PAG) oils. Using a mineral oil with R-134a will result in A/C compressor failure because of poor lubrication. Use only the oil specified for the system.
- While evacuating the system, the vacuum pump should remain on and connected to the system for at least 30 minutes after 26 to 29 inches of mercury is reached.

REVIEW QUESTIONS

Short Answer

1. What should you do if you suspect that an alternative refrigerant had been used in the A/C system and it is not performing properly?
2. Explain how dye can be used to find leaks in the A/C system.
3. What is the purpose of the thermostatic switch in a cycling clutch system?
4. Why should the probe of an electronic leak detector be placed below the area being checked?
5. How will air trapped in the A/C system affect system performance?

Multiple Choice

1. Which of the following statements best defines the term *evacuation*?
   a. A process in which the refrigerant in a system is released.
   b. A condition that exists when a compressor runs until there is no refrigerant left in the system.
   c. The process that pulls all traces of air and moisture from the system.
   d. A process that uses air to force moisture and dirt out of the system.
2. Which of the following statements is *not* true about orifice tube systems?
   a. The suction line must be cool to the touch from the evaporator outlet to the compressor.
   b. The liquid line from the condenser outlet to the evaporator inlet should be cool.
   c. The evaporator should feel very cold.
   d. The accumulator must be cool to the touch.
3. To charge an air-conditioning system while it is running, the refrigerant should be added to ___.
   a. the high side
   b. the low side
   c. both the high and low sides
   d. either the high or the low side
4. All of the following are true statements about flushing an A/C system after a compressor failure, *except* ___.
   a. the condenser must be flushed and the receiver/dryer replaced
   b. filter screens are sometimes located in the suction side of the compressor and in the receiver/dryer. These screens confine foreign material to the compressor, condenser, receiver/dryer, and connecting hoses
   c. use only CFCs for flushing. After the system has been flushed, be sure to oil all components that require it
   d. some manufacturers recommend replacing the clogged components and installing a liquid line (inline) filter just ahead of the expansion valve or orifice tube instead of flushing the system
5. A very important part of a performance test on an A/C system is a pressure test. Pressure also is the key to the operation of the system. Which of the following statements is *not* true?
   a. Pressure on a substance, such as a liquid, changes its boiling point.
   b. The greater the pressure on a liquid, the higher the boiling point.
   c. If pressure is placed on a liquid, the liquid freezes at a higher-than-normal temperature.
   d. The boiling point can be increased by increasing the pressure on the fluid. It can also be decreased by reducing the pressure or placing the fluid in a vacuum.
6. While conducting a pressure test on an A/C system, the ambient temperature is 80 °F, the low-side gauge reads low (8 psi), and the high side also reads low (85 psi). Which of these could cause these readings?
   a. Low refrigerant level
   b. Normal operation
   c. Bad compressor
   d. A high-side restriction

7. The high-side pressure on a system with a cycling clutch and pressure cycling switch is 145 psi, the low-side pressure is 28 psi, and the ambient temperature is 78 °F. What do these gauge readings indicate?
   a. The system is undercharged.
   b. The system is overcharged.
   c. The system is normal.
   d. The evaporator pressure regulator is bad.
8. When checking an A/C system, the evaporator's inlet and outlet tubes feel like they are at the same temperature. Which of these could cause this?
   a. A plugged evaporator
   b. Correct charge of refrigerant in the system
   c. Restricted orifice tube
   d. Leaking condenser
9. All of these are good reasons for replacing an accumulator unit, *except* ___.
   a. the accumulator/dryer is punctured
   b. the accumulator/dryer is saturated with water
   c. the A/C system has been open to the atmosphere for 2 or more hours
   d. the outer shell of the accumulator/dryer is dented
10. In an A/C system, if the low-side pressure is lower than normal, which of the following is the *least* likely cause?
    a. A faulty metering device
    b. Poor airflow across the evaporator
    c. A restriction in the low side of the system
    d. The system being overcharged with refrigerant

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that evacuating (pumping down) an air-conditioning system removes air and moisture from the system. Technician B says that evacuating (pumping down) an air-conditioning system removes dirt particles from the system. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
2. Technician A says that some refrigerant leaks can also be traced to pinholes in the evaporator caused by acid, which forms when water and refrigerant mix. Technician B says that leaks are most often found at the compressor hose connections and at the various fittings and joints in the system. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
3. Technician A says that the presence of oil around a fitting of an air-conditioning line may indicate an oil leak but not a refrigerant leak. Technician B says that using an electronic leak detector is the best way to find the source of a refrigerant leak. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
4. Technician A says that a faulty accumulator will allow contaminants to enter the A/C system. Technician B says that a damaged compressor will allow contaminants to enter the A/C system. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
5. Technician A says that air in the system can cause excessive pressure within the system, restricting the refrigerant's ability to change its state from gas to liquid within the refrigeration cycle. Technician B says that moisture can cause freeze-up at the cap tube or expansion valve, which restricts refrigerant flow or blocks it completely. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

6. Technician A feels up and down the face or along the return bends of the condenser for a temperature change and says that there should be a gradual change from hot to warm from the bottom to the top. Technician B says that a restriction in the condenser will be evident by a sudden change in temperature. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
7. Technician A says that a manifold gauge set can be used during the evacuation of the system. Technician B says that a manifold gauge set can be used to diagnose a problem in the A/C system. Who is correct?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
8. While discussing an inoperative blend air door: Technician A says that to check the proper functioning of the ductwork, a scan tool may be used to command the door to change position. Technician B says that in some cases you can reach under the dash to reconnect the cable or free a stuck flap. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
9. Two technicians were discussing how comparing the temperature of a high-pressure line to that of a low-pressure line would help evaluate an A/C system when the system does not have a sight glass. Technician A says that the high-pressure line will feel warmer than the low-pressure line if the system is operating normally. Technician B says that both lines should feel cold after the system has been run for a while if the system is working normally. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B
10. While conducting an A/C system performance test: Technician A inserts a thermometer into the air duct at the center of the dash and monitors discharge temperature. Technician B follows this test with a complete visual inspection. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

APPENDIX A

Decimal and Metric Equivalents

DECIMAL AND METRIC EQUIVALENTS					
Fractions	**Decimal (in.)**	**Metric (mm)**	**Fractions**	**Decimal (in.)**	**Metric (mm)**
1/64	0.015625	0.397	33/64	0.515625	13.097
1/32	0.03125	0.794	17/32	0.53125	13.494
3/64	0.046875	1.191	35/64	0.546875	13.891
1/16	0.0625	1.588	9/16	0.5625	14.288
5/64	0.078125	1.984	37/64	0.578125	14.684
3/32	0.09375	2.381	19/32	0.59375	15.081
7/64	0.109375	2.778	39/64	0.609375	15.478
1/8	0.125	3.175	5/8	0.625	15.875
9/64	0.140625	3.572	41/64	0.640625	16.272
5/32	0.15625	3.969	21/32	0.65625	16.669
11/64	0.171875	4.366	43/64	0.671875	17.066
3/16	0.1875	4.763	11/16	0.6875	17.463
13/64	0.203125	5.159	45/64	0.703125	17.859
7/32	0.21875	5.556	23/32	0.71875	18.256
15/64	0.234275	5.953	47/64	0.734375	18.653
1/4	0.250	6.35	3/4	0.750	19.05
17/64	0.265625	6.747	49/64	0.765625	19.447
9/32	0.28125	7.144	25/32	0.78125	19.844
19/64	0.296875	7.54	51/64	0.796875	20.241
5/16	0.3125	7.938	13/16	0.8125	20.638
21/64	0.328125	8.334	53/64	0.828125	21.034
11/32	0.34375	8.731	27/32	0.84375	21.431
23/64	0.359375	9.128	55/64	0.859375	21.828
3/8	0.375	9.525	7/8	0.875	22.225
25/64	0.390625	9.922	57/64	0.890625	22.622
13/32	0.40625	10.319	29/32	0.90625	23.019
27/64	0.421875	10.716	59/64	0.921875	23.416
7/16	0.4375	11.113	15/16	0.9375	23.813
29/64	0.453125	11.509	61/64	0.953125	24.209
15/32	0.46875	11.906	31/32	0.96875	24.606
31/64	0.484375	12.303	63/64	0.984375	25.003
1/2	0.500	12.7	1	1.00	25.4

APPENDIX B

General Torque Specifications

NOTE: The values in this chart should only be used when manufacturer's specifications are *not* available. Also, the values are only valid when SAE 10 oil is used to lubricate the threads of the bolt.

Diameter In inches	SAE 2		SAE 5		SAE 8	
	Ft.-lb	N-m	Ft.-lb	N-m	Ft.-lb	N-m
1/4	7	8	9	12	13	17
5/6	12	16	18	25	26	35
3/8	21	29	33	45	63	64
7/16	34	46	52	72	100	100
1/2	52	70	80	110	115	155
9/16	75	100	115	158	165	225
5/8	104	120	160	217	225	305
3/4	180	242	280	385	400	540
7/8	175	238	455	610	640	865
1	265	355	675	915	955	1290

Diameter In millimeters	Class 5.8		Class 8.8		Class 10.9	
	Ft.-lb	N-m	Ft.-lb	N-m	Ft.-lb	N-m
5	3	4	5	6	9	7
6	5	7	8	11	15	11
8	13	18	20	28	38	28
10	26	36	42	60	80	57
12	50	68	70	92	130	96
14	70	95	110	150	210	155
16	110	150	175	235	325	240
18	155	210	245	330	445	325
20	220	295	400	550	790	510
24	375	500	585	795	1100	810

GLOSSARY

Note: Terms are highlighted in color, followed by Spanish translation in bold.

Abrasion Wearing or rubbing away of a part.
Abrasión El desgaste o consumo por rozamiento de una parte.
Abrasive cleaning Cleaning that relies on physical abrasion, such as wire brushing and glass bead blasting.
Limpieza abrasiva La limpieza que cuenta con un abrasión físico, tal como el limpiar con cepillo de alambre o con un chorro de perlitas de vidrio.
Absorbed glass mat (AGM) battery A design for sealed lead-acid batteries. The electrolyte is absorbed in a matrix of glass fibers, which holds the electrolyte next to the plate and immobilizes it, preventing spills.
Batería con malla de fibra de vidrio absorbente (AGM) Diseño de baterías selladas de ácido-plomo. El electrolito se absorbe en una matriz de fibra de vidrio, lo cual retiene al electrolito junto al plato, y lo inmoviliza, previniendo así derrames.
Acceleration The rate of increase in speed.
Aceleración El índice de incremento en velocidad.
Accumulator A container that stores hydraulic fluid under pressure. It can be used as a fluid shock absorber or as an alternate pressure source. A spring or compressed gas behind a sealed diaphragm provides the accumulator pressure. They are commonly used in automatic transmissions, air-conditioning systems, and antilock brake systems.
Acumulador Contenedor que almacena fluido hidráulico bajo presión. Puede usarse como fluido para amortiguadores o como fuente de presión alterna. Resorte o gas comprimido detrás de un diafragma sellado proporciona depression al acumulador. Por lo general, se usan en transmisiones automáticas, sistemas de aire acondicionado, y sistemas de frenos antibloqueo.
Acid A compound that has an excess of H ions and breaks into hydrogen (H^+) ions and another compound when placed in an aqueous (water) solution.
Ácido Un compuesto que tiene un exceso de iones de H, que se rompe en los iones de hidrógeno y un otro compuesto cuando está colocado en una solución acuosa (del agua).
Acidity In lubrication, acidity denotes the presence of acid-type chemicals, which are identified by the acid number. Acidity within oil causes corrosion, sludges, and varnish to increase.
Acidez En la lubricación, la acidez se refiere a la presencia de los químicos de tipo ácido, que se identifican por un número de ácido. La acidez en los aceites causa aumentos en la corrosión, la grasa y el barnís.
Active restraint A manual seat and shoulder belt assembly that must be activated by an occupant.
Sujeción activo Una asamblea manual de cinturón de seguridad que debe ser implementado por el ocupante.
Active suspension A computer-controlled suspension system with double-acting solenoids at each wheel.
Suspensión activa Un sistema de suspensión controlado por computadora con solenoides de doble acción en cada rueda.
Actuator A control device that delivers mechanical action in response to an electrical signal.
Solenoide Un dispositivo de control que entrega una acción mecánica como respuesta a un señal eléctrico.
A/D converter An electronic device that changes analog signals to digital signals.
Convertidor de A/D Un dispositivo electrónico que cambia los señales análogos a los señales digitales.
Adaptive air bags An airbag system that automatically adjusts the deployment rate of the airbag according to the weight of the passenger.
Bolsas de aire adaptativas Un sistema de bolsas de aire que ajusta de manera automática la velocidad de despliegue de la bolsa de aire, de acuerdo con el peso del pasajero.
Adaptive learning An operational mode of a control computer that adjusts operation parameters according to various conditions.
Operación de adaptación Un modo de operación de una computadora de control que ajusta los parámetros de operación según varias condiciones.
Adaptive suspension An electronically controlled suspension system that adjusts shock levels according to load and operating conditions.
Suspensión adaptativa Un sistema de suspensión controlado en forma electrónica que ajusta los niveles de amortiguación de acuerdo con la carga y las condiciones de operación.
Additive In automotive oils, a material added to the oil to give it certain properties; for example, a material added to engine oil to lessen its tendency to congeal or thicken at low temperatures.
Aditamento En los aceites automotrices, una materia añadida al aceite para que ésta tenga ciertas propiedades; por ejemplo, una materia agregada al aceite de motor para disminuir su tendencia a solidificarse o ponerse espeso en las temperaturas bajas.
Adhesion The property of lubricating oil that causes it to stick or cling to a bearing surface.
Adhesión La propriedad del aceite de lubricación que causa que se pega o se adhiera a una superficie portante.
Adhesive Substance that causes adjoining bodies to stick together.
Adhesivo Una substancia que causa que dos cuerpos contiguos se pegan.
Aeration The process of mixing air with a liquid. Aeration occurs in a shock absorber from rapid fluctuation in movement.
Aeración El proceso de mezclar el aire con un líquido. La aeración ocurre en un amortiguador de barquinazos por causa de una variación rápida en el movimiento.
Aerobic Typically refers to a sealant or adhesive that dries in the presence of oxygen.
Aeróbico Típicamente se refiere a un sellante o un adhesivo que se seca cuando esta presente el oxígeno.
Aerodynamics The study of the effects of air on a moving object.
Aerodinámica El estudio de los efectos del aire en un objeto móvil.
Aftermarket The network of businesses that supplies replacement parts and services to independent service shops, specialty repair shops, car and truck dealerships, fleet and industrial operations, and the general buying public.
Mercado de repuestas no originales La cadena de negocios que proveen las repuestas y los servicios a los talleres de servicio independientes, los talleres de refacción especializadas, los comerciantes de coches y camiones, las operaciones de flete e industrias, y las compras del público común.
Air bag system System that uses impact sensors, vehicle's on-board computer, an inflation module, and a nylon bag in the steering column and dash to protect the driver and passenger during a head-on collision.
Sistema de bolsa de aire Un sistema que utiliza sensores de impacto, la computadora del vehículo, un módulo inflador y bolsas de nilón en la columna de dirección y el tablero de instrumentos, para proteger al conductor y al pasajero en caso de un choque de frente.

Air conditioning The process of adjusting and regulating, by heating or refrigerating, the quality, quantity, temperature, humidity, and circulation of air in a space or enclosure; to condition the air.

Aire acondicionado El proceso de ajustar, regular calentando o enfriando, la calidad, la cantidad, la temperatura, la humedad, y la circulación de aire en un espacio o espacio cerrado; para acondicionar el aire.

Air-conditioning clutch An electromechanical device mounted on the air-conditioning compressor used to start and stop compressor action, thereby controlling refrigerant circulating through the system.

Embrague de climatizador (aire acondicionado) Dispositivo electromecánico montado en el compresor del equipo climatizador y que se utiliza para poner en marcha y detener dicho compresor, controlando de ese modo el refrigerante que circula por el sistema.

Air ducts Tubes, channels, or other tubular structures used to carry air to a specific location.

Conductos de aire Los tubos, las canalizaciones, u otras estructuras tubulares que sirven para traer el aire a una posición específica.

Air filter A filter that removes dust, dirt, and particles from the air passing through it.

Filtro de aire Un filtro que retira polvo, suciedad y partículas del aire que pasa por él.

Air gap The space between spark plug electrodes, motor and generator armatures, and field shoes.

Entrehierro El espacio entre los electrodos de las bujías, el enducido del motor y del generador, y las piezas inductoras.

Air induction system An engine system that directs outside air into the engine's intake manifold.

Sistema de inducción de aire Un sistema de motor que dirige el aire externo hacia el múltiple de admisión del motor.

Air injection The introduction of fresh air into an exhaust manifold for additional burning and to provide oxygen to a catalytic converter.

Inyección por aire La introducción del aire fresco al múltiple de escape para mejor combustión y para proveer el oxígeno al convertidor catalítico.

Air Injection Reactor (AIR) An emission control system responsible for adding outside air to the catalytic converter or exhaust stream.

Reactor de inyección de aire (AIR) Sistema de control de emisión responsable de agregar aire externo al convertidor catalítico o flujo de escape.

Air-fuel ratio (A/F) sensor Similar to an oxygen sensor, this sensor is placed in the exhaust stream and sends signals to the PCM in response to very slight changes in exhaust oxygen content.

Sensor de proporción aire/combustible Similar a un sensor de oxígeno, este sensor se coloca en el flujo de escape y envía señales al PCM, en responsable de ligeros cambios.

Alignment An adjustment to a line or to bring into a line.

Alineación Un ajuste que se efectúa en una linea o alinear.

Alkaline fuel cell (AFC) The type of fuel cell used by NASA. These cells use a water-based solution of potassium hydroxide (KOH) as the electrolyte and electrodes coated with a catalyst.

Pila de combustible alcalina (AFC) Uno de los tipos de pila de combustible utilizados por la NASA. Estas celdas usan una solución basada en agua con hidróxido de potasio (KOH) como electrólito, y electrodos cubiertos con un catalizador.

Alloy A mixture of different metals such as solder, which is an alloy consisting of lead and tin.

Aleación Una mezcla de metales distinctos como la soldadura, que es una aleación que consiste del plomo y el estaño.

All-wheel drive (AWD) System of driving all four wheels only when traction conditions dictate.

Tracción total (todoterreno) Un sistema de tracción que maneja las cuatro ruedas sólo cuando indican las condiciones de la tracción.

Alternating current Electrical current that changes direction between positive and negative.

Corriente alterna Corriente eléctrica que recorre un circuito ya sea en dirección positiva o en dirección negativa.

Alternator An AC (alternating current) generator that produces electrical current and forces it into the battery to recharge it.

Alternador Un generador de ca (corriente alterna) que produce corriente eléctrica y la dirige a una batería para cargarla.

Ambient temperature Temperature of air surrounding an object.

Temperatura del ambiente La temperatura en la atmósfera alrededor de un objeto.

American wire gauge (AWG) A standard method of denoting the diameter of electrically conducting wire.

Calibre Americano (AWG) Método estándar que indica el diámetro de cable conductor de electricidad.

Ammeter The instrument used to measure electrical current flow in a circuit.

Amperímetro El instrumento que se usa para medir los corrientes eléctricos de un circuito.

Ampere The unit for measuring electrical current; usually called an amp.

Amperio La unidad para medir el corriente eléctrico; por lo común se refiere como "amp" en inglés.

Ampere-hour (AH) rating The rating that is based on the total number of amperes the battery can supply in a 20-hour period at a fixed rate of discharge. If a battery is rated at 200 ampere/hours, it can supply 10 amperes per hour for 20 hours.

Tasa ampere-hora (AH) Esta tasa se basa en el total del número de amperes que una batería puede suministrar en un período de 20 horas a una tasa fija de descarga. Si una batería se tasa a 200 amperes/horas puede suministrar 10 amperes durante 20 horas.

Amplifier A circuit or device used to increase the voltage or current of a signal.

Amplificador Un circuito o un dispositivo que se usa para aumentar el voltage o el corriente de un señal.

Amplify To enlarge or strengthen original characteristics; a term associated with electronics.

Amplificar Aumentar o fortalecer las características originales; un término que se asocia con lo electrónico.

Amplitude A measurement of a vibration's intensity.

Amplitud Una medida de intensidad de una vibración.

Anaerobic Typically refers to a sealant or adhesive that dries without being exposed to oxygen.

Anaerobio Típicamente se refiere a un sellante o un adhesivo que se seca sin ser expuesto al oxígeno.

Analog A nondigital measuring method that uses a needle to indicate readings. A typical dashboard gauge with a moving needle is an analog instrument.

Análogo Un método no numérico de medir que usa una aguja para indicar las lecturas. Un indicador típico de un tablero de intrumentos con una aguja que se mueve es un instrumento análogo.

Annulus Another name for the ring gear of a planetary gearset.

Ánulo Otro nombre para la corona de un tren de engranajes planetario.

Anodize An electrochemical process that coats and hardens the surface of aluminum.

Anodizar Un proceso electroquímico que cubre y endurece la superficie del aluminio.

Antifreeze A material, such as alcohol or glycerin, added to water to lower its freezing point.

Anticongelante Una materia, tal como el alcohol o la glicerina, que se agrega al agua para disminuir su punto de congelación.

Antiknock Index (AKI) The octane rating required by law and the one displayed on gasoline pumps. It is the average of RON and MON and is stated as (R1M)/2.

Índice antidetonante (AKI) Proporción de octano se requiere por ley y se muestra en las bombas de gasolina. Es el promedio entre RON y MON y se escribe como (R1M)/2.

Antilock brake system (ABS) A series of sensing devices at each wheel that control braking action to prevent wheel lockup.

Sistema de frenos antideslizante Una seria de dispositivos sensibles en cada rueda que controla la acción del enfrenamiento y previene que las ruedas se bloquean.

Antiseize compounds A type of lubrication that prevents dissimilar metals from reacting with one another and seizing.

Compuestas antiagarrotamiento Un tipo de lubricación que previene que los metales desemejantes se reaccionan y se agarran.

Antisway bar A suspension geometry that resists a vehicle's tendency to drop or squat on the rear springs when accelerating.
Barra de anticabeceo Una geometría de suspensión que resiste la tendencia de un vehículo a desplomarse o apoyarse sobre los muelles posteriores al acelerar.
Aqueous A solution that is mostly water.
Acuosa Una solución acuosa es una solución que es agua en su mayor parte.
Aramid fibers Refer to a family of synthetic materials that are stronger than steel but weigh little more than half of what an equal volume of fiberglass would weigh.
Fibras de aramida Se refieren a una familia de materiales sintéticos que son más fuertes que el acero pero pesan poco más de la mitad de lo que un volumen igual de fibra de vidrio pesaría.
Armature The rotating part of a motor. It is positioned in the center of the field coils and housing.
Rotor La parte giratoria de un motor. Está ubicado en el centro de las bobinas de campo y la carcasa.
Asbestos A silicate compound with excellent heat dissipation abilities and high coefficient of friction, but contains millions of small, linked fibers that give it both strength and flexibility but are a health hazard.
Asbesto Un compuesto de silicato con excelente capacidad de disipación de calor y un elevado coeficiente de fricción; contiene millones de pequeñas fibras enlazadas que le dan tanto fuerza como flexibilidad, pero son peligrosas para la salud.
Asynchronous motor A type of AC motor in which the rotor rotates at a slower speed than that of the rotating magnetic field.
Motor asíncrono Tipo de motor CA en el cual el rotor gira a una velocidad menor que la rotación del campo magnetico.
Aspect ratio The height of a tire, from bead to tread, expressed as a percentage of the tire's section width.
Relación de aspecto La altura de un neumático, de la ceja a la banda, que se expresa como un porcentaje de lo ancho de una sección del neumático.
Asymmetric Unequal surfaces or sizes.
Asimétrico Desigual en las superficies o en los tamaños.
ATF Automatic transmission fluid.
ATF Fluido para transmisión automática.
Atkinson cycle The cycle during which the intake valves are kept open for a while during the compression stroke, reducing the actual displacement and the power output of the engine.
Ciclo Atkinson Durante el ciclo Atkinson, las válvulas de entrada se mantienen abiertas por un tiempo durante el golpe de compresión, esto reduce el desplazamiento y la salida de energía del motor.
Atmospheric pressure The weight of the air at sea level (about 14.7 pounds per square inch or less at higher altitudes).
Presión atmosférica El peso del aire a nivel del mar (aproximadamente unas 14.7 libras por pulgada cuadrada o menos en las altitudes más altas).
Atom The smallest particle of an element in which all the chemical characteristics of the element are present.
Átomo La partícula más pequeña de un elemento en el la cual todas las características químicas del elemento estén presentes.
Atomization The stage in which the metered air-fuel emulsion is drawn into the airstream in the form of tiny droplets.
Atomización La etapa en la cual la emulsión calibrada del aire-combustible se introduce al chorro del aire en la forma de pequeñas gotas.
Automotive Service Excellence (ASE) The National Institute for Automotive Service Excellence (ASE) has a voluntary certification program for automotive, heavy-duty truck, auto body repair, and engine machine shop technicians.
Excelencia en servicio automotriz (ASE) El Instituto Nacional de Excelencia en Servicio Automotriz (ASE) tiene un programa voluntario de certificación para técnicos automotrices, de camiones de uso pesado, de reparación de carrocería de autos y de talleres de maquinado de motores.
Average responding A type of voltage reading in which the average voltage peak is displayed.
Respuesta promedio Tipo de lectura de voltaje en el cual se muestra el pico promedio de voltaje.
Axial Having the same direction or being parallel to the axis or rotation.
Axial Teniendo el mismo dirección o siendo paralelo al eje o la rotación.
Axial load A type of load placed on a bearing that is parallel to the axis of the rotating shaft.
Carga axial Un tipo de carga puesto en un cojinete paralelo al eje de una flecha que gira.
Axial play Movement that is parallel to the axis or rotation.
Holgura axial El movimiento que es paralelo al eje o a la rotación.
Babbitt A soft slippery material made of mostly lead and tin that is used to line steel flat bearings.
Babbitt Un material resbaloso y suave, fabricado en su mayor parte de plomo y estaño, que se utiliza para recubrir los cojinetes planos de acero.
Backing plate Found on drum brake systems, the plate is the mounting point for the hydraulic cylinder and the brake hardware.
Placa de fijación Se encuentra en los sistemas de freno de tambor; la placa es el punto de montaje para el cilindro hidráulico y el mecanismo del freno.
Backlash The clearance or play between two parts, such as meshed gears.
Juego La cantidad de holgura o juego entre dos partes, tal como los engranajes endentados.
Backpressure Pressure created by restriction in an exhaust system.
Contrapresión La presión creada por una restricción en un sistema de escape.
Balancing coil gauge A type of gauge that utilizes coils to create magnetic fields instead of a permanent magnet.
Bobina equilibrada Un tipo de manómetro que utiliza las bobinas para crear un campo magnético en vez de un imán permanente.
Ball bearing An antifriction bearing that uses a series of steel balls held between inner and outer bearing races.
Cojinete de bolas Un cojinete de antifricción que usa una serie de bolas del acero sujetados entre pistas interiores y exteriores.
Ball joint A pivot point for turning a front wheel to the right or left. Ball joints can be considered either nonloaded or loaded when carrying the car's weight.
Unión esférica Un punto de pivote en el cual gira una rueda delantera hacia la derecha o a la izquierda. Las uniones esféricas se pueden considerar como sin carga o con carga al sostener el peso del coche.
Band A steel band with an inner lining of friction material; a device used to hold a clutch drum at certain times during automatic transmission operation.
Banda Banda de acero con un revestimiento de material de fricción. Dispositivo que se usa para sostener un tambor del embrague en ciertos momentos durante la operación de transmisión automática.
Barometric pressure A sensor or its signal circuit that sends a varying frequency signal to the processor relating actual barometric pressure.
Presión barométrico Un sensor o su circuito de señal que manda un señal de frecuencia variada al procesor refiriendo la presión barométrico actual.
Base A solution that has an excess of OH ions, also called an alkali. Also the center layer of a bipolar transistor.
Base Una solución que tiene un exceso de iones del OH, también llamada un álcali. También la capa central de un transistor bipolar.
Base ignition timing The point where the ignition timing is set when the engine is static.
Tiempo de encendido base El punto en donde se ajusta el tiempo de encendido cuando el motor se encuentra estático.
Battery A device for storing energy in chemical form so it can be released as electricity.
Batería Un dispositivo para almacenar energía en forma química para que se pueda liberar como electricidad.
Battery cable A heavy electrical conductor used to connect a vehicle's battery to the starter motor or chassis ground.
Cable de batería Un conductor eléctrico sólido que se usa para conectar la batería de un vehículo al motor de arranque o la masa del chasís (tierra).

Battery cell That part of a storage battery made from two dissimilar metals and an acid solution. A cell stores chemical energy for use later as electrical energy.
Célula de batería Aquella parte de una batería acumuladora hecha de dos metales desemejantes y una solución de ácido. Una célula almacena la energía química para usarse después como energía eléctrica.
Baud rate The speed of communication and is equal to the number of bits per second that a computer can process.
Velocidad de baudios La velocidad de comunicación y es igual al número de bits por segundo que puede procesar una computadora.
BDC Bottom dead center, position of the piston.
BDC Punto muerto exterior, posición del pistón.
Bead The edge of a tire's sidewall, usually made of steel wires wrapped in rubber, used to hold the tire to the wheel.
Ceja La extremidad del refuerzo lateral de un neumático, suele ser hecho de alambres de acero cubiertos en caucho, que sujeta el neumático a la rueda.
Bearing Soft metallic shells used to reduce friction created by rotational forces.
Cojinete Una pieza hueca de metal blanda que sirve para reducir la fricción creada por las fuerzas giratorias.
Bearing clearance The amount of space left between a shaft and the bearing surface for lubricating oil to enter.
Holgura del cojinete La cantidad del espacio que se deja entre la flecha y la superficie portante por la cual entra el lubricante.
Bearing crush The process of compressing a bearing into place as the bearing cap is tightened.
Aplastamiento del cojinete El proceso de colocar un cojinete comprimiéndolo cuando se aprieta la tapa del cojinete.
Bearing race The machined circular surface of a bearing against which the roller or ball bearings ride.
Pista del cojinete La superficie circular maquinada del cojinete en la cual ruedan los rodillos o bolas.
Bearing spread The condition in which the distance across the outside parting edges of the bearing insert is slightly greater than the diameter of the housing bore.
Aplastamiento del cojinete La condición en la cual la distancia de las extremidades exteriores de la pieza inserta del cojinete es un poco más grande que el diámetro de la caja.
Bell housing A term often used for clutch housing.
Cárter del embrague Un término que se usa con frecuencia para la caja del embrague.
Belleville spring A round, slightly cone-shaped disc used to return a hydraulic piston in a clutch assembly to a static, unapplied position.
Resorte Belleville o resorte de presión Disco redondo, ligeramente cónico, usado para regresar un pistón hidráulico en un ensamble de embrague a la posición estática, posición no aplicada.
Belt alternator starter (BAS) A combination motor/generator that is driven by the engine's crankshaft via a drive belt. It replaces both the engine's alternator and starter motor.
Arrancador de alternador de banda (BAS) Combinación de motor/generador que maneja el cigüeñal, por medio de la banda de transmisión. Reemplaza tanto al alternador del motor como al motor del arrancador.
Bias A diagonal line of direction. In relationship to tires, bias means that belts and plies are laid diagonally or crisscrossing each other.
Bies Una línea de dirección diagonal. Perteneciente a los neumáticos, bies quiere decir que las bandas y los pliegues se colocan diagonalmente y se cruzán entre sí.
Binary code A series of numbers represented by 1s and 0s or offs and ons.
Código binario Una serie de números representados por los 1s y los 0s o por apagado y prendido.
Biodiesel fuels A biodegradable fuel for use in diesel engines. It is produced with organically derived oils or fats. It may be used as a replacement for, or as a component of, diesel fuel.
Combustibles biodiésel Combustible biodegradable para usar en motores diésel. Se produce a partir de derivados del petróleo o grasas en forma organic. Puede utilizarse como reemplazo o como un componente del combustible diésel.
Bit One character of binary code.
Bit Un carácter del código binario.
Bleeding The process of removing air from a closed hydraulic system.
Purga El proceso de eliminar el aire de un sistema hidráulico cerrado.
Bloodborne pathogens Pathogenic microorganisms that are present in human blood and can cause disease. These pathogens include, but are not limited to, hepatitis B virus (HBV) and human immunodeficiency virus (HIV).
Patógenos transmisibles por sangre Microorganismos patógenos que están presentes en la sangre humana y pueden causar enfermedades. Estos patógenos incluyen, pero no están limitados a, virus de hepatitis B (HBV) y virus de inmunodeficiencia humana (HIV).
Blowby The unburned fuel and products of combustion that leak past the piston rings and into the crankcase during the last part of the combustion stroke.
Fuga El combustible no consumido y los productos de la combustión que se escapan alrededor de los anillos de los pistones y entran al cárter en las últimas etapas de la carrera de combustión.
Bolt diameter The measurement across the major diameter of a bolt's threaded area or across the bolt shank.
Diámetro del perno La medida del diámetro mayor de la parte fileteada de un perno o atravéz del asta del perno.
Bolt head The part of a bolt that the socket or wrench fits over in order to torque or tighten the bolt.
Cabeza del perno La parte del perno sobre la cual se pone el dado o la llave para apretar o torcer al perno.
Bolt shank The smooth area on a bolt from the bottom surface of the head to the start of the threads.
Vástago del perno El área lisa de un perno, desde la superficie inferior de la cabeza hasta donde empiezan las ranuras de rosca.
Boot Rubber protective cover with accordion pleats used to contain lubricants and exclude contaminating dirt, water, and grime. Located at each end of rack and pinion assembly and front-wheel-drive CV joints.
Protectores de caucho Una cubierta protectora hecho de caucho que tiene pliegues estilo acordión que sirve para contener las lubricantes y prevenir la entrada de los contaminantes como el lodo, el agua y el mugre. Se ubican en cada extremidad de la asamblea de piñon y cremallera.
Bore A dimension of cylinder size representing the diameter of the cylinder.
Diámetro del orificio Una dimensión de tamaño del cilindro que representa el diámetro del cilindro.
Bottom dead center (BDC) A common term used to denote with the piston of a cylinder is the farther it can be in its bore.
Punto muerto inferior (BDC) Un término común que se utiliza para denotar cuando el pistón de un cilindro se encuentra en la parte más baja de su recorrido.
Brake band A circle-shaped part lined with friction material that acts as a brake or holding device to stop and hold a rotating drum that has a gear train member connected to it.
Banda de freno Una parte circular recubierta con materia fricativa que sirve para frenar o como un dispositivo de asir para detener y sostener un tambor giratorio al cual está conectado un miembro del tren de engrenaje.
Brake booster A vacuum or hydraulic device used to increase the pressure applied to the plunger in the master cylinder. It lessens the amount of pressure that must be applied to the brake pedal and increases the responsiveness of the brake system.
Reforzador del freno Un dispositivo hidráulico o de vacío que se utiliza para aumentar la presión aplicada al émbolo en el cilindro maestro. Reduce la cantidad de presión que debe aplicarse al pedal del freno y aumenta la capacidad de respuesta del sistema de frenos.
Brake drum A bowl-shaped cast-iron housing against which the brake shoes press to stop its rotation.
Tambor de freno Un alojamiento de hierro colado en forma de tazón contra el que se oprimen las zapatas de los frenos para detener su rotación.
Brake fade Occurs when friction surfaces become hot enough to cause the coefficient of friction to drop to a point where the application of severe pedal pressure results in little actual braking.
Amortiguamiento de frenar Ocurre cuando la superficie de fricción se sobrecalienta al punto de causar que caiga el coeficiente de fricción a tal punto que la aplicación de presión riguroso en el pedal de frenos resulta en muy poco enfrenamiento.

Brake fluid A hydraulic fluid used to transmit force through brake lines. Brake fluid must be noncorrosive to both the metal and rubber components of the brake system.

Líquido para frenos Un líquido hidráulico que se usa para transmitir potencia por las líneas de frenos. Dicho líquido debe ser no corrosivo para los componentes tanto metálicos como de caucho del sistema de frenos.

Brake pads The part of a disc brake system that holds the linings.

Tacos de presión Las piezas de un sistema de frenado que sostienen las guarniciones (balatas).

Brake rotor Disc-shaped component that revolves with hub and wheel. The lining pads are forced against the rotor to provide a friction surface for the brake system, so as to slow or stop a vehicle.

Rotor de freno Componente en forma de disco que gira con el cubo y la rueda.

Brake shoe The metal assembly onto which the frictional lining is attached for drum brake systems.

Zapata de freno El ensamblaje metálico sobre el que se sujeta la guarnición de fricción (balata) para los sistemas de freno de tambor.

Break-in The specific procedures for running an engine after it has been rebuilt to prevent engine damage and to insure good initial oil control and long engine life.

Ablande Los procedimientos específicos para operar un motor después de reconstruirlo para evitar dañarlo y asegurar un buen control de aceite inicial, además de una larga vida útil del motor.

British thermal unit (Btu) A measurement of the amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit.

Unidad térmica británica Una medida de la cantidad del calor que se requiere para aumentar la temperatura de 1 libra de agua por 1 grado fahrenheit.

BTDC Before top dead center, position of the piston.

BTDC Antes del punto muerto interior Una posición del pistón.

Bump steer Erratic steering that is caused from rolling over bumps, cornering, or heavy braking; same as orbital steer and roll steer.

Dirección de choques La dirección errática que se causa al pasar por encima de los topes, a dar la vuelta, o en el enfrenamiento violento; quiere decir lo mismo que la dirección orbital y la dirección de inclinación.

Burnish To smooth or polish with a sliding tool under pressure.

Bruñir Pulir o suavizar por medio de una herramienta deslizandola bajo presión.

Byte A group of individual characters of binary code.

Byte Grupode caracteres individuales del código binario.

CAFE standards Law requiring automakers to not only manufacture clean-burning engines but also to equip vehicles with engines that burn gasoline efficiently.

Normas CAFE La ley requeriendo que los fabricantes de automóviles no sólo fabrican los motores de combustión limpia sino que tambien equipan los vehículos con los motores que consumen la gasolina en una manera eficiente.

Caliper Major component of a disc brake system. Houses the piston(s) and supports the brake pads.

Articulación Uno de los componentes principales de un sistema de freno de disco. Contiene el o los pistones y sostiene los tacos de presión.

Cam follower The device that moves with the camshaft in an overhead camshaft engine to transmit the movement of the cam lobes to the valve train. The name is often applied to a valve lifter.

Leva de guía El dispositivo que se mueve con el árbol de levas en un motor con árbol de levas a la cabeza para transmitir el movimiento de las levas del ruptor al tren de válvulas. Este nombre se aplica comúnmente a un elevador de válvula.

Camber The attitude of a wheel and tire assembly when viewed from the front of a car. If it leans outward, away from the car at the top, the wheel is said to have positive camber. If it leans inward, it is said to have negative camber.

Camber (comba) La actitud de una asamblea de la rueda y el neumático al verse desde la frente del coche. Si se inclina hacia afuera, se dice que la rueda tiene una comba positiva. Si se inclina hacia el interior, se dice que tiene una comba negativa.

Camshaft The component in the engine that opens and closes the valves.

Árbol de levas El componente en el motor que abre y cierra las válvulas.

CAN (Controller Area Network) Bus A commonly used multiplexing protocol for serial communication. The communication wire is a twisted-pair wire.

CAN (Controlador de área de red) Bus Protocolo multiplexado comúnmente usado para comunicación serial. El cable de comunicación es un cable conductor doble retorcido.

Candlepower A measurement of the brightness of light.

Unidad de intensidad luminosa Una medida del brillantez de la luz.

Capacitance The unit of measure for a capacitor's ability to store an electric charge.

Capacitancia La unidad de medida de la habilidad de un capacitor para almacenar una carga eléctrica.

Capacitance test A test used to measure a battery's ability to store an electric charge by measuring its capacitance.

Prueba de capacitancia Una prueba que se utiliza para medir la habilidad de una batería de almacenar una carga eléctrica mediante la medición de su capacitancia.

Capacitor A device for holding and storing a surge of current.

Capacitor Un dispositivo que sostiene y almacena una sobretensión de corriente.

Carbon dioxide (CO_2) Compressed into solid form, this material is known as dry ice and remains at a temperature of −109°. It goes directly from a solid to a vapor state.

Anhídrido carbónico Comprimido para formar un sólido, esta materia se conoce como hielo seco y sostiene una temperatura de 2109°F. Va directamente del estado sólido a un vapor.

Carbon monoxide (CO) Poisonous gas formed in engine exhaust.

Óxido de carbono Un gas venenoso producido en el escape de un motor.

Carburizing A method used to surface-harden steel by heat or mechanical means to increase the hardness of the outer surface while leaving the core relatively soft.

Carburación Un método usado para endurecer la superficie del acero por el calor o medios mecánicos para aumentar la dureza de la superficie externa mientras que deja la base relativamente suave.

Case harden To harden the surface of steel.

Cementar Endurecer la superficie del acero.

Caster Angle formed between the kingpin axis and a vertical axis as viewed from the side of the vehicle. Caster is considered positive when the top of the kingpin axis is behind the vertical axis.

Ángulo de caster El ángulo formado entre la linea de pivote y un eje vertical al verse del lado del vehículo. El caster se considera positivo cuando la extremidad superior de la línea de pivote es atrás del eje vertical.

Catalyst A compound or substance that can speed up or slow down the reaction of other substances without being consumed itself. In an automatic catalytic converter, special metals (e.g., platinum or palladium) are used to promote more complete combustion of unburned hydrocarbons and a reduction of carbon monoxide.

Agente catalítico Una compuesta o una substancia que puede acelerar o retardar la reacción de otras substancias sin ser consumida. En un convertidor catalítico automático, se usan metales especiales (por ejemplo, el platino y el paladio) para promover la combustión completa del hidrocarburo sobrante y para reducir el óxido de carbono.

Catalytic converter An emission device located in front of the muffler in the exhaust system. It looks very much like a heavy muffler and contains catalysts to clean up an engine's emissions before they leave the end of the exhaust pipe.

Convertidor catalítico Un dispositivo de emisiones ubicado en la parte delantera del silenciador en el sistema del escape. Se parece mucho a un silenciador de trabajo pesado y contiene loscatalizadores para limpiar las emisiones del motor antes de que salgan del tubo de escape.

Category 3 & 4 (CAT III and IV) Classifications of test equipment. Meters classified as CAT III or CAT IV are required for testing electric drive vehicles because of the high-voltages, three-phase current, and the potential for high transient voltages.

Categoría 3 & 4 (CAT III y IV) Las clasificaciónes de los equipos de prueba. Se requieren medidores clasificados como CAT III o CAT IV para probar vehículos impulsados eléctricamente debido a los altos voltajes, la corriente trifásica y el potencial de altos voltajes de transición.

Caustic Something that causes corrosion.
Cáustico Algo que causa la corrosión.
Center link A steering linkage component connected between the pitman and idler arm.
Varilla central Un componente de enlace de dirección que conecta entre el brazo Pitman y el brazo loco.
Center of gravity The point about which the weight of a car is evenly distributed; the point of balance.
Centro de gravedad El punto en el cual el peso del coche es distribuido en una manera uniforme; el punto del equilibrio.
Centrifugal force A force tending to pull an object outward when it is rotating rapidly around a center.
Fuerza centrífuga Una fuerza que tiene la tendencia de jalar un objeto hacia afuera cuando éste gira rápidamente alrededor de un punto central.
Centripetal force A force that acts on something and keeps it in a circular motion by pulling it toward the center of the circle.
Fuerza centrípeta Una fuerza que actua sobre algo y lo mantiene moviendo circularmente tirandolo hacia el centro del círculo.
Cetane rating (CN) The rating used to measure a diesel fuel's ignition quality. The higher the cetane number, the shorter the ignition lag time from the point the fuel enters the combustion chamber until it ignites.
Cetano Usado para medir la calidad de arranque de un combustible diesel. Mientras más alto el índice de cetano, más corto es el tiempo de demora entre el momento en que el combustible entra a la cámara de combustión y el momento en que enciende.
Chatter A shaking or shuddering that is felt when the clutch or other device is engaged.
Chasquido Un temblor o sacudida que se siente al accionar el embrague u otro dispositivo.
Check ball valve A valve that allows fluid or air flow in one direction but not in the opposite direction.
Válvula esférica de retención Una válvula que permite el flujo de líquido o aire en una dirección, pero no en dirección opuesta.
Chlorofluorocarbon (CFC) CFCs are depleting the protective ozone layer through a chemical reaction.
Clorofluorocarburo Compuesto que está agotando la capa protectora de ozono mediante una reacción química.
Chamfer A bevel or taper at the edge of a hole.
Chaflán Un bisel o ahusamiento en la orilla de un hoyo.
Chamfering The process of removing the sharp edges around a bore or hole.
Achaflanar El proceso de quitar las orillas afiladas alrededor de un orificio o un hoyo.
Charcoal canister A small plastic or steel container filled with activated charcoal that can store gasoline vapors until the right time for them to be drawn into the engine and burned.
Bote de carbón vegetal Un pequeño recipiente de plástico o acero, lleno de carbón activado, que puede almacenar vapores de gasolina hasta el momento adecuado para su introducción al motor y su combustión.
Chase To straighten or repair damaged threads.
Embutir Enderezar o reparar los filetes dañados.
Chassis ground The use of the vehicle's frame and/or body as a common connection to the negative terminal of a battery.
Tierra de chasis El uso del marco y/o el cuerpo del vehículo como una conexión común a la terminal negativa de la batería.
Check valve A gate or valve that allows passage of gas or fluid in one direction only.
Válvula de seguridad Una válvula que permite fluir la presión en un sólo sentido.
Chemical cleaning Cleaning that relies primarily on some type of chemical action to remove dirt, grease, scale, paint, or rust.
Limpieza química La limpieza que cuenta primariamente con la acción química para remover el lodo, la grasa, las incrustaciones, la pintura, o los óxidos.
Circuit breaker A circuit protection device that opens when excessive current is present in its circuit.
Interruptor de circuito Un dispositivo de protección de circuitos que se abre cuando hay corriente excesiva en su circuito.
Clamping diode A special diode used to prevent voltage spikes. It is typically installed in parallel to a coil, creating a bypass for the electrons during the time the circuit is opened.
Diodo de fijación Diodo especial usado para prevenir picos de voltaje. Por lo general, se instala paralelo a un serpentín creando así una desviación para los electrones durante el tiempo que durante el que el circuito permanece abierto.
Clockspring A conductive ribbon in a plastic case mounted on top of the steering column that maintains electrical contact between the air bag inflator module and the air bag electrical system.
Resorte de la bolsa de aire Un listón conductor en una caja de plástico montada sobre la columna de dirección que mantiene contacto eléctrico entre el módulo inflador de la bolsa de aire y el sistema eléctrico de la bolsa de aire.
Closed circuit An electrical circuit that has a completed path from the negative of the battery to the positive terminal.
Circuito cerrado Un circuito eléctrico que ha completado el recorrido desde el borne negativo de la batería hasta el borne positivo.
Closed loop An electronic feedback system in which the sensors provide constant information on what is taking place in the engine.
Bucle cerrado Un sistema de reacción electrónico en el cual los detectores proveen información constante de lo que está pasando en el interior del motor.
Clutch An electromechanical device mounted on the air-conditioning compressor used to start and stop compressor action, thereby controlling refrigerant circulating through the system.
Embrague Un dispositivo electromecánico montado en el compresor del aire acondicionado, utilizado para comenzar y detener la acción del compresor, regulando así la circulación del refrigerante a través del sistema.
Cluster gear A one-piece machined gear assembly containing first, second, third, and fourth counter gears.
Bloque de engranajes Un conjunto de engranajes maquinado en una sola pieza que contiene el primer, segundo, tercer y cuarto engranaje intermedio.
Clutch disc The part of a clutch that receives the driving motion from the flywheel and pressure plate assembly and transmits that motion to the transmission input shaft.
Disco del embrague La parte de un embrague que recibe el movimiento propulsor del volante y la asamblea del plato opresor y transmite esa acción a la flecha de entrada de la transmisión.
Clutch fork A forked lever that moves the clutch release bearing and hub back and forth.
Horquilla del embrague Una palanca bifurcada que mueve al balero collarín del embrague hacia afrente y hacia atrás.
Clutch release bearing A sealed, prelubricated ball bearing that moves the pressure plate release levers or diaphragm spring through the engagement and disengagement process.
Collarín del embrague Un cojinete esférico, prelubricado y sellado, que mueve las palancas de liberación del plato opresor o el resorte diafragma por medio del proceso del enganche y el desenganche.
Coefficient of friction (COF) A relative measurement of the friction developed between two objects in contact with each other.
Coeficiente de la fricción La medida relativa de la fricción que ocurre entre dos superficies que estan en contacto la una con la otra.
Coil-over-plug (COP) An ignition design that places an individual ignition coil over each spark plug.
Encendido individual (COP) Un diseño de encendido que coloca una bobina de encendido individual sobre cada bujía.
Coil pack The name commonly used to describe the assembly of multiple ignition coils on an engine with distributorless ignition.
Paquete de bobinas Término utilizado normalmente para describir el conjunto de varias bobinas en un motor con encendido sin distribuidor.
Cold cranking amps (CCA) A common method of rating most automotive starting batteries. This rating is based on the load in amperes that a battery is able to deliver for 30 seconds at 0°F (–17.7°C) without its voltage dropping below a predetermined level.
Amperes de arranque en frío (AAF) Método común para medir la mayoría de las baterías de arranque. Esta medición se basa en la carga, en amperes, que puede entregar una batería durante 30 segundos a 0°F (–17.7 °C) sin que su voltaje caiga más abajo de un nivel preestablecido.

Collector The portion of a bipolar transistor that receives the majority of electrical current.

Colector La porción de un transistor bipolar que recibe la mayoría del corriente eléctrico.

Combination valve An H-valve, used in some early air-conditioning systems, combining a suction throttling valve and an expansion valve.

Válvula combinada Una válvula en H utilizada en algunos sistemas iniciales de climatización (aire acondicionado), que combina una válvula reguladora de succión y otra de expansión.

Combustion Rapid oxidation with the release of energy in the form of heat and light.

Combustión Oxidación rápida, con liberación de energía en la forma de calor y luz.

Combustion chamber The space between the top of a piston and the cylinder head where the engine's combustion takes place.

Cámara de combustión El espacio entre la parte superior del pistón y la cabeza del cilindro en donde se lleva acabo la combustión.

Commission A common pay plan for technicians in which technicians are paid a minimum, hourly wage plus a percentage of what the shop received from the customer for performing various services.

Comisión Un plan de pago común para los técnicos, en donde se les paga un sueldo por horas mínimo más un porcentaje de lo que reciba el taller del cliente por realizar una variedad de servicios.

Common rail (CR) injection A fuel injection system that holds the fuel in an assembly before it is injected into the cylinder. Late model diesel engines use this injection system.

Inyección directa (CR) Un sistema de inyección de combustible que mantiene el combustible en un ensamble antes de inyectarlo en el cilindro. Los motores diesel más recientes usan este sistema de inyección.

Commutator An assembly is made up of heavy copper segments separated from each other and the armature shaft by insulation. Individual segments are connected to the individual windings in the armature. Brushes ride on the surface of the commutator.

Conmutador Un conjunto que consta de segmentos de cobre pesado separados entre sí y del eje del rotor mediante aislamiento. Los segmentos individuales están conectados a los bobinados individuales del rotor. En la superficie del conmutador hay escobillas.

Compound A mixture of two or more ingredients.

Compuesta Una mezcla de dos o más ingredientes.

Compound motor A type of electric motor in which the field coils and armature are connected by series and shunt wiring. These motors combine the characteristics of good starting torque with constant speed.

Motor compuesto Un tipo de motor eléctrico en el que las bobinas de campo y el rotor se conectan mediante cables en serie y en derivación. Estos motores combinan las características de un buen torque de arranque con una velocidad constante.

Compressed natural gas (CNG) Natural gas that has been condensed by high pressure, typically between 2,000 and 3,600 pounds per square inch.

Gas natural comprimido (CNG) Gas natural que se condensa mediante alta presión, por lo general entre 2,000 y 3,600 libras por pulgada cuadrada.

Compression The act of reducing volume by pressure.

Compresión La acción de reducir el volumen por efectos de la presión.

Compression ratio The ratio of the volume in the cylinder above the piston when the piston is at bottom dead center to the volume in the cylinder above the piston when the piston is at top dead center.

Relación índice de compresión La relación del volumen en el cilindro arriba del pistón cuando el pistón está en el punto muerto inferior al volumen en el cilindro arriba del pistón cuando el pistón está en el punto muerto superior.

Compression stroke The second stroke of the four-stroke engine cycle, in which the piston moves from bottom dead center and the intake valve closes. This traps and compresses the air-fuel mixture in the cylinder.

Carrera de compresión La segunda carrera de un ciclo de un motor de cuatro tiempos, en la cual el pistón mueve del punto muerto inferior y se cierre la válvula de admisión. Esto encierre y comprime la mezcla de aire-combustible en el cilindro.

Compressor A driven device that increases the pressure of a gas or air.

Compresor Un dispositivo impulsado que aumenta la presión de un gas o del aire.

Concentric Two or more circles having a common center.

Concéntrico Dos círculos o más que comparten un centro común.

Condensation The process of a vapor becoming a liquid; the reverse of evaporation.

Condensación El proceso por el cual un vapor se convierte en un líquido; lo opuesto de la evaporación.

Condense To cool a vapor to below its boiling point. The vapor condenses into a liquid.

Condensar El proceso de enfriar un vapor a una temperatura más baja de su punto de ebullición. El vapor condensa, formando un líquido.

Condenser A capacitor made from two sheets of metal foil separated by an insulator.

Condensador Es un capacitador construido de dos láminas de metal separadas por un aislante.

Conductance test A test that measures conductance and provides a reliable indication of a battery's condition and is correlated to battery capacity. Conductance can be used to detect cell defects, shorts, normal aging, and open circuits, which can cause the battery to fail.

Prueba de conductancia Prueba que mide la conductancia y proporciona una indicación confiable de la condición de una batería y se correlaciona a la capacidad de la batería. La conductancia puede ser usada para detectar defectos, cortocircuitos, edad normal, y circuitos abiertos, que pueden hacer que la batería falle.

Conduction The movement of heat through a material.

Conducción El movimiento de calor a través de un material.

Conductive charging The type of fuel cell used by NASA. These cells use a water-based solution of potassium hydroxide (KOH) as the electrolyte and electrodes coated with a catalyst.

Carga conductiva Un tipo de pila de combustible utilizada por la NASA. Estas celdas usan una solución basada en agua con hidróxido de potasio (KOH) como electrólito, y electrodos cubiertos con un catalizador.

Conductor A device that readily allows for current flow.

Conductor Un dispositivo que permite fácilmente el flujo del corriente.

Connecting rod The link between the piston and crankshaft.

Biela La acoplación entre el pistón y la cigüeñal.

Continuously variable transmission (CVT) A transmission that automatically changes torque and speed ranges without requiring a change in engine speed. A CVT is a transmission without fixed forward speeds.

Transmisión continua variable (TCV) Transmisiones que automáticamente cambian de rangos de torque y velocidad sin requerir un cambio en la velocidad del motor. Una TCV es una transmisión sin velocidades delanteras fijas.

Continuity A term used to describe the presence of a completed circuit between two points.

Continuidad Término usado para describir la presencia de un circuito completo entre dos puntos.

Contraction A reduction in mass or dimension; the opposite of expansion.

Contracción Una reducción en la masa o en la dimensión; lo opuesto de la expansión.

Control arms Suspension parts that control coil spring action as a wheel is affected by road conditions.

Palanca de comando Las partes de suspención que controlan la acción del muelle de control al afectarse una rueda por las condiciones de la carretera.

Convection The transfer of heat by the movement of a heated object.

Convección El transferimiento de calor a través del movimiento de un objeto que ha sido calentado.

Coolant A mixture of water and ethylene glycol-based antifreeze that circulates through the engine to help maintain proper temperatures.

Fluido refrigerante Una mezcla del agua con el anticongelante a base de glicol etileno que circula por el motor y ayuda en mantener las temperaturas indicadas.

Cords The inner materials running through the plies that produce strength in the tire. Common cord materials are fiberglass and steel.

Cuerdas Las materiales interiores recorriendo por los pliegues que producen la solidez del neumático. Las materiales más comunes para las cuerdas son la fibra de vidrio y el acero.

Core The center of the radiator, made of tubes and fins, used to transfer heat from the coolant to the air.

Núcleo El centro de un radiador, hecho de tubos y aletas, que sirve para transferir el calor del líquido refrigerante a la atmósfera.

Corporate Average Fuel Economy Different models from each manufacturer are tested for the number of miles they can be driven on a gallon of gas. The fuel efficiencies of these vehicles are averaged together to arrive at a corporate average.

Estándar Promedio Empresarial de Ahorro de Combustible Se ponen a prueba distintos modelos de cada fabricante para determinar el número de millas que pueden recorrer con un galón de combustible. El promedio empresarial es el promedio de la eficiencia de combustible de estos vehículos.

Core plug A plug used to seal openings where necessary for casting the object in a cast structure.

Tapón del núcleo Un tapón diseñado para sellar las aperturas necesarias para fundar el objeto en un molde.

Corrosivity The characteristic of a material that enables it to dissolve metals and other materials or burn the skin.

Corrosidad La característica de una materia que permite que disuelva a los metales u otras materias o quema la piel.

Counter EMF (CEMF) A force that is created in a rotating armature. The faster the armature spins, the more induced voltage is present in the armature. The induced voltage opposes, or is counter to, the battery's voltage. This limits the current following through the armature windings.

Contra EMF (CEMF) Fuerza que se crea en una armadura giratoria. Mientras más rápido gira la armadura, mas voltaje inducido está presente en la armadura. El voltaje inducido se opone, o es contrario al voltaje de la batería. Esto limita la corriente a través de los devanados de la armadura.

Countershaft Often referred to as the cluster gear assembly and is a one-piece machined unit containing first, second, third, and fourth counter gears.

Eje intermedio auxiliar A menudo se conoce como el conjunto de engranajes y es una unidad maquinada de una sola pieza que contiene el primer, segundo, tercer y cuarto engranaje intermedio.

Counterweight Weight forged or cast into the crankshaft to reduce vibration.

Contrapeso Un peso que se ha forjado o colado al cigueñal para reducir la vibración.

Coupling point Point in torque converter operation where the turbine speed is 90 percent of impeller speed and there is no longer any torque multiplication.

Punto de acoplamiento Punto en la operación del conversor de torque en donde la velocidad de la turbina es del 90% de la velocidad del impulsor y ya no hay multiplicación de torque.

Crank pin The machined, offset area of a crankshaft where the connecting rod journals are machined.

Espiga de manívela La superficie maquinada, descentrada de un cigueñal en donde los muñones de la biela se maquinan.

Crank throw The distance from the crankshaft main bearing centerline to the connecting rod journal centerline. The stroke of any engine is the crank throw.

Carrera La distancia del eje de quilla del cojinete principal del cigueñal al eje de quilla del muñon de la biela. Una carrera del pistón de cualquier motor es una carrera.

Cranking amps (CA) rating A method of rating automotive starting batteries. This rating is based on the load in amperes that a battery is able to deliver for 30 seconds at 32°F (0°C) without its voltage dropping below a predetermined level.

Tasa de amperes de arranque en frío (CA) Método que consiste en medir baterías automotrices de arranque. Esta tasa se basa en la carga, en amperes, que una batería puede entregar durante 30 segundos a 32°F (0°C) sin que su voltaje caiga más abajo de un nivel predeterminado.

Crankshaft A rotating component mounted in the lower side of the block that changes vertical piston motion to rotary motion.

Cigüeñal Un componente giratorio montado en la parte inferior del bloque que convierte el movimiento vertical del pistón en movimiento giratorio.

Crankshaft position (CKP) sensor A sensor that monitors the motion of the pistons and the rotation of the crankshaft. It electronically tracks the position of the crankshaft and relays that information to an ignition control module.

Sensor de posición del cigüeñal (CKP) Un sensor que monitorea el movimiento de los pistones y la rotación del cigüeñal. Rastrea en forma electrónica la posición del cigüeñal y transmite esa información a un módulo de control de encendido.

Crimp The use of pressure to force a thin holding part to clamp to, or conform to the shape of, a part so it cannot move.

Engarzar El uso de la presión en forzar una parte delgada de sujeción para agarrar, o conformar a la forma de, una parte sujetada.

Critical thinking The art of being able to judge or evaluate something without bias or prejudice.

Pensamiento crítico El arte de poder juzgar o evaluar algo sin predisposición o prejuicio.

Cross counts The number of times that the O_2 voltage signal changes above or below 0.45 volt in a second.

Cuentas cruzadas Número de veces que la señal O_2 del voltaje cambia arriba o debajo de 0.45 voltios en un segundo.

Cross groove joint A CV joint that uses six balls and inner and outer bearing races. The grooves in the races are cut on an angle.

Junta de ranura transversal Una junta homocinética que usa seis bolas y pistas de cojinete exteriores e interiores. Las ranuras en los canales de rodamiento se cortan en ángulo.

Crude oil The natural state of oil as it is pulled from the earth and before it is refined.

Aceite crudo El estado natural del aceite cuando sale de la tierra y antes de que sea refinado.

Curb weight The weight of the vehicle when it is not loaded with passengers or cargo.

Peso en vacío Peso del vehículo cuando no está cargado con pasajeros o carga.

Cup seal A circular rubber seal with a depressed center section surrounded by a raised sealing lip to form a cup. Cup seals often are used on the front ends of hydraulic cylinder pistons because they seal high pressure in the forward direction of travel but not in the reverse.

Sello de copa Un sello de goma circular con una sección central oprimida rodeado por un borde de sellado levantado en forma de copa. Los sellos de copa se utilizan con frecuencia en los extremos delanteros de los pistones de cilindros hidráulicos porque sellan la alta presión en la dirección normal del recorrido, pero no en sentido inverso.

Current The number of electrons flowing past a given point in a given amount of time.

Corriente El número de los electronos que fluyen al través de un punto específico en un dado periódo del tiempo.

Cutpoint The report from an I/M 240 test that shows the amount of gases emitted during the different speeds and loads of the test. It also shows the average output for each of the gases and the cutpoint, which is the maximum allowable amount of each gas.

Punto de corte Informe de una prueba I/M 240 que indica la cantidad de gases emitida durante las diferentes velocidades y cargas de la prueba. También indica el promedio de salida para cada uno de los gases y el punto de corte, la cantidad máxima permitida de cada gas.

CV joint Constant velocity joint. A flexible coupling between two shafts that permits each shaft to maintain the same driving or driven speed regardless of operating angle, allowing for a smooth transfer of power. The CV joint consists of an inner and outer housing with balls in between or a tripod and yoke assembly.

Junta homocinética Junta de velocidad constante: un acoplamiento flexible entre dos ejes que permite que la velocidad entre ellos sea constant en todo momentosin importar el ángulo de operación, lo cual permite una transferencia regulada de la energía. La velocidad constante consiste de una carcasa interna y externa con balines en el medio o un ensamble de trípode y horquilla.

Cycling clutch An air-conditioning design that controls the output of the system by cycling the compressor's clutch.
Embrague cíclico Un diseño de aire acondicionado que controla la salida del sistema mediante la operación del embrague del compresor en ciclos.
Cylinder A circular tubelike opening in a compressor block or casting in which the piston moves up and down or back and forth; a circular drum used to store refrigerant.
Cilindro Una apertura circular parecida a un tubo en un bloque del compresor o una pieza en los que el pistón se mueve de arriba hacia abajo o de un lado a otro; un tambor circular utilizado para el almacenaje de anticongelante.
Cylinder block A large casting of metal (cast iron or aluminum) that is drilled with holes to allow for the passage of lubricants and coolant through the block and provide spaces for movement of mechanical parts. The block contains the cylinders, which are round passageways fitted with pistons. The block houses or holds the major mechanical parts of the engine.
Bloque de cilindros Una fundición grande de metal (hierro fundido o aluminio) perforada con orificios para permitir el paso de lubricantes y refrigerante a través del bloque y proveer espacios para el movimiento de piezas mecánicas. El bloque contiene los cilindros, que son pasajes redondos que contienen pistones. El bloque aloja o contiene las piezas mecánicas principales del motor.
Cylinder head On most engines the cylinder head contains the valves, valve seats, valve guides, valve springs, and the upper portion of the combustion chamber.
Cabeza de los cilindros En la mayoría de los motores, la cabeza de los cilindros contiene las válvulas, asientos de las válvulas, sus guías, sus resortes y la parte superior de la cámara de combustión.
Cylindrical cell A type of electrochemical cell in which the electrodes are rolled together and fit into a metal cylinder. A separator soaked in an electrolyte is placed between the plates.
Célula cilíndrica Un tipo de célula electroquímica en la cual los electrodos están enrollados juntos y caben en un cilindro de metal. Un separador empapado en un electrolito se coloca entre las placas.
Dampen To slow or reduce oscillations or movement.
Amortiguar Retardar o reducir las vibraciones o el movimiento.
Dampers A common name for shock absorbers.
Amortiguadores Un nombre común para las piezas que absorben los impactos.
Data link connector (DLC) This is the connector used to connect into a vehicle's computer system for the purpose of diagnostics. Prior to J1930 this was commonly referred to as the ALDL.
Conector de enlace de datos (DLC) El conector de enlace de datos. Es el conector utilizado para conectarse al sistema de computadora de un vehículo y realizar diagnósticos. Antes de J1930, se le conocía comúnmente como ALDL.
Daytime running lights (DRLs) Mandated on all vehicles in Canada and standard on some vehicles for the U.S., these headlamps are always on but with reduced brightness.
Luces de circulación diurna (DRL) Obligatorias en todos los vehículos en Canadá y estándar en algunos vehículos de Estados Unidos, estas luces delanteras siempre están encendidas pero con un brillo reducido.
Dead axle An axle that does not rotate but merely forms a base on which to attach the wheels.
Eje muerto Un eje que no gira sino solamente forma una plataforma en la cual se puede conectar las ruedas.
Deceleration The rate of decrease in speed.
Desaceleración El índice de la disminución de la velocidad.
Deck The top of the engine block where the cylinder head mounts.
Cubierta del monoblock La parte superior de un bloque del motor en donde se conecta la culata.
Deductible Often, according to the terms of a warranty, the owner must pay a certain amount of money, called the deductible. The manufacturer pays for all repair costs over the deductible amount.
Deducible Con frecuencia, de acuerdo con los términos de una garantía, el propietario debe pagar cierta cantidad de dinero, conocida como deducible. El fabricante paga todos los costos de reparación que excedan el monto del deducible.
Deflection Bending or movement away from normal due to loading.
Desviación Curvación o movimiento fuera de lo normal debido a la carga.
Deflection angle The angle at which the oil is deflected inside the torque converter during operation. The greater the angle of deflection, the greater the amount of torque applied to the output shaft.
Ángulo de desviación El ángulo en el que se desvia el aceite en el convertidor de par durante su operación. Cuanto más el ángulo de desviación, más torsión se aplica en la flecha de potencia.
Delta winding A type of stator winding connection that connects three windings in series and has the appearance of the Greek letter delta. AC generators with delta windings are capable of putting out higher amperages.
Devanado en delta Un tipo de conexión de devanado de estator que conecta tres devanados en serie y tiene la apariencia de la letra griega delta. Los generadores de AC con devanados en delta son capaces de producir mayores amperajes.
Density Compactness; relative mass of matter in a given volume.
Densidad La firmeza; la masa relativa de la materia en un volumen indicado.
Desiccant A special substance that absorbs moisture.
Desicante Una substancia especial que absorbe la humedad.
Detergent A compound of soaplike nature used in engine oil to remove engine deposits and hold them in suspension in the oil.
Detergente Una compuesta parecida al jabón que se usa en el aceite de motor para quitar los depósitos del motor y mantenerlos suspendidos en el aceite.
Detonation As used in an automobile, indicates a hasty burning or explosion of the mixture in the engine cylinders. It becomes audible through a vibration of the combustion chamber walls and is sometimes confused with a ping or spark knock.
Detonación Aplicado al automóvil, indica una combustión apresurada o una explosión de la mezcla en los cilindros del motor. Se oye por medio de las vibraciones de los paredes de la cámara de combustión y a veces se confunde con un golpeteo o una detonación de las bujías.
Diagnosis A way of looking at systems that are not functioning properly and finding out why. It is based on an understanding of the purpose and operation of the system that is not working properly.
Diagnóstico Forma de observar los sistemas que no están funcionando adecuadamente, y averiguar el porqué. Se basa en la comprensión del propósito y la operación del sistema que no está funcionando adecuadamente.
Diagnostic trouble code (DTC) Numerical codes generated by an electronic control system to indicate a problem in a circuit or subsystem or to indicate a general condition that is out of limits.
Código diagnóstico de falla (DTC) Códigos numéricos generados por un sistema de control electrónico para indicar un problema en un circuito o subsistema, o para indicar una condición general fuera de los límites.
Dial bore gauge Tool used to determine cylinder bore size, out-of-round, and taper.
Calibrador de orificios Herramienta utilizada para determinar el tamaño del orificio de un cilindro, la deformación circunferencial y la conicidad.
Dial caliper Versatile measuring instrument capable of taking inside, outside, depth, and step measurements.
Calibre de carátula (pie de rey) Un instrumento de medir versátil que es capable de tomar las medidas interiores, exteriores, de profundidad, y de paso a paso.
Dial indicator A measuring tool used to adjust small clearances up to 0.001 inch. The clearance is read on a dial.
Calibrador de carátula Una herramienta de medida que sirve para ajustar las pequeñas holguras hasta el 0.001 de una pulgada. La holgura se lee en un cuadrante.
Diaphragm A flexible, impermeable membrane on which pressure acts to produce mechanical movement.
Diafragma Una membrana flexible e impermeable sobre la cual tiene un efecto la presión para producir un movimiento mecánico.
Die A tool used to restore external threads on a fastener.
Dado Una herramienta utilizada para restaurar las roscas externas en un sujetador.

Dielectric An insulator material.
Dieléctrico Una material de aislador.
Diesel engine An engine that relies on compression rather than electrical ignition to initiate the spark to ignite the air/fuel mixture.
Motor diesel Un motor que depende de la compresión en vez del encendido eléctrico para iniciar la chispa y encender la mezcla aire/combustible.
Differential A gear assembly that transmits power from the drive shaft to the wheels and allows two opposite wheels to turn at different speeds for cornering and traction.
Diferencial Una asamblea de engrenajes que transmite la potencia del árbol de mando a las ruedas y permite que dos ruedas opuestas giran a velocidades distinctos para ejecutar las vueltas y la tracción.
Diffusion The random movement of gas particles; also ensures that any two gases sharing the same container will totally mix.
Difusión El movimiento al azar de las partículas de gas también asegura que cualquier dos gases que comparten el mismo envase se mezclarán totalmente.
Digital A voltage signal that is pulsed on or off.
Digital Un señal del voltaje que pulsa prendida o apagada.
Digital EGR valve An EGR valve that is controlled digitally by a computer.
Válvula digital de recirculación de gases de escape (EGR) Una válvula EGR controlada en forma digital por una computadora.
Digital multimeter (DMM) A tool that combines the voltmeter, ohmmeter, and ammeter together in one diagnostic instrument and provides a digital reading.
Multímetro digital (DMM) Una herramienta que combina el voltímetro, ohmímetro y amperímetro en un solo instrumento de diagnóstico, además de proveer una lectura digital.
Dilution A thinner or weaker solution. Oil is diluted by the addition of fuel and water droplets.
Dilución Desleir o debilitar. El aceite se diluye por la agregación de las gotas del combustible o del agua.
Diode A simple semiconductor device that permits flow of electricity in one direction but not in the opposite direction.
Diodo Un dispositivo sencillo de semiconductor que permite el flujo de la electricidad en una dirección pero no en la dirección opuesta.
Direct current (DC) A type of electrical power used in mobile applications. A unidirectional current of substantially constant value.
Corriente continua Un tipo de potencia eléctrica utilizada en aplicaciones movibles. Una corriente que fluye en un solo sentido de un valor substancialmente constante.
Direct drive The downward gear engagement in which the input shaft and output shaft are locked together.
Transmisión directa El enganchamiento en descenso del engrenaje en el cual la flecha de entrada y la flecha de producción se enclavan.
Direct injection (DI) A diesel fuel injection system in which fuel is injected directly onto the top of the piston.
Inyección directa (DI) Un sistema de inyección de diesel en el cual el combustible se inyecta directamente arriba del pistón.
Direct ignition system (DIS) A distributorless ignition system in which spark distribution is controlled by the vehicle's computer.
Encendido directo Un sistema del encendido sin distribuidor en el cual la distribución de la chispa se controla por medio de la computador del vehículo.
Direct TPM A type of tire pressure monitoring system that uses sensors located in each wheel.
Sistema de control de presión de neumáticos directo Sistema de control de presión de neumáticos que emplea sensores ubicados en cada rueda.
Direct-methanol fuel cell (DMFC) A type of the PEM fuel cell that uses liquid methanol as the fuel, rather than hydrogen.
Pila de combustible de metanol directo (DMFC) Un tipo de pila de combustible PEM que usa metanol líquido como combustible, en vez de hidrógeno.
Directional stability The ability of a car to travel in a straight line with a minimum of driver control.
Estabilidad direccional La abilidad de un coche de viajar en una linea recta con control mínimo del conductor.
Disc brakes Brakes in which the frictional forces act on the faces of a disc.
Frenos de disco Frenos en los que las fuerzas de fricción se aplican sobre las caras de un disco.
Discharge line Connects the compressor outlet to the condenser inlet.
Línea de descarga La que conecta la salida del compresor a la entrada del condensador.
Discharge side An air-conditioning design that controls the output of the system by cycling the compressor's clutch.
Lado de descarga Un diseño de aire acondicionado que controla la salida del sistema accionando el embrague del compresor en ciclos.
Displacement The volume the cylinder holds between the top dead center and bottom dead center positions of the piston.
Desplazamiento (cilindrada) El volumen que contiene el cilindro entre la posiciones del punto muerto superior y el punto muerto inferior del pistón.
Distributor The mechanism within the ignition system that controls the primary circuit and directs the secondary voltage to the correct spark plug.
Distribuidor El mecanismo dentro del sistema de ignición que controla el circuito primario y dirige el voltaje secundario a las bujías correctas.
Distributor ignition (DI) system SAE J1930 terminology for an ignition system with a distributor.
Sistema de la ignición con distribuidor El término utilizado por la SAE J1930 para referirse a un sistema de la ignición que tiene un distribuidor.
DOHC Dual overhead camshaft.
DOHC Arbol de levas doble superior.
Dome Typically refers to the shape of the top of a piston.
Fondo hemisférico Típicamente se refiere al contorno de la parte superior de un pistón.
DOT U.S. Department of Transportation.
DOT Departamento de Transportes de los Estados Unidos de América.
Double wishbone A multilink suspension system in which the links may be shaped like a wishbone.
Doble horquilla Un sistema de suspensión multibrazo en el que los brazos pueden tener forma de horquilla.
Double-offset joint Another name for a plunging ball-type joint.
Junta de doble desplazamiento Otro nombre para una junta de tipo bola deslizante.
Dowel A pin extending from one part to fit into a hole in an attached part; used for both location and retention.
Espiga Una clavija que extiende de una parte para quedarse en el hoyo de otra parte conjunta; se usa para la localización y la retención.
Drive cycle The operating conditions that must exist before OBD II self-diagnosis can take place. It includes an engine start and operation that brings the vehicle into closed loop and includes whatever specific operating conditions are necessary, either to initiate and complete a specific monitoring sequence or to verify a symptom or repair.
Ciclo de manejo Las condiciones de operación que deben existir antes de que se lleve a cabo el auto diagnóstico OBD II, Incluye un arranque y operación de motor que trae al vehículo a una curva cerrada e incluye las condiciones de operación específicas necesarias ya sea para encender o terminar una secuencia de monitoreo completa o para verificar un síntoma o una reparación.
Drive member A gear that drives, or provides power for, other gears in a planetary gearset.
Miembro de ataque Un engrenaje que impulsa, o provee la potencia para los otros engrenajes en un conjunto planetario.
Drive shaft A hollow metal tube that has a universal joint at each end.
Eje motriz Un tubo metálico hueco que tiene una junta universal en cada extremo.
Driveability The degree to which a vehicle operates properly. Includes starting, running smoothly, accelerating, and delivering reasonable fuel mileage.

Manejo El punto en el cual un vehículo opera correctamente. Incluye el encendido, marchar sin averías, la aceleración y la entregada de un kilometraje económico.
Driveline windup The phenomenon that occurs when the two driving axles must rotate at different speeds, such as when the vehicle is making a turn.
Rotación del eje longitudinal de la transmisión El fenómeno que ocurre cuando los dos ejes motrices deben girar a distintas velocidades, como cuando el vehículo gira a la izquierda o a la derecha.
Drivetrain The assembly that carries the power from the engine to the drive wheels, includes the transmission (transaxle), driveline, differential and final drive gears, and axle shafts. The term used to refer to the operating conditioning in which the vehicle is accelerated with a definite application of the throttle to demand engine torque.
Tren de transmisión El conjunto que transmite la potencia del motor a las ruedas de tracción, incluye la transmisión (transeje), línea motriz, el diferencial y los engranajes del diferencial, y los ejes propulsores. El término utilizado para referirse a la condición de operación en la que el vehículo se acelera con una aplicación definida del acelerador para exigir torque del motor.
Dry sump An oil pan or sump that does not store oil. It merely seals the bottom of the crankcase.
Cárter seco Colector o recipiente que no guarda aceite. Simplemente sella la parte inferior del cárter.
Dual-mass flywheel A flywheel made with two rotating plates connected by springs and dampers. Used to smooth out crankshaft vibrations.
Volante bimasa Volante conformado por dos platos rotativos conectados por resortes y amortiguadores. Se usa para atenuar las vibraciones del cigüeñal.
Duo-servo drum brake A drum brake design with increased stopping power due to the servo or self-energizing effect of the brake.
Frenos tipo servo Un diseño de freno de tambor que tiene más potencia de enfrenar debido al servo o al efecto autoenergético del freno.
Duration The length of time something occurs or happens.
Duración La longitud de tiempo en el que algo ocurre o sucede.
Duty cycle The percentage of on-time to total cycle time of fuel injectors.
Ciclo del trabajo El porcentaje del tiempo de trabajar al tiempo del ciclo total de los inyectores del combustible.
Dwell time The degree of crankshaft rotation during which the primary circuit is on.
Ángulo de cierre El grado de rotación del cigueñal en el cual esta encendido el circuito primario.
Dynamic Refers to balance when the object is in motion.
Dinámico Refiere al balance mientras que un objeto esté en movimiento.
Dynamic balance The balance of an object when it is in motion; for example, the dynamic balance of a rotating driveshaft.
Equilibrio dinámico El equilibrio de un objeto cuando está en movimiento; por ejemplo, el equilibrio dinámico de un eje de transmisión al girar.
Dynamic pressure The pressure of a fluid while it is in motion.
Presión dinámica La presión de un líquido mientras que está en movimiento.
Dynamometer An instrument for measuring mechanical power.
Dinamómetro Un instrumento para medir el poder mecánico.
Eccentric The part of a camshaft that operates the fuel pump.
Eccéntrico La parte de un árbol de levas que opera la bomba del combustible.
Efficiency A ratio of the amount of energy put into an engine as compared to the amount of energy coming out of the engine; a measure of the quality of how well a particular machine works.
Eficiencia Una relación de la cantidad de energía que consume un motor comparado con la cantidad de energía que produce el motor; una medida de la calidad de la máquina y su marcha.
EGR Exhaust gas recirculation. The system that allows a small amount of exhaust gas to be routed into the incoming air-fuel mixture to reduce NO_x emissions.
EGR Sistema de recirculación de gas del escape. Permite que se dirija una cantidad pequeña del gas del escape a la mezcla de admisión de aire y combustible para reducir descargas (emisiones) de NO_x.
EI The J1930 acronym for a distributorless ignition system.
EI La abreviación J1930 para un sistema de la ignición sin distrubuidor.
Elasticity The principle by which a bolt can be stretched a certain amount. Each time the stretching load is reduced, the bolt returns back to its exact, original, normal size.
Elasticidad El principio por el cual un perno puede extenderse por un cierta cantidad. Cada vez que la carga tensor se reduce, el perno regresa exactamente a su tamaño normal y original.
Electrically erasable PROM (EEPROM) An electrically erasable programmable read only memory chip.
PROM que se puede borrar eléctricamente (EEPROM) Un chip de memoria de solo lectura programable que se puede borrar eléctricamente.
Electrically inert materials Materials that do not have free electrons and therefore cannot conduct current.
Materiales eléctricamente inertes Materiales que no tienen electrones libres y por lo tanto no pueden conducir corriente.
Electrochemical The chemical action of two dissimilar materials in a chemical solution.
Electroquímico La acción química de dos materiales desemejantes en una solución química.
Electrochemical degradation (ECD) An electrochemical attack on rubber cooling system hoses. It occurs because the hose, engine coolant, and the engine/radiator fittings form a galvanic cell. This chemical reaction causes very small cracks in the hose, allowing the coolant to attack and weaken the reinforcement in the hose.
Degradación electroquímica Ataque electroquímico en mangueras de hule del sistema de enfriamiento. Ocurre porque la manguera, el enfriador del motor, y los conectores del motor/radiador forman una célula galvánica. Esta reacción química causa grietas muy pequeñas en la manguera, lo que permite que el enfriador ataque y debilite el refuerzo de la manguera.
Electrochemical reaction Chemical reactions that produce free electrons.
Reacción electroquímica Reacciones químicas que producen electrones libres.
Electrodes The firing terminals found in a spark plug.
Electrodo Los terminales de chispeo que se encuentran en una bujía.
Electrolysis A chemical and electrical decomposition process that can damage metals, such as brass, copper, and aluminum, in the cooling system.
Electrólisis (deposición) Un proceso de decomposición química y eléctrica que puede dañar a los metales, tales como el latón, el cobre y el aluminio, en el sistema de enfriamiento.
Electrolyte A material that has atoms that become ionized, or electrically charged, in solution. Automobile battery electrolyte is a mixture of sulfuric acid and water.
Electrólito Una materia que tiene átomos que se han ionizado, o que tienen una carga eléctrica, en una solución. El electrólito para las baterías automotrices es una mezcla del ácido sulfúrico y el agua.
Electromagnet A magnet formed by electrical flow through a conductor.
Electroimán Un imán que se produce por un corriente eléctrico fluyendo por un conductor.
Electromagnetic induction Moving a wire through a magnetic field to create current flow in the wire.
Inducción electromagnético Crear un corriente eléctrico en un alambre al moverlo por un campo magnético.
Electromagnetism A form of magnetism that occurs when current flows through a conductor.
Electromagnetismo Una forma del magnetismo que ocurre al fluir un corriente por un conductor.
Electromechanical Refers to a device that incorporates both electronic and mechanical principles together in its operation.
Electromecánico Refiere a un dispositivo que incorpora ambos principios del electrónico y mecánico en su operación.
Electromotive force (EMF) A technical name for voltage.
Fuerza electromotriz (FEM) Nombre técnico para voltaje.

Electronic Pertaining to the control of systems or devices by the use of small electrical signals and various semiconductor devices and circuits.

Electrónico Perteneciente al control de los sistemas o de los dispositivos por medio de los pequeños señales eléctricos y por varios de los dispositivos semiconductores y los circuitos.

Electronic fuel injection (EFI) A generic term applied to various types of fuel injection systems.

Inyección electrónica de combustible Un término general aplicado a varios sistemas de inyección de combustible.

Electronic ignition (EI) Refers to ignition systems that are electronically based, not mechanically based.

Encendido electrónico (EI) Se refiere a los sistemas de encendido basados en componentes electrónicos y no mecánicos.

Electrostatic discharge (ESD) A phenomena that occurs when the energy in static electricity moves from one component to another.

Descarga electrostática (ESD) Un fenómeno que ocurre cuando la energía en la electricidad estática se mueve de un componente a otro.

Element A substance with only one type of atom.

Elemento Una sustancia con solamente un tipo de átomo.

Embedability The ability of the bearing lining material to absorb dirt.

Incrustabilidad La abilidad que tiene una material de forro de un cojinete en absorber la suciedad.

Emitter A portion of a transistor from which electrons are emitted, or forced out.

Emisor Una porción de un transistor de la cual se emite o se expulsan los electrones.

Enable criteria The operating conditions that must be met to run some OBD II monitors.

Criterios de activación Condiciones de operación requeridas para el funcionamiento de algunos monitores OBD II.

End play The amount of axial or end-to-end movement in a shaft due to clearance in the bearings.

Juego axial La cantidad del movimiento axial o de una extremidad a otra de una flecha debido a la holgura de los cojinetes.

Energy The ability to do work.

Energía La abilidad de trabajar.

Energy density A battery's rated energy per unit of volume. Measured in units of watt-hours per liter (Wh/L).

Densidad de la energía La energía nominal de una batería por unidad de volumen. Se mide en unidades de vatios-hora por litro (Wh/L).

Energy-conserving oil These oils are designed to reduce friction, which in turn reduces fuel consumption. Friction modifiers and other additives are used to achieve this.

Aceite conservador de energía Estos aceites están diseñados para reducir la fricción, lo cual reduce el consumo de combustible. Se utilizan modificadores de fricción y otros aditivos para lograr esto.

Engine block The main structure of the engine that houses the pistons and crankshaft. Most other engine components attach to the engine block.

Monobloque La estructura principal del motor que contiene los pistones y el cigüeñal. La mayoría de los otros componentes del motor se conectan al monobloque.

Engine control module (ECM) Often part of the powertrain control module. The module controls the operation of various engine systems.

Módulo de control del motor (ECM) A menudo forma parte del módulo de control del tren de potencia. El módulo controla la operación de varios sistemas del motor.

Engine efficiency A measure of the relationship between the amount of energy put into the engine and the amount of energy available from the engine.

Eficacia del motor Una medida de la relación entre la cantidad de energía puesta en el motor y la cantidad de energía disponible del motor.

EP toxicity The characteristic of a material that enables it to leach one or more of eight heavy metals in concentrations greater than 100 times standard drinking water concentrations.

Toxicidad EP La característica de una materia que permite que disuelva uno o más de los ocho metales pesados en concentraciones mayores de 100 veces la concentración del agua potable.

Equilibrium Exists when the applied forces on an object are balanced and there is no overall resultant force.

Equilibrio Existe cuando las fuerzas aplicadas en un objeto es equilibradas y no hay fuerza resultante total.

Equalizer lever Part of the parking brake linkage that balances application force and applies it equally to each wheel. The equalizer often contains the linkage adjustment point.

Palanca del ecualizador Parte del varillaje del freno de estacionamiento que balancea la fuerza de aplicación y la aplica de manera uniforme en cada rueda. A menudo el ecualizador contiene el punto de ajuste del varillaje.

Erasable PROM (EPROM) An electrically erasable programmable read only memory chip.

PROM que se puede borrar (EPROM) Un chip de memoria de solo lectura, programable y que se puede borrar electrónicamente.

Ethanol A widely used gasoline additive known for its abilities as an octane enhancer.

Etanol Un aditivo muy común que se reconoce por su capacidad de elevar los niveles del octano.

Evacuate The process of applying vacuum to a closed refrigeration system to remove air and moisture.

Vaciar El proceso de aplicar un vacío a un sistema cerrado de refrigeración para quitarle el aire y la humedad.

EVAP A system that purges the fuel vapors from the fuel tank and recirculates them to the fuel delivery system.

EVAP Un sistema que purga los vapores de combustible del tanque de combustible y los recircula hacia el sistema de distribución de combustible.

Evaporate Action of atoms or molecules when they break free from the body of the liquid to become gas particles.

Evaporar Acción de los átomos o las moléculas cuando se escapan del cuerpo de un líquido para convertirse en partículas del gas.

Evaporation A natural process in which the moisture contained by an object leaves and enters the atmosphere.

Evaporación Un proceso natural en el cual la humedad deja un objeto y entra la atmósfera.

Evaporator The component of an air-conditioning system that conditions the air.

Evaporador El componente en un sistema de aire acondicionado que acondiciona el aire.

Exhaust manifold A component that collects and then directs engine exhaust gases from the cylinders.

Múltiple de escape Un componente que colecciona y luego dirige los gases de escape del motor desde los cilindros.

Exhaust valve An engine part that controls the expulsion of spent gases and emissions out of the cylinder.

Válvula de escape Una parte del motor que controla la expulsión de los gases consumidos y las emisiones afuera del cilindro.

Expansion An increase in size. For example, when a metal rod is heated, it increases in length and perhaps also in diameter; expansion is the opposite of contraction.

Expansión Un aumento en el tamaño. Por ejemplo, al calentarse una varilla de metal, aumenta en longitud y quizá en su diámetro tambien; la expansión es lo contrario de la contracción.

Expansion tank A small tank sometimes located inside the main gas tank that allows for expansion of fuel in a full tank on a hot day.

Tanque de dilatación Un tanque pequeño que suele estar al interior del depósito principal de gasolina y que permite que se dilate el combustible cuando el depósito esté lleno en días calurosos.

Expansion valve A component in an air-conditioning system used to create a pressure on one side and reduce the pressure on the other side.

Válvula de expansión Un componente de un sistema de aire acondicionado que sirve para crear presión en un lado y reducirla en el otro.

Extended range EV An electric vehicle that uses an additional source to provide electrical energy when the battery is near depleted.

EV de alcance extendido Un vehículo eléctrico que utiliza una fuente adicional para proporcionar energía eléctrica cuando la batería está casi agotada.

External gear A gear with teeth across the outside surface.

Engranaje externo Un engranaje con dientes a lo largo de la superficie exterior.

Fail-safe circuit The circuit that is found in some hydraulic systems that allows limited operation when a component or components have failed.

Circuito de seguridad en falla Circuito que se encuentra en algunos sistemas hidráulicos, que permite operación limitada cuando uno o varios componentes han fallado.

Fan clutch A device used on engine-driven fans to limit their terminal speed, reduce power requirements, and lower noise levels.

Embrague del ventilador Un dispositivo utilizado en los ventiladores accionados por motores para limitar su velocidad terminal, disminuir los requisitos de potencia, y bajar los niveles de ruido.

Farad (F) The standard measure of capacitance. A one-farad capacitor can store one coulomb of charge at one volt.

Faradio (F) La medida estándar de capacitancia. Un capacitor de un faradio puede almacenar un culombio de carga a un voltio.

Fast charging A battery recharging process that uses high current delivered for a short time.

Carga rápida Un proceso de recarga de baterías en el que se suministra corriente alta durante un tiempo corto.

Fatigue Deterioration of a bearing metal under excessive intermittent loads or prolonged operation.

Fatiga La deterioración de un metal de apoyo bajo las cargas intermitentes o durante la operación prolongada.

Feedback Normally refers to the process in which computer commands and the results of such are monitored by the computer.

Retroalimentación Normalmente se refiere al proceso en el cual la computadora manda y los resultados se regulan por la computadora.

Feeler gauge A feeler gauge is a thin strip of metal or plastic of known and closely controlled thickness used to measure clearances and gaps.

Calibrador de espesor Un calibrador de espesor es una tira delgada de metal o plástico de un grosor conocido y controlado estrictamente que se utiliza para medir espacios libres y separaciones.

Ferrous metal A metal that contains iron or steel and is, therefore, subject to rust.

Metal férreo Un metal que contiene el hierro o el acero y que, por lo tanto, puede oxidarse.

Field coil A coil of wire on an alternator rotor or starter motor frame that produces a magnetic field when energized.

Bobina inductora Una bobina de alambre en un rotor de un alternador o un armazón de un motor de arranque que produce un campo magnético al establecer el corriente.

Fillets The smooth curve where the shank flows into the bolt head.

Filetes La curva lisa en donde el asta se convierte a la cabeza del tornillo.

Final drive gear The final set of reduction gears the engine's power passes through on its way to the drive wheels.

Engrane o velocidad final El ultimo juego de reductores por el cual pasa la fuerza del motor en camino a las ruedas motrices.

Firing order The order in which the cylinders of an engine move through the power stroke.

Orden de encendido El orden en el cual mueven los pistones de un motor en la carrera encendido-expansión.

Fixed caliper A brake caliper that is bolted to its support and does not move when the brakes are applied. A fixed caliper must have pistons on both the inboard and the outboard sides.

Mordaza fija Una mordaza de freno atornillada a su soporte que no se mueve cuando se aplican los frenos. Una mordaza fija debe tener pistones tanto en el lado interior como el exterior.

Fixed joint A CV joint that cannot telescope or plunge to compensate for suspension travel.

Junta fija Una junta homocinética que no puede extenderse o replegarse para compensar el recorrido de la suspensión.

Fixed rotor A rotor that has the hub and the rotor cast as a single part.

Rotor fijo Un rotor en el que la maza y el rotor están fundidos en una sola pieza.

Flange A projecting rim or collar on an object that keeps it in place.

Collarín Una orilla sobresaliente o un collar en un objeto que lo sujeta en su lugar.

Flare An expanded, shaped end on a metal tube or pipe.

Abocinado (abocardado) Una extremidad extendida o formada en un tubo de metal.

Flat-rate manuals Literature containing figures dealing with the length of time specific repairs are supposed to require. Flat-rate manuals often contain a parts list with prices as well.

Manuales de valuación La literatura que se trata de los detalles del tiempo de obra requirido por varias reparaciones específicas. Los manuales de valuación suelen incluir tambien una lista de repuestas con sus precios.

Flexible fuel vehicles (FFV) A vehicle that can operate on either methanol or ethanol and regular gasoline or any combination of the two from the same tank.

Vehículos de combustible flexible (VCF) Un vehículo que puede operar con metanol o etanol y gasolina común o cualquier combinación de ambos en el mismo tanque.

Flexplate A round, flywheel-like disc mounted to an engine's crankshaft when the vehicle is equipped with an automatic transmission.

Placa de flexión Una placa redonda parecida al volante montada al cigueñal de un motor de un vehículo que ha sido equipado con una transmisión automática.

Floating caliper A caliper that is mounted to its support on two locating pins, or guide pins. The caliper slides on the pin in a sleeve or bushing.

Mordaza flotante Una mordaza que está montada en su soporte sobre dos pernos localizadores, o pernos guía. La mordaza se desliza sobre el perno en una camisa o buje.

Floating drum A brake drum that is separate from the wheel hub or axle. A floating drum usually is held in place on studs in the axle flange or hub by the wheel and wheel nuts.

Tambor flotante Un tambor de freno que está separado de la maza o el eje de la rueda. Por lo general, la ruedas y sus tuercas mantienen el tambor flotante en su lugar sobre espárragos ubicados en la pestaña del eje o la maza.

Floating rotor A rotor and hub assembly made of two separate parts.

Rotor flotante Un conjunto de rotor y maza formado por dos piezas separadas.

Flow charts Diagnostic aids that guide you through a step-by-step troubleshooting process based on symptoms and testing.

Diagramas de flujo Ayudas de diagnóstico que lo guían por un proceso detallado de localización de averías basado en los síntomas y en pruebas.

Flow-directing valves Valves that direct pressurized fluid to the appropriate apply device to cause a change in gear ratios.

Válvulas desviadoras de flujo Válvulas que dirigen el líquido presurizado al dispositivo de aplicación apropiado para provocar un cambio en las relaciones de engranajes.

Fluid Something that does not have a definite shape; therefore, liquids and gases are fluids.

Fluido Algo que no tiene una forma definida, por lo tanto los líquidos y los gases son fluidos.

Flux density The number of flux lines per square centimeter.

Densidad de flujo El número de lineas de flujo por centímetro cuadrado.

Flux field The magnetic field formed by magnetic lines of force.

Campo de flujo El campo magnético formado por líneas de fuerza magnética.

Flywheel A heavy circular component located on the rear of the crankshaft that keeps the crankshaft rotating during nonproductive strokes.

Volante del motor Un componente pesado redondo, ubicado en la parte trasera del cigüeñal que mantiene el cigüeñal girando durante las carreras no productivas.

Foot pads Contact points on the arms of a lift that can be lifted up to contact the vehicle's lift points to add clearance between the arms and the vehicle.

Almohadillas de piso Puntos de contacto en los brazos de un elevador que pueden levantarse para hacer contacto con los puntos de levantamiento de un vehículo para agregar espacio libre entre los brazos y el vehículo.

Foot-pound A unit of measurement for torque. One foot-pound is the torque obtained by a force of 1 pound applied to a wrench handle 12 inches (one foot) long.

Pie-libra Una unidad de medida de torsión. Un pie-libra es la torsión que se obtiene por la fuerza de una libra que se aplica a una llave de tuercas cuyo mango mide 12 pulgadas en longitud.

Force A push or pushing effort measured in pounds.

Fuerza Un esfuerzo de jalar o empujar que se mide en libras.

Forge The process of shaping metal by stamping it into a desired shape.
Forgar El proceso de formar el metal al imprimirlo en una forma requerida.
Forward bias A positive voltage that is applied to the P-material and a negative voltage that is applied to the N-material in a semiconductor.
Polarización directa Un voltaje positivo que se aplica al cristal P y un voltaje negativo que se aplica al cristal N de un semiconductor.
Four-wheel alignment Four-wheel alignment measures the angles at the four wheels and adjustments are made to ensure the front wheels are rotating in same direction as the rear wheels.
Alineación de las cuatro ruedas La alineación de las cuatro ruedas mide los ángulos en las cuatro ruedas y se realizan ajustes para asegurar que las ruedas delanteras giren en la misma dirección que las traseras.
Four-wheel drive (4WD) A vehicle design where there is driving axles at both the front and rear, so that all four wheels can be driven.
Tracción en las cuatro ruedas (4WD) Un diseño de vehículo en donde hay ejes motores tanto en la parte delantera como en la trasera, de modo que haya tracción en las cuatro ruedas.
Fractional distillation The process of separating the various petroleum products from crude oil by heat. The different hydrocarbon chain lengths have progressively higher boiling points.
Destilación fraccionaria El proceso de separar los diversos productos del petróleo del petróleo crudo mediante calor. Las distintas longitudes de las cadenas de hidrocarburos tienen puntos de ebullición cada vez más altos.
Free play Looseness in a linkage between the start of application and the actual movement of the device, such as the movement in the steering wheel before the wheels start to turn.
Juego libre Flojedad en una biela que aparece entre el tiempo en que se comienza usar a una aplicación y el movimiento actual del dispositivo, tal como el movimiento en un volante de dirección antes de que comienzan a girar las ruedas.
Free travel The distance a clutch pedal moves before it begins to take up slack in the clutch linkage.
Juego libre La distancia que mueve el pedal de embrague antes de que comienza accionar la biela del embrague.
Freewheeling A mechanical device that engages the driving member to impart motion to a driven member in one direction but not the other. Also known as an overrunning clutch.
Embrague de volante libre Un dispositivo mecánico que engrana el miembro de impulso con el miembro de tracción y confiere el movimiente en una dirección, pero no en la otra. Tambien se conoce como un embrague de sobremarcha.
Freeze frame With this feature of OBD II systems, the PCM takes a snapshot of the activity of various inputs and outputs at the time the PCM illuminated the MIL.
Imagen congelada En esta función de los sistemas OBD II, el PCM toma una instantánea de la actividad de varias entradas y salidas en el momento que la PCM ilumina la MIL.
Frequency The rate at which something occurs.
Frecuencia La velocidad en la cual algo ocurre.
Friction The resistance to motion that occurs when two objects rub against each other.
Fricción La resistencia al movimiento que ocurre al frotarse dos objetos.
Friction disc In the clutch a flat disc, faced on both sides with friction material and splined to the clutch shaft. It is positioned between the clutch pressure plate and the engine flywheel. Also called the clutch disc or driven disc.
Disco de fricción Es un disco plano en el embrague con material de fricción en ambas caras y estrías hacia el eje del embrague. Está colocado entre la placa de presión del embrague y el volante del motor. También se conoce como disco de embrague o disco accionado.
Fuel cell electric vehicle (FCEV) An electric vehicle that uses the electricity generated by a fuel cell to power the traction motor(s).
Vehículo eléctrico con pila de combustible (FCEV) Un vehículo eléctrico que usa la electricidad generada por una pila de combustible para operar el o los motores de tracción.
Fuel cell stack An assembly of several hundred fuel cells connected in series and layered or stacked next to each other. Each fuel cell produces electricity and the combined output of the cells is used to power a vehicle.
Pila de células de combustible Ensamble de varios cientos de células de combustible en una serie, acomodados o apilados uno junto a otro. Cada célula de combustible produce electricidad y el resultado de las células se usa para suministrar energía a un vehículo.
Fuel pressure regulator A device designed to limit the amount of pressure buildup in a fuel delivery system.
Regulador de presión del combustible Un dispositivo diseñado para limitar la cantidad de acumulación de presión en un sistema de suministro de combustible.
Fuel pump A mechanical or electrical device used to move fuel from the fuel tank to the carburetor or injectors.
Bomba de combustible Un dispositivo mecánico o eléctrico que se utiliza para llevar combustible del depósito al carburador o los inyectores.
Fuel rail A metal or plastic pipe in which the upper ends of the injectors are installed in port injection systems.
Carril del combustible Un tubo de metal o plástico en el cual se instalan las extremidades superiores de los inyectores en los sistemas de inyección de puerto/de lumbreras.
Fulcrum The support or point of rest on which a lever rests; also called the pivot point.
Punto de apoyo El soporte o punto de descanso en el cual descansa una palanca; tambien se llama el punto de pivote.
Full-floating axle shaft A type of live axle arrangement in which the weight of the vehicle is not supported by the axle.
Flotante Un tipo de dispositivo de eje motor en el cual el peso del vehículo no se soporta por el eje.
Full hybrid A hybrid vehicle that is able to run on the engine, the batteries, or a combination of the two.
Híbrido completo Un vehículo híbrido capaz de funcionar con el motor, las baterías o una combinación de ambos.
Full-round bearing A one piece insert bearing commonly used on camshafts.
Cojinete totalmente cerrado Un cojinete de inserto de una pieza que se utiliza comúnmente en los árboles de levas.
Full-wave rectification The conversion of the total AC voltage signal to a DC voltage signal.
Rectificación de onda completa La conversión de la señal de voltaje de AC total en una señal de voltaje de DC.
Fuse An electrical device used to protect a circuit against accidental overload or unit malfunction.
Fusible Un dispositivo eléctrico utilizado para proteger un circuito contra una sobrecarga imprevista o un mal funcionamiento de la unidad.
Fusible link A type of fuse made of a special wire that melts to open a circuit when current draw is excessive.
Fusible térmico El tipo de fusible fabricado de un alambre especial que se funde para abrir un circuito cuando ocurre una sobrecarga del circuito.
Galling wear Uniting two solid surfaces that are in rubbing contact; used to describe the normal wear of valve lifters.
Desgaste por rozamiento Uniendo a dos superficies sólidos que están en contacto frotativo; se usa para describir el gasto normal de las levantaválvulas.
Ganged A type of switch in which several circuits are controlled by moving one control or lever.
Acoplados Un tipo de interruptor en el cual varios circuitos se controlan al mover un control o una palanca.
Gas Gaseous fuel (normally natural gas) that is burned to produce heat energy. The word also is used to refer to gasoline.
Gas Combustible gaseoso (por lo general, gas natural) que se quema para producir energía calorífica. La palabra también se utiliza para referirse a la gasolina.
Gasket A thin layer of material or composition that is placed between two machined surfaces to provide a leakproof seal between them.
Junta Una capa delgada de material o compuesto que se coloca entre dos superficies rectificadas para proveer una junta hermética para evitar fugas entre ellas.

Gasoline direct-injection (GDI) A fuel system where gasoline is injected directly into the combustion chamber.

Inyección directa de gasolina (GDI, por sus siglas en inglés) Sistema de combustible en el cual se inyecta gasolina directamente dentro de la cámara de combustión.

Gateway A module that allows for data exchange between different buses. It translates a message on one bus and transfers that message to another bus without changing the message. The gateway interacts with each bus according to the protocol of that bus.

Puerta de enlace Módulo que permite el intercambio de información entre diferentes camiones. Traduce un mensaje en un camión y lo transfiere a otro camión sin cambiar el mensaje. La puerta de enlace interactúa con cada camión según el protocolo de dicho camión.

Gear A wheel with external or internal teeth that serves to transmit or change motion.

Engranaje Rueda con dientes externos o internos que sirve para transmitir o modificar un movimiento.

Gear pitch The number of teeth per given unit of pitch diameter. Gear pitch is determined by dividing the number of teeth by the pitch diameter of the gear.

Paso del engrenaje El número de los dientes por una unidad dada de un diámetro de paso. El paso del engrenaje se determine al dividir el número de los dientes por el diámetro del paso del engrenaje.

Gear ratio An expression of gear size and tooth count of gears that are meshed together. The ratio reflects torque multiplication.

Relación de engranes Una expresión del tamaño del engrenaje y el número de los dientes que se engranan. La relación refleja la multiplicación de par.

Gear whine A high-pitched sound developed by some types of meshing gears.

Zumbido del engranaje Un sonido agudo que desarrollan algunos tipos de pares de ruedas dentadas.

Generator An electrical device that produces alternating current that is rectified to DC current by the brushes and commutator.

Generador Un dispositivo eléctrico que produce corriente alterna que se rectifica como corriente continua mediante las escobillas y el conmutador.

Glaze A thin residue on the cylinder walls formed by a combination of heat, engine oil, and piston movement.

Porcelana (barniz) Un residuo en los paredes de los cilindros que se forma por una combinación del calor, el aceite del motor y el movimiento de los pistones.

Glitches Abnormal, slight movements of a waveform on a lab scope. These can be caused by circuit problems or noise in the circuit.

Fallos transitorios Pequeños movimientos, anormales, de una forma de onda en un ámbito de laboratorio. Estos los pueden causar problemas de circuito o ruido en el circuito.

Glow plug An electrical device used on diesel engines to warm the combustion chamber and/or fuel when outside temperatures are low. These allow for quicker cold starts.

Bujía incandescente Un dispositivo eléctrico utilizado en motores diesel para calentar la cámara de combustión y/o el combustible cuando las temperaturas exteriores son bajas. Estas bujías permiten arranques en frío más rápidos.

Governor A device that limits the speed of a device.

Regulador Un dispositivo que limita la velocidad de otro dispositivo.

Grade marks Marks on fasteners that indicate strength.

Marcos de grado Las marcas en las fijaciones que indican su fuerza.

Graphite Very fine carbon dust with a slippery texture used as a lubricant.

Grafito Polvo de carbón muy fino con textura resbalosa usado como lubricante.

Grease A combination of oil and a thickening agent.

Grasa Una combinación de aceite y un agente de espesamiento.

Greenhouse gas A name given to the effect that certain gases have on global warming.

Gas de invernadero Nombre que se le da al efecto que ciertos gases tienen en el calentamiento global.

Grid The basic framework of the lead-acid battery plates. They are the lead alloy framework that supports the active material of the plate.

Rejilla La estructura básica de las placas de batería de plomo-ácido. Son la estructura de aleación de plomo que soporta el material activo de la placa.

Gross pay The total amount of what you earned on a job. This is not "take home" pay.

Sueldo bruto La cantidad total que usted gana en un trabajo. No es el sueldo neto.

Gross weight The total weight of a vehicle plus its maximum rated payload.

Peso bruto El peso total de un vehículo más su carga útil nominal máxima.

Ground The negatively charged side of a circuit. A ground can be a wire, the negative side of the battery, or even the vehicle chassis.

Tierra El lado de un circuito que tiene una carga negativa. Una tierra puede ser un alambre, el lado negativo de una batería, o hasta el chasis del vehículo.

Ground wire A wire that connects a component to the negative side of the battery through the vehicle's chassis. The use of the ground wire eliminates the need to run a separate wire from the component to the negative terminal of the battery.

Cable de masa Un cable que conecta un componente al lado negativo de la batería a través del chasis del vehículo. El uso del cable de masa elimina la necesidad de tender un cable separado del componente al terminal negativo de la batería.

Gum In automotive fuels, gum refers to oxidized petroleum products that accumulate in the fuel system, carburetor, or engine parts.

Sarro (goma) En los combustibles automotrices, el sarro se refiere a los productos petróleos oxidados que acumulan en el sistema de combustible, el carburador, o en las partes del motor.

Haldex clutch Found as the center differential in some all-wheel-drive vehicles, this unit distributes the drive force variably between two axles. It consists of a hydraulic pump, a wet multi-disc clutch, and an electronically controlled valve.

Embrague Haldex Se encuentra como el diferencial central en algunos vehículos de tracción en todas las llantas, esta unidad distribuye la fuerza de manejo variada entre los dos ejes. Consiste en una bomba hidráulica, un embrague húmedo de muchos discos, y una válvula controlada electrónicamente.

Half shaft Either of the two drive shafts that connect the transaxle to the wheel hubs in FWD cars. Half shafts have constant velocity joints attached to each end to allow for suspension motions and steering. The shafts may be of solid or tubular steel and may be of different lengths. Balance is not critical, as half shafts turn at roughly one-third the speed of RWD drive shafts.

Semieje cualquiera De los dos ejes motores que conectan el dispositivo de acoplamiento intermedio a los cubos de las ruedas en los vehículos de tracción en las cuatro ruedas. Los semiejes tienen juntas de velocidad constante fijas a cada extremo para permitir los movimientos de la suspensión y la dirección. Los ejes pueden ser de acero tubular o sólido y tener longitudes diferentes. El equilibrio no es crítico, ya que los semiejes giran a aproximadamente un tercio de la velocidad de los ejes motores de los vehículos de tracción trasera.

Half-wave rectification The conversion of half of the total AC voltage signal to a DC voltage signal.

Rectificación de media onda La conversión de la mitad de la señal de voltaje de AC total a una señal de voltaje de DC.

Hall effect The consequence of moving current through a thin conductor that is exposed to a magnetic field; as a result of this, voltage is produced.

Efecto Hall La consecuencia de pasar un corriente por un conductor delgado que se expone a un campo magnético; por consecuencia, se produce el voltaje.

Hall-effect switch A device that produces a voltage pulse dependent on the presence of a magnetic field.

Interruptor de efecto Hall Un dispositivo que produce un pulso de voltaje que depende de la presencia de un campo magnético.

Halogen The term used to define a group of chemically related nonmetallic elements.

Halógeno El termino para describir un grupo de elementos no metálicos del mismo género químico.

Hand tap A tool used for hand cutting internal threads.

Macho de roscar de mano Una herramienta que sirve para cortar a mano las roscas interiores.

Hardening A process that increases the hardness of a metal, deliberately or accidentally, by hammering, rolling, carburizing, heat treating, tempering, or other physical processes.

Endurecer Un proceso que aumenta la dureza de un metal, deliberadamente o accidentalmente, por el martilleo, rodar, la carburación, el calor, templar, u otros procesos físicos.

Hardware The guides, clips, and other components that hold brake pads in place and reduce brake noise.

Material de fijación Las guías, los clips y otros componentes que sostienen las pastillas de freno y disminuyen el ruido de frenos.

Hard spots Areas in the friction surface of a brake drum or rotor that have become harder than the surrounding metal; sometimes called islands of steel.

Regiones endurecidos Las averías en la superficie de fricción del tambor o el rotor de un freno que se han endurecido más que el metal que los rodea; a veces se llaman islas de acero.

Hazardous waste Any material found on the Environmental Protection Agency list of known harmful materials. Waste is also considered hazardous if it has one or more of the following characteristics: ignitability, corrosivity, reactivity, and EP toxicity.

Desechos tóxicos Cualquier material que se nombra en la lista de materiales dañosos de la agencia de protección del medio ambiente (EPA). Los desechos tambien se consideran tóxicos si tiene uno o más de las características siguientes: la inflamabilidad, la calidad corrosiva, la reactividad y la toxicidad EP.

Head gasket Gasket used to prevent compression pressures, gases, and fluids from leaking. It is located on the connection between the cylinder head and the engine block.

Junta de la cabeza Una junta que se emplea para prevenir que se escapen las presiones, los gases y los fluidos de la compresión. Se ubica en la conexión entre la cabeza de los cilindros y el monobloque.

Heads-up display (HUD) A system that projects visual images of gauge readings onto the windshield using a vacuum fluorescent light source to complement in-dash instrumentation.

Pantalla de visualización frontal (HUD) Un sistema que proyecta imágenes visuales de lecturas de calibradores en el parabrisas usando una fuente de luz fluorescente de vacío para complementar los instrumentos del tablero.

Heat A form of energy caused by the movement of atoms and molecules.

Calor Una forma de energía causada por el movimiento de átomos y de moléculas.

Heat checks Small cracks on a metal surface caused by excessive heat, commonly found on the surfaces of brake drums and rotors and usually can be machined away.

Grietas por choque térmico Pequeñas grietas en una superficie de metal producidas por el calor excesivo; se encuentran comúnmente en las superficies de los tambores y rotores de freno, y por lo general pueden rectificarse.

Heat range A rating used to express how well a spark dissipates heat.

Rango de calor Una medida que expresa la abilidad de una chispa de dispersar el calor.

Heat shield An assembly designed to restrict the transfer of high heat from one component to another.

Pantalla térmica Un ensamblaje diseñado para restringir la transferencia de calor elevado de un componente a otro.

Heat sink A device used to dissipate heat and protect parts.

Fuente fría Un dispositivo que sirve para dispersar el calor y proteger las partes.

Heat treating The changing of the properties of a metal by using heat.

Tratamiento por calor El cambiar de las características de un metal usando calor.

Heated oxygen sensor (HO_2S) An oxygen sensor that is heated so it can respond before the engine is totally warmed up.

Sensor de oxígeno calentado (HO_2S) Un sensor de oxígeno que se calienta de modo que pueda responder antes de que el motor esté totalmente caliente.

Heater control valve A manual or automatic valve in the heater hose used for opening or closing, providing coolant flow control to the heater core.

Válvula de control del calentador Una válvula manual o automática en la manguera del calentador que se usa para abrir o cerrar, proporcionando control de flujo de refrigerante al núcleo del calentador.

Heater core A small heat exchanger in the passenger compartment through which engine coolant is circulated.

Núcleo del calentador Un pequeño intercambiador térmico en el compartimiento del pasajero por el que se hace circular el refrigerante del motor.

Helical gear A gear with teeth that are cut at an angle or are spiral to the gear's axis of rotation.

Engranaje helicoidal Un engranaje cuyos dientes han sido cortados en un ángulo o que son un espiral al eje de rotación del engrenaje.

Hemispherical combustion chamber A half-circle combustion design in which the valves are located on either side of the spark plug which centered in the chamber.

Cámara de combustión hemisférica Un diseño de combustión en semicírculo en el que las válvulas se encuentran a ambos lados de la bujía, que está centrada en la cámara.

Heptane A standard reference fuel with an octane number of zero, meaning that it knocks severely in an engine.

Eptano Un combustible de norma cuyo índice de octano es el cero, lo que significa que causa que el motor golpetea severamente.

Hertz (Hz) The unit by which frequency is most often expressed, equal to one cycle per second.

Hertzio (Hz) La unidad de medida que se utiliza para expresar frecuencia y es igual a un ciclo por segundo.

High-intensity discharge (HID) headlamps Headlamps that are also called Xenon headlamps. These are high-voltage lamps that produce about twice as much light as conventional headlamps.

Faros de descarga de alta intensidad Estos faros también se llaman faros de xénon. Son faros de alto voltaje que producen como el doble de luz que los faros convencionales.

High side The high pressure portion of an air-conditioning system.

Lado de alta La porción de alta presión de un sistema de aire acondicionado.

High tension High voltage. In automotive ignition systems, voltages (up to 40 kilovolts) in the secondary circuit of the system as contrasted with the low, primary circuit voltage (nominally 6 or 12 volts).

Alta tensión El voltaje alto. En los sistemas del encendido, los voltajes (hasta los 40 kilovoltios) en el circuito secundario del sistema en contraste del voltaje bajo del circuito principal (de 6 o 12 voltios nominalmente).

Holddown spring Small springs that hold drum brake shoes in position against the backing plate while providing flexibility for shoe application and release.

Resorte sujetador Pequeños resortes que sujetan las zapatas de los frenos de tambor en su posición contra la placa de fijación al tiempo que proporcionan flexibilidad para la aplicación y liberación de las zapatas.

Hone An abrasive for correcting small irregularities of differences in diameter in a cylinder, such as an engine cylinder or brake cylinder.

Piedra de rectificar Un abrasivo que sirve para corregir las pequeñas irregularidades en los diámetros de un cilindro, tal como un cilindro de un motor o un cilindro de freno.

Hook-end seals A metal sealing ring that has small hooks at each end to lock the ends together.

Sellos con extremo de gancho Un anillo sellador metálico que tiene pequeños ganchos en cada extremo para enganchar los extremos entre sí.

Horsepower The rate at which torque is produced.

Caballo de fuerza El índice de la cual se produce el esfuerzo de torsión.

Hot spot Refers to a comparatively thin section of area of the wall between the inlet and exhaust manifold of an engine, the purpose being to allow the hot exhaust gases to heat the comparatively cool incoming mixture. Also used to designate local areas of the cooling system that have attained above average temperatures.

Región de calor Refiere a una sección delgada en el muro entre la admisión y el escape del múltiple de un motor, su propósito es

permitir que los gases calientes del escape calientan a la mezcla entrando que es comparativamente fría. Este término tambien sirve para designar las areas locales del sistema del enfriamento que han alcanzado las temperaturas más altas que las normales.

Hub The inner component of a multidisc clutch that is splined with the friction discs of the clutch and a component of the planetary gearset. When the clutch is applied, the hub will drive, rotate or hold a planetary gearset component.

Maza El componente interno de un embrague multidisco, estriado con los discos de fricción del embrague y un componente del tren de engranajes planetarios. Cuando se aplica el embrague, la maza se acciona, rota o sujeta un componente del tren de engranajes planetarios.

Hunting gearset A differential gearset in which one drive pinion gear tooth contacts every ring gear tooth after several rotations.

Conjunto de engranaje con diente suplementario Un conjunto de engranajes del diferencial en el cual cada diente del piñon de mando se engrena con cada diente del engranaje de corona después de varias rotaciones.

Hybrid electric vehicle (HEV) A vehicle with two distinct power sources, typically an electric motor and an internal combustion engine.

Vehículo híbrido eléctrico (HEV) Vehículo con dos fuentes distintas de energía. Por lo general, consta de un motor eléctrico y un motor interno de combustión.

Hydraulic hybrid Similar to a hybrid electric vehicle, except energy for the alternative power source is stored in tanks of hydraulic fluid under pressure. This vehicle has a hydraulic propulsion system.

Hibrido hidráulico Parecido a los vehículos híbridos eléctricos, excepto que energía para la fuente alterna se almacena en tanques de líquido hidráulico bajo presión. Estos vehículos tienen un sistema de propulsión hidráulica.

Hydrocarbons (HC) Particles of gasoline present in the exhaust and in crankcase vapors that have not been fully burned.

Hidrocarburos Las partículas de la gasolina presentes en los gases de escape y en los vapores de la caja de cigueñal que no se han quemado completamente.

Hydroforming Some automotive frames are made with this process that uses high-pressure water to shape the steel into the desired shape, rather than heat.

Hidroconformado Algunos chasis automotrices se fabrican mediante este proceso que utiliza agua a alta presión para moldear el acero en la forma deseada, en vez de usar calor.

Hydrofluorocarbon (HFC) The chemical family currently used as the source of refrigerant (R-134a) for air-conditioning systems. It contains no chlorine and causes less damage to the ozone layer when released to the atmosphere.

Hidrofluorocarbono (HFC) Familia química usada actualmente como fuente del refrigerante (R-134a) para sistemas de aire acondicionado. Contiene cloro y provoca menos daño a la capa de ozono cuando se libera a la atmosfera.

Hydrogen H is the chemical symbol for hydrogen. It is the lightest element of the table of elements and the most abundant element in the universe.

Hidrógeno H es el símbolo químico del hidrógeno. Es el elemento más ligero de la tabla de elementos, y el más abundante en el universo.

Hydrometer Instrument for measuring the density of liquids in relation to water. This tool is commonly used to measure the state of charge in a lead-acid battery by measuring specific gravity of the electrolyte.

Hidrómetro Instrumento para medir la densidad de los líquidos en relación al agua. Esta herramienta se utiliza comúnmente para medir el estado de carga en una batería de plomo-ácido midiendo la gravedad específica del electrólito.

Hypereutectic A type of piston that has high silicon content. They offer low thermal expansion rates, improved groove wear, good resistance to high temperatures, and greater strength and scuff and seizure resistance.

Hipereutéctico Un tipo de pistón con un alto contenido de silicio. Ofrecen relaciones de expansión térmica bajas, un mejor desgaste de las ranuras, buena resistencia a las altas temperaturas, además de una mayor fuerza y más resistencia al raspado y a las fisuras.

Hypoid gear A type of spiral, beveled ring and pinion gearset in a differential. Hypoid gears mesh below the ring gear centerline.

Engrenajes hipoíde Un conjunto de engrenajes de un diferencial de anillo y piñon de forma espiral y biselado. Los engrenajes hipoídes se engrenan abajo de la linea central de la corona.

Hyundai ix35 FCEV A compact crossover vehicle powered by a hydrogen fuel cell.

Hyundai ix35 FCEV Vehículo *crossover* compacto impulsado por una pila de combustible de hidrógeno.

Idler arm A steering linkage component fastened to the car frame that supports the right end of the center link.

Brazo intermedio Componente de enlace de dirección montado en el armazón del vehículo que sostiene el extremo derecho del enlace central.

Idler gear A gear pulley used to keep tension on a chain or drive belt. Also, a gear that rides between a set of gears and does not affect the ratio but does change the direction of the output gear.

Engranaje loco Una polea que se utiliza para mantener la tensión en una cadena o correa. También es un engranaje que viaja entre un conjunto de engranajes y no afecta la relación, pero sí cambia la dirección del piñón conducido.

Idler pulley A pulley used to tension or torque the belt(s).

Polea tensora Una polea utilizada para proveer tensión o par de torsión a la(s) banda(s).

Ignitability The characteristic of a solid that enables it to spontaneously ignite. Any liquid with a flash point below 140°F (60°C) is also said to possess ignitability.

Inflamabilidad La característica de un sólido que lo permite encenderse espontáneamente. Cualquier líquido con una temperatura de inflamabilidad menos del 140°F (60°C) posee la característica de la inflamabilidad.

Ignition coil A transformer containing a primary and secondary winding that acts to boost the battery voltage of 12 volts to as much as 30,000 volts to fire the spark plugs.

Bobina de encendido Un transformador contiene un devanado primario y otro secundario que actúan para reforzar el voltaje de la batería de 12 voltios a hasta 30,000 voltios para activar las bujías.

Ignition system The system that creates and distributes a timed spark to the cylinder.

Sistema de encendido Crea y distribuye una chispa sincronizada al cilindro.

Ignition timing The point at which ignition occurs in a cylinder.

Tiempo de encendido El punto en el que se produce el encendido en el cilindro.

Impedance Refers to the operating resistance of a component or piece of equipment. The higher the impedance, the lower the operating amperage.

Impedancia Se refiere a la resistencia de operación de un componente o parte de equipo. Mientras más alta la impedancia, menor el amperaje de operación.

Impeller The part of a torque converter that is driven by the engine's crankshaft.

Impulsor Una parte de un convertidor del par que es accionada por el cigueñal del motor.

Impermeable Characterístic of materials that adsorb fluids.

Impermeable Una característica de los materiales que fijan los líquidos por adsorción.

Impurities Trace elements that are added to electrically inert materials to produce a semiconductor.

Impurezas Oligoelementos que se agregan a los materiales eléctricamente inertes para producir un semiconductor.

Inboard joint The CV joint that connects the drive axle to the transaxle of the differential assembly.

Junta interior La junta de velocidad constante que conecta el eje motor al árbol intermedio del conjunto del diferencial.

Included angle The sum of the angle of camber and steering axis inclination.

Ángulo comprendido La suma del ángulo del camber y la inclinación del eje de la dirección.

Indirect TPM A type of tire pressure monitoring system that uses date from the ABS wheel speed sensors to detect decreased tire pressure.

Sistema de control de presión de neumáticos indirecto Sistema de control de presión de neumáticos que emplea la información

brindada por los sensores de velocidad de rueda ABS para detectar disminuciones en la presión de los neumáticos.

Induced voltage Voltage that is produced by current flow in a wire without any actual contact to the wire.

Voltaje inducido Voltaje producido por el flujo de corriente en un cable sin que haya contacto real con el cable.

Induction The process of producing electricity through magnetism rather than direct flow through a conductor.

Inducción El proceso de producción de la electricidad por el magnetismo en vez de un corriente directo por un conductor.

Inductive charging A recharging method that transfers electricity from charger to a battery through a magnetic field.

Carga inductiva Un método de recarga que transfiere la electricidad del cargador a una batería a través de un campo magnético.

Inductive reluctance A characteristic of a material that defines how easily it can be magnetized.

Renuencia inductiva Característica de un material que define qué tan fácilmente se puede magnetizar.

Inertia The constant moving force applied to carry the crankshaft from one firing stroke to the next.

Inercia La fuerza del movimiento constante aplicada a un cigueñal para progresar de una carrera a la próxima.

Inertia switch A switch that automatically shuts off the fuel pump if the vehicle is involved in a collision or rolls over.

Conmutador inercia Un interruptor que automáticamente apaga a la bomba de combustible si el vehículo se involucra en un choque o si se voltea.

Input shaft The shaft carrying the driving gear by which the power is applied, as to the transmission.

Árbol de transmisión El eje que transporta el engranaje impulsor que aplica la potencia, como en la transmisión.

Insert bearing A bearing made as a self-contained part and then inserted into the bearing housing.

Cojinete inserta Un cojinete fabricado como una parte autónoma y que se inserta en la caja del cojinete.

Installed spring height The distance from the valve spring seat to the underside of the retainer when it is assembled with keepers and held in place.

Altura del resorte instalado La distancia del asiento del resorte de la válvula a la parte inferior del retén cuando ha sido instalado con las cuñas y se fija en su lugar.

Installed stem height The distance from the valve spring seat and to the stem tip.

Altura del vástago instalado La distancia del asiento del muelle de la válvula al punto extremo del vástago.

Instrument voltage regulator (IVR) Used to stabilize and limit voltage for accurate instrument operation.

Regulador de voltaje de instrumentos (IVR) Se utiliza para estabilizar y limitar el voltaje para la operación precisa de los instrumentos.

Insulated circuit A circuit that includes all of the high-current cables and connections from the battery to the starter motor.

Circuito aislado Un circuito que incluye a todos los cables de alta tensión y las conexiones de la batería al motor de arranque.

Insulated gate bipolar transistor (IGBT) A solid-state device that converts DC voltage into three-phase AC voltage to power an electrical motor or other device.

Transistor Bipolar de compuerta aislada (IGBT) Dispositivo en estado sólido que convierte voltaje de CD a voltaje de CA trifásico para activar un motor eléctrico u otro dispositivo.

Insulation resistance tester A tester that measures the amount of voltage that can leak through the insulation of a wire or cable.

Probador de resistencia de aislamiento Un probador que mide la cantidad de voltaje que puede fugarse a través del aislamiento de un alambre o cable.

Insulator A material that does not allow for good current flow.

Aislador Una materia que no permite un flujo del corriente.

Intake valve The control passage of the air-fuel mixture entering the cylinder.

Válvula de admisión El pasaje de control para la mezcla de aire-combustible entrado en el cilindro.

Integral Made in one piece.

Integral Hecho en una sóla pieza.

Integral antilock brake system An antilock brake system in which the ABS hydraulic components, the standard brake hydraulic components, and a hydraulic power booster are joined in a single.

Sistema de frenos antibloqueo integral Un sistema de frenos antibloqueo en el que los componentes hidráulicos del ABS, los componentes hidráulicos del freno estándar y un reforzador hidráulico se unen en uno solo.

Integrated circuit A large number of diodes, transistors, and other electronic components, all mounted on a single piece of semiconductor material and able to perform numerous functions.

Circuito integrado La cantidad de diodos, transistores u otros componentes electrónicos, todos montados en una sola pieza de material semiconductor y capaz de ejecutar varias funciones.

Integrated circuit voltage regulator A compact voltage regulator mounted either inside or on the back of the AC generator.

Regulador de voltaje de circuito integrado Un regulador de voltaje compacto que se monta ya sea dentro o en la parte posterior del generador de AC.

Integrated motor assist (IMA) The motor/generator assembly used in Honda hybrids and fits between the engine and the transmission.

Asistencia integrada de motor (IMA) El ensamble del motor/generador usado en los híbridos de Honda y cabe entre el motor y la transmisión.

Integrated starter alternator damper (ISAD) Similar to Honda's IMA, this unit replaces the flywheel, generator, and starter motor. It is placed between the engine and transmission in some hybrid vehicles.

Arrancador regulador de alternador integrado (ISAD) Parecida al IMA de Honda, esta unidad remplaza el volante, generador, y arrancador. Se coloca entre el motor y la transmisión en algunos vehículos híbridos.

Interaxle (center) differential Another name for the center differential unit used in some 4WD vehicles.

Diferencial entre ejes Otro nombre para la unidad de diferencial central que se utiliza en algunos vehículos 4WD.

Intercooler A device used on some turbocharged engines to cool the compressed air.

Refrigerante intermedio Un dispositivo que se usa en algunos motores turbocargados para enfriar al aire comprimido.

Inverter A device that converts AC electricity to DC electricity and DC to AC.

Inversor Dispositivo que convierte electricidad CA a electricidad CD, y CD a CA.

Ion An electrically charged particle or molecule.

Ion Una partícula o molécula con carga eléctrica.

Isolation/dump valves The isolation/dump valves block off or isolate fluid pressure from the master cylinder from certain brakes when the ABS is active.

Válvulas de aislamiento/descarga Las válvulas de aislamiento/descarga bloquean o aíslan la presión hidráulica del cilindro maestro de ciertos frenos cuando el sistema ABS se encuentra activado.

Isooctane A standard reference fuel with an octane number of 100, meaning that it does not knock in an engine.

Iso-octano Un combustible de norma con un índice de octano de cien, lo que significa que resulta en que el motor no golpetea.

Jack stands Safety stands, used to hold a vehicle up while using a floor jack.

Torres Los soportes de seguridad. Sirven para sostener un vehículo en alto mientras que se usa un gato de piso.

Jobbers Part of the part distribution network, they sell parts and supplies to shops and "do-it-yourselfers."

Intermediarios Forman parte de la red de distribución de repuestos. Venden repuestos y suministros a los talleres y a quienes arreglan sus propios automóviles.

Jounce Upward suspension movement.

Sacudo Un movimiento hacia arriba de la suspensión.

Keep-alive memory (KAM) A series of vehicle battery-powered memory locations in the microcomputer that allows the microcomputer to store information on input failure identified in normal operations for use in diagnostic routines. KAM adopts some calibration parameters to compensate for changes in the vehicle system.

Memoria de retención Una seria de localizaciones de memoria mantenidas por la batería del vehículo que permiten que la microcomputador registra la información de fallos de entrada, que se identifícan en las operaciones normales para usarse en las pruebas diagnósticos. La memoria de retención utiliza algunos de los parámetros calibrados para compensar por los cambios en el sistema del vehículo.

Kickdown Normally refers to an automatic transmission shifting into a lower gear to meet the demands of the driver or a heavier load.

Disparo descendente Normalmente se refiere a una transmisión automática que efectúa un cambio descendente para acomodar al chofer o para acomodar a una carga más pesada.

Kilovolt (kV) One-thousand volts (1,000).

Kilovoltio (kV) Mil voltios (1,000).

Kinetic balance Balance of the radial forces on a spinning tire determined by an electronic wheel balancer.

Balanceo cinético El balanceo dinámico de las fuerzas radiales en una llanta que gira. Se determine por un balanceador de ruedas electrónico.

Kinetic energy Energy in motion.

Energía cinético La energía en movimiento.

Knurling A technique used for restoring the inside diameter dimensions of a worn valve guide by plowing tiny furrows through the surface of the metal.

Moletear Un método para restorar las dimensiones del diámetro interior de una guía de la válvula gastada partiendo al metal de la superficie en pequeños surcos.

KOEO The acronym for a test condition in which the key is on and the engine is not running.

KOEO Acrónimo para una condición de prueba en la cual la llave está puesta y el motor no está encendido.

KOER The acronym for a test condition in which the key is on and the engine is running.

KOER Acrónimo para una condición de prueba en la cual la llave está puesta y el motor está encendido.

Lambda sensor A form of oxygen sensor used on some European cars.

Sensor lambda Un tipo de detector del oxígeno que se usa en algunos coches europeos.

Lamination Thin layers of soft metal used as the core for a magnetic circuit.

Láminas Las hojas delgadas del metal blando que sirven de alma de un circuito magnético.

Land The areas on a piston between the grooves.

Meseta del pared Las areas de un pistón entre las muescas.

Lash The operational gap between two objects.

Juego La holgura que permite operar dos objetos.

Latent heat The heat required to change a mass's state of matter.

Calor latente El calor requerido para cambiar una masa a un estado differente.

Lateral runout A side-to-side variation, or wobble, as something is rotated.

Desviación lateral Una variación o bamboleo de lado a lado, cuando algo rota.

Leakdown The relative movement of the plunger with respect to the hydraulic valve lifter body after the check valve is seated by pressurized oil. A small amount of oil leakdown is necessary for proper hydraulic valve lifter operation.

Fuga por abajo El movimiento relativo del émbolo con respeto al cuerpo de la levantaválvula hidráulica después de que la válvula de un sólo paso se asienta por el aceite a presión. Una pequeña cantidad de fuga es necesario para asegurar una operación correcta de la levantaválvula hidráulica.

Lean An air-fuel mixture that has more air than is required for a stoichiometric mixture.

Mezcla pobre Una mezcla de combustible y aire que tiene más aire de lo que requiere una mezcla estoquiométrica.

Lepelletier gears A compound planetary gearset that is based on a simple planetary gearset connected to a Ravigneaux compound gearset.

Engranaje Lepelletier Un conjunto de engranaje central compuesto que se basa en un simple conjunto de engranaje central conectado a un conjunto compuesto de engranaje Ravigneaux.

Lever A device made up of a bar turning about a fixed point, called the fulcrum, that uses a force applied at one point to move a mass on the other end of the bar.

Palanca Un dispositivo compuesto de una barra que da la vuelta sobre un punto fijo, llamado el fulcro, que utiliza una fuerza aplicada en un punto para mover una masa en el otro extremo de la barra.

Light-emitting diode (LED) A type of digital electronic display used as either single indicator lights or grouped to show a set of letters or numbers.

Diodo emisor de luz (LED) Un tipo de indicador electrónico digital que tiene luces indicadores individuales o en grupos para formar un conjunto de letras o números.

Limited-slip differential (LSD) A type of differential that allows more torque to be sent to the wheel with the most traction.

Deslizamiento limitado Un tipo de diferencial que permite que más energía del par se envía a la rueda con más tracción.

Line boring An engine block machining operation in which the main bearing housing bores are rebored to standard size and in perfect alignment.

Rectificación en linea Una operación maquinaria del bloque del motor en la cual los taladros principales de la caja se taladran de nuevo para asegurar un tamaño uniforme y una alineación perfecta.

Line pressure The hydraulic pressure that operates apply devices and is the source of all other pressures in an automatic transmission. It is developed by pump pressure and regulated by the pressure regulator.

Presión de línea Presión hidráulica que opera dispositivos de aplicación y es la fuente de todas las otras presiones en una transmisión automática. Se desarrolla por presión de bomba y se regula por regulador de presión.

Linear rate springs A coil spring with equal spacing between the coils, one basic shape, and constant wire diameter having a constant deflection rate regardless of load.

Resortes de variación lineal Resortes en espiral de espaciamiento igual entre espiras, una forma básica y un diámetro de alambre constante, con una tasa constante de desviación, sea cual sea la carga.

Lineman's gloves Electrically insulated gloves. These gloves must be worn whenever working on or around high-voltage circuits.

Guantes de técnico Guantes con aislamiento eléctrico. Se deben usar estos guantes cuando se trabaja en o cerca de circuitos de alto voltaje.

Lip seals An assembly consisting of a metal or plastic casing, a sealing element made of rubber, and a garter spring to help hold the seal against a turning shaft.

Sellos del labio Una asamblea que consiste de un cárter de metal o de plástico, un elemento sellante hecho de caucho, y un resorte de liga que sirve para apretar al sello contra una flecha que gira.

Liquefied petroleum gas (LP gas) A mixture of hydrocarbons found in natural gas and used primarily as a home heating fuel and motor vehicle fuel.

Gas de petróleo licuado (gas LP) Una mezcla de hidrocarburos que se encuentran en el gas natural y se utilizan principalmente como combustible para calentar hogares y como combustible para vehículos de motor.

Lithium-ion (Li-Ion) A battery in which lithium is used as the electrochemically active material and the electrolyte is a liquid that conducts lithium ions.

Ion de litio (Li-Ion) Batería que funciona con litio usada como material electroquímicamente activo y el electrolito es un líquido que conduce iones de litio.

Live axle An axle on which the wheels are firmly affixed. The axle drives the wheels.

Eje motor Un eje en el cual las ruedas se montan rígidamente. El eje acciona las ruedas.

Load The work an engine must do, under which it operates more slowly and less efficiently. The load could be that of driving up a hill or pulling extra weight.

Carga El trabajo que debe ejecutar el motor, bajo el cual opera más lentamente y con menos eficiencia. La carga puede ser el de viajar cuesta arriba o de arrastrar el peso extra.

Load test A battery test conducted to determine how well a battery performs under a load.
Prueba de carga Una prueba de batería que se realiza para determinar el desempeño de una batería bajo una carga.
Lobe The part of the camshaft that raises the lifter.
Lóbulo La parte del árbol de levas que alza el buzo.
Locking hubs Wheel hubs used to lock drive axles to the wheels. When locked, power moves from the axle to the wheel. When unlocked, power stops at the axles.
Mazas de enclavamiento Mazas de rueda que se utilizan para trabar los ejes de accionamiento con las ruedas. Al trabarse, la potencia se transfiere del eje a la rueda. Al destrabarse, la potencia se detiene en los ejes.
Lockup The point at which braking power overcomes the traction of the vehicle's tires and skidding occurs. The most efficient stopping occurs just before lockup is reached. Locked wheels cause loss of control, long stopping distances, and flat-spotting of the tires.
Enclavamiento El punto en el cual el enfrenamiento supera la tracción de los neumáticos del vehículo y ocurre el patinaje. El enfrenamiento más eficiente se efectúa justo antes de que ocurre el enclavamiento. Las ruedas enclavadas causan una pérdida del control, el enfrenamiento dilatorio y el gasto irregular de los neumáticos.
Lockup torque converter A converter with a friction disc that locks the impeller and turbine together.
Convertidor de par de torsión de bloqueo Un convertidor con un disco de fricción que bloquea al impulsor y la turbina.
Logic gate Electronic circuit that acts as a gate to output voltage signals depending on different combinations of input signals.
Compuerta lógico El circuito electrónico que sirve como una puerta a las señales del voltaje de salida según las combinaciones distinctas de señales de entrada.
Long block This is basically a short block with cylinder heads.
Bloque largo Es básicamente un bloque corto con culatas de cilindro.
Look-up tables The part of a microcomputer's memory that indicates in the form of calibrations and specifications how an engine should perform.
Obtención de datos de una tabla La parte de una memoria del microcomputador que indica en la forma de las calibraciones y las especificaciones como debe funcionar el motor.
Low side The low pressure portion of an air-conditioning system.
Lado de baja La porción de baja presión de un sistema de aire acondicionado.
LP gas Liquified petroleum gas, often referred to as propane, which burns clean in the engine and can be precisely controlled.
Licuados del petróleo El gas de petróleo en forma líquido, típicamente llamado el propano, que se quema completamente en el motor y que puede ser controlado precisamente.
Lubrication The process of reducing friction between the moving parts of an engine.
Lubricación El proceso de reducir la fricción entre dos partes que mueven en un motor.
MacPherson strut suspension A suspension system in which the strut is connected from the steering knuckle to an upper strut mount, and the strut replaces the shock absorber.
Suspensión del puntal de tipo MacPherson Un sistema de suspensión en donde el puntal se conecta al muñón de la dirección a un montaje superior para el puntal, y el puntal reemplaza el amortiguador.
Magnet Any body with the property of attracting iron or steel.
Imán Cualquier cuerpo que tiene la propriedad de atraer al hierro o al acero.
Magnetic field The area surrounding the poles of a magnet that is affected by its attraction or repulsion forces.
Campo magnético El área alrededor de los polos de un imán que se afectan por las fuerzas de atracción o repulsión.
Magnetic pulse generator An engine position sensor used to monitor the position of the crankshaft and control the flow of current to the center base terminal of the switching transistor.
Generador de pulsos magnéticos Un detector de la posición del motor que sirve para regular la posición de la cigueñal y controlar el flujo del corriente al terminal de la base central del transistor interruptor.
Magnetism A force between two poles of opposite potential caused by the alignment of electrons.
Magnetismo Fuerza entre dos polos de potencial opuesto, provocada por la alineación de los electrones.
Magnetoresistive A type of sensor that produces a digital signal based on the change in the magnetic field within the sensor.
Sensor magnetorresistivo Tipo de sensor que produce una señal digital a partir de la variación del campo magnético que se encuentra dentro de él.
Magnitude Normally refers to the height of an electrical signal.
Magnitúd Normalmente se refiere a la intensidad de un señal eléctrico.
Mainline pressure Pressure that is regulated in an automatic transmission hydraulic system.
Presión de la línea procedente de la bomba La presión que se regula en un sistema de transmisión hidráulica automática.
Maintenance-free battery A battery test conducted to determine how well a battery performs under a load.
Batería libre de mantenimiento Una prueba de batería que se realiza para determinar el desempeño de una batería bajo una carga.
Malfunction indicator lamp (MIL) A warning lamp in a vehicle's instrument panel that lets the driver know when the vehicle's electronic control units detected a problem.
Lámpara indicadora de fallas (MIL) Una lámpara de advertencia en el tablero de instrumentos de un vehículo que permite al conductor saber cuándo las unidades de control electrónico del vehículo detectan un problema.
Malleable Able to be shaped.
Maleable Capaz de ser formado.
Manifold A structure used to channel intake air in and exhaust gases out of the engine's cylinders.
Múltiple Una estructura que se utiliza para dirigir el aire de admisión hacia dentro y los gases de escape hacia afuera de los cilindros del motor.
Manifold absolute pressure A measure of the degree of vacuum or pressure within an intake manifold; used to measure air volume flow.
Presión absoluta en el múltiple Una medida del grado del vacío o de la presión dentro de un múltiple de admisión; sirve para medir el volumen del flujo del aire.
MAP sensor The sensor that measures changes in the intake manifold pressure that result from changes in engine load and speed.
Sensor MAP El detector que mide los cambios de presión en el múltiple de admisión que resultan según los cambios de la carga y la velocidad del motor.
Margin The area between the valve face and the head of the valve.
Margen El área entre la cara de la válvula y la cabeza de la válvula.
Mass The amount of matter in an object.
Masa La cantidad de materia en un objeto.
Mass airflow (MAF) sensor An EFI air intake sensor that measures the mass, not the volume, of the air flowing into the intake manifold.
Sensor de la masa del aire Un detector del admisión del aire de inyección de combustible electrónico que mide la masa, en vez del volumen, del aire que fluye al múltiple de admisión.
Master cylinder The liquid-filled cylinder in the hydraulic brake system or clutch where hydraulic pressure is developed when the driver depresses a foot pedal.
Cilindro maestro El cilindro lleno de líquido del sistema de freno hidráulico o embrague donde se desarrolla la presión hidráulica cuando el conductor oprime un pedal.
Material safety data sheets (MSDS) Information sheets containing chemical composition and precautionary information for all products that can present a health or safety hazard.
Folletos de información de materiales y precauciones (MSDS) El folleto que contiene la información pertinente a la composición química y la indicaciones precavidos para todos los productos que pueden presentar peligros a la salud o la seguridad.
Matter Anything that occupies space.
Materia Cualquier cosa que ocupa el espacio.
Maxi-fuse A heavy-duty circuit protection device that has the appearance of a large blade-type fuse.
Maxifusible Un dispositivo de protección de circuitos de uso pesado, que tiene la apariencia de un fusible tipo cuchilla grande.

Mechanical advantage The result of a machine or system that increases the force available to do work.
Ventaja mecánica El resultado de una máquina o de un sistema que aumente la fuerza disponible para hacer el trabajo.
Mechanical efficiency (engine) The ratio between the indicated horsepower and the brake horsepower of an engine.
Eficiencia mecánica (motor) La relación entre la potencia indicada en caballos y el caballo indicado al freno de un motor.
Memory The part of a computer that stores, or holds, the programs and other data.
Memoria La parte de una computador que archiva, o guarda, a las aplicaciones u otros datos.
Mesh To fit together, as gear teeth.
Engrenar Ajustarse bien, tal como los dientes de un engrenaje.
Metallic linings Brake friction material made from powdered metal that is formed into blocks by heat and pressure.
Recubrimientos metálicos Material de fricción de frenado, fabricado con metal pulverizado al cual se da forma de bloque mediante calor y presión.
Metered To control the amount of fuel passing into an injector. Fuel is metered to obtain the correct measured quantity.
Medir Controlar la cantidad del combustible que pasa al inyector. El combustible se mide para asegurar una cantidad medida correcta.
Metering valve A component that momentarily delays the application of front disc brakes until the rear drum brakes begin to move. Helps to provide balanced braking.
Válvula dosificadora Un componente que retrasa momentáneamente la aplicación de los frenos de disco delanteros hasta que comienzan a moverse los frenos de tambor traseros. Contribuye a asegurar un frenado más equilibrado.
Methanol The lightest and simplest of the alcohols; also known as wood alcohol.
Metano El más ligero y más sencillo del grupo de alcohol; tambien llamado el alcohol piroleñoso.
Microprocessor The portion of a microcomputer that receives sensor input and handles all calculations.
Microprocesor La parte de un microcomputador que recibe la información de los detectores y se encarga de todas las calculaciones.
Millisecond One thousandth of a second.
Milisegundo Una milésima de un segundo.
Miscibility The ability of one chemical to mix well with another chemical.
Miscible La característica de una química a mezclarse bien con otra química.
Misfiring Failure of an explosion to occur in one or more cylinders while the engine is running; can be continuous or intermittent failure.
Fallo de encendido El fallo en que una detonación ocurre en uno o más cilindros mientras que este en marcha el motor; puede ser un fallo continuo o intermitente.
Mode Manner or state of existence of a thing; for example, heat or cool.
Modo Manera o estado de existencia de una cosa; por ejempto, calor o fresco.
Modulation Pulsing.
Modulación Pulsante.
Molecule The smallest particle of an element or compound that can exist in the free state and still retain the characteristics of the element or compound.
Molécula La partícula más pequeña de un elemento o un compuesto que puede existir en el estado libre y todavía conservar las características del elemento o del compuesto.
Momentum A type of mechanical energy that is the product of an object's weight times its speed.
Momento Un tipo de energía mecánica que es el producto del peso de un objeto multiplicado por su velocidad.
Monolith A single body shaped like a pillar or long tubular structure used as a catalyst in a catalytic converter.
Monolito Un cuerpo sólo en forma de columna o una estructura larga y tubular que sirve de catalizador en un convertidor catalítico.
Muffler (1) A hollow, tubular device used in the lines of some air conditioners to minimize the compressor noise or surges transmitted to the inside of the car. (2) A device in the exhaust system used to reduce noise.
Silenciador (1) Un dispositivo tubular hueco que se usa en las líneas de algunos equipos de aire acondicionado para reducir al mínimo el ruido del compresor o las sobrecargas transmitidas al interior del vehículo. (2) Un dispositivo del sistema de escape que sirve para reducir el ruido.
Multimeter A tool that combines the voltmeter, ohmmeter, and ammeter together in one diagnostic instrument.
Multímetro Una herramienta que combina las funciones del voltiometro, del ohmímetro, y del amperímetro en un instrumento diagnóstico.
Multiple-disc assembly is clutch A device in a transmission used to hold or drive a member of a planetary gearset.
Conjunto de embrague multidisco Dispositivo del sistema de transmisión que se usa para sostener o impulsar un miembro de engranajes planetario.
Multiple-disc clutch A clutch with a number of driving and driven discs as compared to a single plate clutch.
Embrague de discos múltiples Un embrague que tiene varios discos de arrastre y accionados, a diferencia de un embrague de una sola placa.
Multiple-pole, multiple throw (MPMT) The common designation for a switch that has multiple throws and poles.
Múltiples polos, múltiples tiros (MPMT) Nombre común cado a un interruptor que tiene múltiples tiros y polos.
Multiplexing A means of transmitting information between computers. A system in which electrical signals are transmitted by a peripheral serial bus instead of common wires, allowing several devices to share signals on a common conductor.
Multiplexar Una manera de transferir la información entre las computadoras. Un sistema en el cual los señales eléctricos se transmiten por medio de un bus serial periférico en vez de por los alambres comunes, así permitiendo que varios dispositivos comparten los señales en un conductor común.
Multiviscosity oil A chemically modified oil that has been tested for viscosity at cold and hot temperatures.
Aceite de viscosidad de grado múltiple Un aceite modificado químicamente cuya viscosidad se ha probado en temperaturas bajas y altas.
Net pay Pay from employment, this is equal to gross pay minus taxes and benefit costs.
Sueldo neto sueldo del empleo, que equivale al sueldo bruto menos los impuestos y costos de beneficios.
Neutral safety switch A switch wired into the ignition switch to prevent engine cranking unless the transmission shift lever is in neutral.
Interruptor de seguridad neutral Un interruptor cableado en el interruptor de encendido para evitar que arranque el motor a menos que la palanca de la transmisión esté en neutral.
Newton-meter (N-m) The metric measurement of torque or twisting force.
Newton metro (Nm) Medida métrica de torque o fuerza de torsión.
Nickel-metal hydride (NiMH) A battery made of nickel hydroxide and hydride alloys. The electrolyte is potassium hydroxide.
Níquel metal hidruro (NiMH) Batería hecha de hidróxido de níquel y aleación de hidruro. El electrolito es hidróxido de potasio.
Nodular iron A metal used in pressure plates that contains graphite, which acts as a lubricating agent.
Hierro nodular Un metal usado en los platos opresores que contiene el grafito, que funciona como un agente de lubricación.
Nonasbestos organic linings (NAO) Organic brake linings that are made of nonmetallic fibers bonded together to form a composite material.
Revestimientos orgánicos no de asbestos (NAO) Estos revestimientos parafrenos se hacen con fibras no metálicas unidas para formar un material compuesto.
Nonhunting gearset A differential gearset in which one drive pinion gear tooth contacts only three ring gear teeth after several rotations.
Conjunto de engrenaje sin diente suplementario Un conjunto de engrenaje en el cual un diente del engrenaje de piñón engrane solamente con tres dientes del engrenaje del anillo después de varias rotaciones.
Nonintegral antilock brake system This is also called an add-on ABS unit and is separate from the master cylinder and power booster.
Sistema de frenos antibloqueo no integral También se conoce como unidad de ABS agregada y está separado del cilindro maestro y del reforzador del freno.

Nonservo drum brake A drum brake that develops self-energizing action only on the leading shoe.

Freno de tambor sin servo Un freno de tambor que desarrolla una acción autoenergizante solo en la zapata principal.

Nonverbal communication A form of communications that includes such things as body language and tone. Body language includes facial expression, eye movement, posture, and gestures.

Comunicación no verbal Una forma de comunicaciones que incluye cosas tales como el lenguaje corporal y el tono de voz. El lenguaje corporal incluye la expresión facial, el movimiento de los ojos, la postura y los gestos.

Nonvolatile RAM (VRAM) A type of computer memory that does lose its stored information when it loses its power source.

RAM no volátil (VRAM) Un tipo de memoria de computadora que pierde su información almacenada al perder su fuente de alimentación.

Normally aspirated The method by which an internal combustion engine draws air into the combustion chamber. As the piston moves downward in the cylinder, it creates a vacuum that draws air into the combustion chamber through the intake manifold.

Aspirado normalmente El método por el cual un motor de combustión interno hace entrar al aire en la cámara de combustión. Al moverse hacia abajo el pistón en el cilindro crea un vacío que hace entrar el aire a la cámara de combustión a través del múltiple de admisión.

Occupational Safety and Health Administration (OSHA) A government agency charged with ensuring safe work environments for all workers.

OSHA Administración de Salud y Seguridad Ocupacional, la cual es una agencia gubernamental encargada de asegurar ambientes de trabajo seguros para todos los trabajadores.

Octane A unit of measurement on a scale intended to indicate the tendency of a fuel to detonate or knock.

Índice de octano Una unidad de medida en una gama cuya intención es de indicar la tendencia de un combustible de causar una detonación o los golpeteos.

OEM parts Parts made by the original vehicle manufacturer.

Partes EOF Las partes hechas por el fabricante original del vehículo.

Offset Placed off center. Also, the measurement between the center of the rim and the point where a wheel's center is mounted.

Descentrado Ubicado fuera del centro. Tambien, la medida entre el centro del ancho del rim y el punto en que se monta la rueda.

Ohm A unit of measured electrical resistance.

Ohmio Una unidad de medida de la resistencia eléctrica.

Ohm's law A basic law of electricity expressing the relationship between current, resistance, and voltage in any electrical circuit. It states that the voltage in the circuit is equal to the current (in amperes) multiplied by the resistance (in ohms).

Ley de los ohmios Una ley básica de la electricidad que describe la relación entre el corriente, la resistencia, y el voltaje en cualquier circuito eléctrico. Declara que el voltaje en un circuito iguala al corriente (en amperios) multiplicado por la resistencia (en ohmios).

Ohmmeter The meter used to measure electrical resistance.

Ohmímetro El medidor utilizado para medir la resistencia eléctrica.

Open circuit An electrical circuit that has a break in the wire.

Circuito abierto Un circuito eléctrico que tiene una quebradura en el alambre.

Open circuit voltage The no load voltage of a cell or battery measured with a high resistance voltmeter.

Voltaje de circuito abierto El voltaje sin carga de una pila o batería, que se mide mediante un ohmímetro de alta resistencia.

Open loop An electronic control system in which sensors provide information, the microcomputer gives orders, and the output actuators obey the orders without feedback to the microcomputer.

Bucle abierto Un sistema de control electrónico en el cual los detectores proveen la información, el microcomputador da los ordenes, y los actuadores de salida obedecen a éstas ordenes sin realimentación a la microcomputadora.

Organic soils Type of dirt that contains carbon and cannot be effectively removed with plain water.

Suelos orgánicos Tipo de suciedad que contiene carbón y no puede quitarse de manera eficaz con agua corriente.

Orifice tube A tube with a precisely sized hole that controls fluid flow.

Tubo de orificio Tubo que tiene un agujero de tamaño preciso para controlar el flujo de líquidos.

Original equipment manufacturer (OEM) Parts manufactured by the original vehicle manufacturer are called original equipment manufacturer (OEM) parts.

Partes originales del fabricante (OEM, por sus siglas en inglés) Las partes producidas por el fabricante original del vehículo se llaman partes OEM.

Oscillation Any single swing of an object back and forth between the extremes of its travel.

Oscilación Cualquier movimiento único de un objeto hacia adelante y hacia atrás entre los extremos de su recorrido.

Out-of-round An inside or outside diameter, designed to be perfectly round, having varying diameters when measured at different points across its diameter.

Ovulado Un diámetro interior o exterior, por diseño perfectamente redondo, que tiene varios diámetros cuando se mide en puntos distintos a través de su diámetro.

Outboard joint The CV joint that connects the drive axle to the wheel spindle.

Junta exterior La junta de velocidad constante que conecta el eje motor al husillo de la rueda.

Output driver An electronic on/off switch located in the processor and operated by the digital commands of the computer used to control the ground circuit of a specific actuator.

Controlador de salida Ubicado en el procesador y operado por comandos digitales de la computadora, un controlador de salida es un interruptor electrónico de encendido/apagado usado para controlar el circuito de tierra de un activador específico.

Overdrive Normally used to express a gear ratio that allows the driven gear to rotate faster than the drive gear.

Sobremarcha Normalemente se usa para describir una relación de engrenaje que permite que el engrenaje arrastrado gira más rápidamente que el engrenaje propulsor.

Overlap The period during which the intake and exhaust valves are open at the same time.

Temporización El periódo en el cual las válvulas de admisión y de escape están abiertas a la misma vez.

Override clutch The mechanism that disengages the starter from the engine as soon as the engine turns more rapidly than the starter has cranked it.

Embrague de invalidación El mecanismo que desembraga el motor de arranque en el momento que el motor gira más rápidamente que el motor de arranque.

Overrunning clutch A device consisting of a shaft or housing linked together by rollers or sprags operating between movable and fixed races. As the shaft rotates, the rollers or sprags jam between the movable and fixed races. This jamming action locks together the shaft and housing. If the fixed race should be driven at a speed greater than the movable race, the rollers or sprags will disconnect the shaft.

Embrague de rodamiento libre Un dispositivo que consiste en un eje o carcasa enlazado mediante rodillos o embragues de rueda libre que operan entre canales de rodamiento móviles y fijos. A medida que gira el eje, los rodillos o embragues de rueda libre se atascan entre los canales de rodamiento móviles y fijos. Esta acción de atascamiento bloquea el eje y la carcasa. Si el canal de rodamiento fijo se acciona a una velocidad mayor que el canal móvil, los rodillos o embragues de rueda libre desconectan el eje.

Oversquare A term used to describe an engine that has a larger bore than stroke.

Oversquare Usado para describir un motor que tenga un cilindro con un diámetro interior más grande que la longitud del movimiento del pistón.

Oxidation The combination of a substance with oxygen to produce an oxygen-containing compound. Also, the chemical breakdown of a substance or compound caused by its combination with oxygen.

Oxidación La combinación de una sustancia con el oxígeno para producir una compuesta que tenga oxígeno. Tambien, una descomposición química de una sustancia o una compuesta causada por su combinación con el oxígeno.

Oxidation catalyst A catalyst that breaks down substance when oxygen is introduced.
Catalizador de oxidación Un catalizador que descompone la substancia cuando se introduce oxígeno.
Oxidation inhibitor Gasoline additives used to promote gasoline stability by controlling gum and deposit formation and staleness.
Inhibitor del oxígeno Los aditivos de la gasolina que promuevan la estabilidad de la gasolina por medio de controlar la formación del sarro y los depósitos y el rancidez.
Oxidation rate Speed by which oxygen is taken into a substance.
Tasa de oxidación La velocidad en que el oxígeno se absorbe por una sustancia.
Oxides of nitrogen (NO_x) Various compounds of oxygen and nitrogen that are formed in the cylinders during combustion and are part of the exhaust gas.
Óxido de nitrógeno (NO_x) Varias compuesta del oxígeno y el nitrógeno que se forman en los cilindros durante la combustión y son parte del vapor del escape.
Oxygen (O_2) sensor An input sensor that sends a voltage signal to the computer in relation to the amount of oxygen in the exhaust stream.
Sensor de oxígeno (O_2) Es un sensor de entrada que le envía una señal de voltaje a la computadora referente a la cantidad de oxígeno en la pipa del escape.
Oxygenates Compounds such as alcohols and ethers that contain oxygen that are added to gasoline to reduce emissions and increase its octane rating.
Oxigenadores Compuestos como alcoholes y éteres que contienen oxígeno que se agregan a la gasolina para reducir emisiones y aumentar su índice de octanaje.
Parallel circuit In this type of circuit, there is more than one path for the current to follow.
Circuito paralelo En este tipo de circuito, hay más que una senda en que puede viajar el corriente.
Parallelism Thickness uniformity of a disc brake rotor. Both surfaces of a rotor must be parallel with each other within 0.001 inch or less.
Paralelismo Uniformidad del grosor de un rotor de freno de disco. Ambas superficies de un rotor deben ser paralelas entre sí, con un error de 0.001 pulgadas o menos.
Parameter identification (PID) A scan tool display for OBD II systems that shows current emission-related data values of inputs and outputs, calculated values, and system status information.
Identificación de parámetros (PID) Un despliegue de herramienta de escaneo para sistemas OBD II que muestra los valores de la información relacionada a la emisión actual de entradas, salidas, valores calculados e información del estado del sistema.
Parasitic load An electrical load that is still present when the ignition switch is off.
Carga parásita Una carga eléctrica que siga presente cuando el interruptor de encendido esta apagado.
Partial nonhunting gearset A gearset in which any one pinion gear tooth will come in contact with only some of the teeth on the ring gear and more than one revolution is required to achieve all possible combinations.
Juego parcial de engranajes sin oscilación Un conjunto de engranajes en el que cualquier diente de engranaje del piñón entrará en contacto con solo algunos de los dientes de la corona y se requiere más de una revolución para lograr todas las combinaciones posibles.
Particulate filter A diesel vehicle emission control device that traps and incinerates diesel particulate emissions after they are exhausted but before they are expelled into the atmosphere.
Filtro de partículas (PM) Dispositivo de control de emisiones de vehículos diésel que atrapa e incinera partículas de emisiones de diésel después que han sido quemadas pero antes que sean lanzadas a la atmósfera.
Parts per million (ppm) The unit commonly used to represent the degree of pollutant concentration where the concentrations are small.
Partes por millón (ppm) La unidad utilizada para representar el grado de concentración de contaminantes cuando las concentraciones son pequeñas.
PCM Power control module.
PCM Módulo de control de la potencia.
PCV valve Positive crankcase ventilation valve. A valve that delivers crankcase vapors into the intake manifold rather than allowing them to escape to the atmosphere.
Válvula de ventilación positiva del cárter Una válvula que conduce vapores del cigüeñal al múltiple de admisión, en lugar de dejar que se descarguen a la atmósfera.
Peak and hold injector A type of fuel injection system that relies on two separate drivers in the PCM, both drivers open the circuit and then one turns off while the other keeps the injector open until it is time for it to close.
Inyector de cantidad máxima y de retención Un tipo de sistema de inyección de combustible que se basa en dos conductores separados en el PCM; ambos conductores abren el circuito y entonces uno se apaga mientras que el otro mantiene el inyector abierto hasta que llegue el momento de cerrarlo.
Peen To stretch or clinch over by pounding with the rounded end of a hammer.
Martillazo Estirar o remachar con la extremidad redondeado de un martillo de bola.
Peltier element A solid state device that transfers heat from one side of the device to the other, depending on the direction of the current flow.
Elemento Peltier Un dispositivo de estado sólido que transfiere calor de un lado del dispositivo al otro, dependiendo de la dirección del flujo de corriente.
Pentroof A modified design of a hemispherical combustion chamber found mostly in engines with four valves per cylinder. The spark plug is located in the center of the chamber and the intake and exhast valves are on opposite sides of the chamber.
Parte superior inclinada Un diseño modificado de una cámara de combustión hemisférica que se encuentra principalmente en los motores con cuatro válvulas por cilindro. La bujía está situada en el centro de la cámara y las válvulas de admisión y de escape están en lados opuestos de la cámara.
Permeable A characteristic of materials that absorb fluids.
Permeable Una característica de los materiales que absorben los líquidos.
Petroleum Oil as it is found in its natural state under the ground.
Petróleo Petróleo crudo como se encuentra en su estado natural bajo la tierra.
pH scale A scale used to measure how acidic or basic a solution is.
Escala del pH Un sistema que mide el grado de acidez de una solución.
Phase Refers to the rotational positions of the various elements of a driveline.
Fase Se refiere a las posiciones giratorias de los varios elementos de una flecha motríz.
Phaser The device mounted to the end of a camshaft that allows camshaft-to-crankshaft timing to change while the engine is running. Phasers can be electronically or hydraulically controlled.
Corrector de fase El dispositivo montado en el extremo de un árbol de levas que permite que la sincronización entre dicho árbol de levas y el cigüeñal cambie mientras el motor está funcionando. Los correctores de fase se pueden controlar electrónica o hidráulicamente.
Phenolic resin Plastic made primarily from phenol, a compound derived from benzene and also called carbolic acid.
Resina fenólica Plástico fabricado principalmente a partir de fenol, un compuesto derivado del benceno y también llamado ácido carbólico.
Pickup coil A weak permanent magnet and wire assembly that in combination with a reluctor forms a position sensor.
Bobina de captación Una asamblea de alambre y un imán débil permanente que en combinación con un reluctor forma un detector de posición.
Piezoelectric injector A fuel injector that relies on the movement of crystals to open and close the flow of fuel into a cylinder.
Inyector piezoeléctrico Un inyector de combustible que se basa en el movimiento de cristales para abrir y cerrar el flujo de combustible hacia un cilindro.
Piezoresistive A characteristic of something that changes resistances in relationship to changes in pressure.
Piezoresistivo Una característica de algo que cambia la resistencia relativamente con los cambios de la presión.

Pilot bushing A plain bearing fitted in the end of a crankshaft. The primary purpose is to support the input shaft of the transmission.
Buje piloto Chumacera simple que se adapta al extremo de un cigüeñal. Su finalidad primordial es la de soportar al eje de entrada de la transmisión.
Pinion gear The smaller of two meshing gears.
Piñón diferencial El más pequeño de dos engranajes enganchados uno al otro.
Pinning Cold crack repair process involving the installation of tapered plugs in the crack or on either side of the crack.
Chavetear Un proceso de reparar las grietas sin calor que involucra la instalación de los espárragos cónicos en las grietas o a un lado de la grieta.
Pintle The center pin used to control a fluid passing through a hole; a small pin or pointed shaft used to open or close a passageway.
Clavija La aguja central que controla al flúido que pasa por un hoyo; una pequeña clavija o flecha puntiaguda que sirve para abrir o tapar un pasillo.
Piston An engine component in the form of a hollow cylinder that is enclosed at the top and open at the bottom. Combustion forces are applied to the top of the piston to force it down. The piston, when assembled to the connecting rod, is designed to transmit the power produced in the combustion chamber to the crankshaft.
Pistón Un componente del motor que consiste de un cilindro hueco cerrado en la parte de arriba y abierto en la parte de abajo. Las fuerzas de combustión se aplican en la parte superior del pistón para forzarlo hacia abajo. El pistón, al conectarse a la biela, es diseñado para transmitir la fuerza producida en la cámara de combustión al cigüeñal.
Piston pin A pin used to connect the piston to the small end of a connecting rod.
Perno de pistón Un pasador que se utiliza para conectar el pistón al extremo pequeño de una varilla de conexión.
Piston rings Components that seal the compression and expansion gases and prevent oil from entering the combustion chamber.
Anillos (aros) del pistón Los componentes que sellan los gases de la compresión y la expansión y previenen que entre el aceite en la cámara de combustión.
Pitch The angle of the valve spring twist. A variable pitch valve spring has unevenly spaced coils.
Paso El ángulo de las espiras de un resorte de válvula. Un resorte de válvula con paso variable tiene separaciones iniguales entre las espiras.
Pitch gauge A tool used to measure the thread pitch of a bolt.
Comprobador de paso de rosca Una herramienta que sirve para medir el paso de las roscas de un perno.
Pitman arm A steering linkage component that connects the steering gear to the linkage at the left end of the center link.
Brazo de dirección (biela de mando) Componente de enlace del sistema de dirección que conecta el mecanismo al extremo izquierdo del enlace central.
Pitting Surface irregularities resulting from corrosion.
Picadura Las irregularidades de la superficie causadas por la corrosión.
Planetary carrier Part of a planetary gearset. The carrier has a shaft for each of the planetary pinion gears. The carrier and pinions are considered one unit—the mid-size gear member. The planetary pinions surround the sun gear and are surrounded by the ring gear.
Portador de planetario Parte de un conjunto de engranajes planetarios. El portador cuenta con un eje para cada uno de los piñones planetarios. El portador y los piñones se consideran una unidad, el miembro de engranaje de tamaño medio. Los piñones planetarios rodean el piñón central y están rodeados por la corona.
Planetary gearset A group of gears named after the solar system because of their arrangement and action. This unit consists of a center (sun) gear around which pinion (planet) gears revolve. The assembly is placed inside a ring gear having internal teeth. All gears mesh constantly. Planetary gearsets may be used to increase or decrease torque and/or obtain neutral, low, intermediate, high, or reverse.
Juego de engranajes planetarios (piñones satélites) Un grupo de engranajes cuyo nombre se inspira en el sistema solar por su disposición y su modo de actuar. Esta unidad consiste en un engranaje central (sol) en torno al que giran piñones diferenciales (planetas). El conjunto se coloca al interior de un engranaje anular con dientes internos. Todos los engranajes están enganchados continuamente. Estos juegos se pueden utilizar para hacer que aumente o disminuya el par de torsión y/u obtener velocidades neutra, baja, intermedia, alta o de retroceso.
Planetary pinions Small gears fitted into the planetary carrier of a planetary gearset.
Piñones planetarios Engranajes pequeños montados en portador planetario de un conjunto de engranajes planetarios.
Plasma An ionized gas and the fourth state of matter after solid, liquid, and gas.
Plasma Un gas ionizado y el estado cuarto después de sólido, de líquido, y del gas.
Plastigage A special wax used to measure bearing clearances.
Plastigage (calibrador de plástico) Una cera especial que sirve para medir las holguras.
Plates A group of the primary parts of a battery, also called electrodes. Each battery cell has at least one plate with an abundance of electrons (negative plate) and another with a lack of electrons (positive plate).
Placas Un grupo de las partes principales de una batería, también llamados electrodos. Cada celda de batería tiene al menos una placa con una abundancia de electrones (placa negativa) y otra con una falta de electrones (placa positiva).
Plate strap The connector inside a lead-acid battery that connects the plates of the same polarity together and to the battery post.
Correa de placa El conector en el interior de una batería de plomo-ácido que conecta las placas de la misma polaridad entre sí y al borne de la batería.
Play Movement between two parts.
Juego El movimiento entre dos partes.
Plies The reinforcing members of a tire composed of layers of cord fabric and rubber that provide the strength to contain the air pressure needed to support a load and resist deflection.
Capas Los miembros de refuerzo de un neumático compuestos de capas de tela de cuerda y caucho que proporcionan la resistencia para contener la presión de aire necesaria para soportar una carga y resistir la deflexión.
Plug-in hybrid electric vehicles (PHEVs) Full hybrids with larger batteries and the ability to recharge from an electric power grid. They are equipped with a power socket that allows the batteries to be recharged when the engine is not running.
Vehículo híbrido eléctrico de conectar (PHEV) Los híbridos totales con baterías más grandes y la habilidad de recargar de una matriz energética eléctrica. Están equipados con un interruptor de energía que permite que las baterías se recarguen cuando el motor no está funcionando.
Plunge joint The type of CV joint that allows the half-shaft to effectively change length in response to suspension movements by having the capability of in and out movements.
Junta homocinética que se extiende longitudinalmente El tipo de junta homocinética que permite que el medio de eje cambie de longitud de manera eficaz en respuesta a movimientos de la suspensión por tener la capacidad de hacer movimientos de entrada y salida.
Pneumatic Operated by compressed air.
Neumático Operado por el aire comprimido.
Polarity The particular state, either positive or negative, with reference to the two poles or to electrification.
Polaridad Un estado particular, sea positivo o negativo, en referencia a los dos polos o a la electrificación.
Pole On an electrical switch, this term refers to the input circuit(s) to the switch.
Polo En un interruptor eléctrico, este término se refiere al/los circuito(s) de entrada al interruptor.
Polyacrylate A type synthetic rubber used for rear main bearing seals. It is tough and abrasion resistant, with moderate temperature resistance to 350 degrees.
Poliacrilato Un tipo de caucho sintético utilizado para los sellos del cojinete principal trasero. Es duro y resistente a la abrasión, con resistencia moderada a la temperatura hasta los 350 grados Fahrenheit.

Polyglycol Polyalkaline-glycol-ether brake fluids that meet specifications for DOT 3 and DOT 4 brake fluids.

Poliglicol Líquido de frenos polialcalino-glicol-éter que cumple con las especificaciones de DOT 3 y DOT 4 para líquidos de frenos.

Polyvinyl ether (PVE) oil A highly viscous refrigerant oil that contains soft adhesive resins, or nonadhesive elastomers.

Aceite de éter polivinílico (PVE) Un aceite refrigerante altamente viscoso que contiene resinas adhesivas suaves o elastómeros no adhesivos.

Poppet nozzles A valve shaped like a "T" and used to open and close a fluid circuit.

Toberas de inyector con válvula Una válvula en forma de "T" y que se utiliza para abrir y cerrar un circuito de fluido.

Poppet valve A valve consisting of a round head with a tapered face, an elongated stem that guides the valve, and a machined slot at the top of the stem for the valve spring retainer.

Válvula champiñón Una válvula que consiste de una cabeza redonda de cara cónica, un vástago alargado que guía a la válvula, y una muesca maquinada en la parte superior del vástago para el retenedor del resorte de la válvula.

Porosity Tiny holes in a casting caused by air bubbles.

Porosidad Los pequeños agujeros en una pieza moldeada causados por las burbujas del aire.

Port The opening in a cylinder head that allows intake air to enter a cylinder or exhaust gas to leave the cylinder. The opening and closing of the port is controlled by a poppet valve.

Puerto La abertura en una culata del cilindro que permite que el aire de admisión ingrese en un cilindro o que el gas de escape salga del cilindro. Una válvula de vástago controla la apertura y el cierre del puerto.

Port fuel injection (PFI) A fuel injection system that uses one injector at each cylinder, thus making fuel distribution exactly equal among all of the cylinders.

Inyección de combustible por aperturas Un sistema de inyección de combustible que usa un inyector en cada cilindro, así proporcionando una distribución del combustible exactamente igual en todos los cilindros.

Positive displacement pumps Oil pump through which a fixed volume of oil passes with each revolution of its drive shaft.

Bombas de desplazamiento positivo Una bomba de aceite por el cual pasa un volumen fijo de aceite con cada revolución del eje propulsor.

Positive seal A valve oil seal that fits tightly around the valve stem and scrapes off the oil as the valve moves.

Sello positivo Un sello de aceite de la válvula que se calza estrechamente alrededor del vástago de la válvula y raspa el aceite a medida que la válvula se mueve.

Postcombustion control systems Emission control systems that clean up the exhaust gases after the fuel has been burned.

Controles de escape poscombustión Los sistemas de control de emisiones que purifican los vapores de gas después de que se haya quemado el combustible.

Potential energy Stored energy.

Energía potencial La energía almacenada.

Potentiometer A variable resistor that acts as a circuit divider to provide accurate voltage drop reading in response to the movement of an object.

Potenciómetro Un resistor variable que sirve de divisor de tensión para proveer una lectura precisa de una caída del voltaje según el movimiento de un objeto.

Power A measure of work being done.

Potencia Una medida del trabajo que se efectúa.

Power brake booster Used to increase pedal pressure applied to a brake master cylinder.

Reforzador de freno mecánico Se usa para incrementar la presión de pedal que se aplica al cilindro maestro del freno.

Power split device The basic name for the CVT transmission used in Ford and Toyota hybrid vehicles. This device is based on planetary gears and divides the output of the engine and the electric motors to drive the wheels or the generator.

Dispositivo divisor de energía El nombre básico para la transmisión CVT usada en los vehículos híbridos Ford y Toyota. Este dispositivo conta de engranajes planetarios y divide la salida del motor y de los motores eléctricos al manejar las ruedas o el generador.

Power-steering pump A hydraulic pump driven by a belt from a crankshaft pulley to provide up to 1,300 psi (8,964 kPa) "boost" pressure necessary to operate the power-steering system.

Bomba de dirección hidráulica (asistida) Una bomba hidráulica impulsada por una banda a partir de una polea de cigüeñal para proporcionar hasta 8,964 kPa (1,300 lbs/pulgada^2) de presión "de refuerzo" necesaria para manejar el sistema de dirección hidráulica (asistida).

Precombustion control system Emission control systems that prevent emissions from being created in the engine, either during or before the combustion cycle.

Control de escape precombustión Los sistemas de control de emisión que previenen que se crean las emisiones en el motor, sea durante o antes del ciclo de combustión.

Preheating The application of heat as a preliminary step to some further thermal or mechanical treatment.

Precalentamiento La aplicación del calor como un paso preliminario de un tratamiento termal o mecánico.

Preignition The process of a glowing spark or deposit igniting the air-fuel mixture before the spark plug.

Detonación El proceso en que una chispa o un depósito caliente enciende la mezcla de aire-combustible antes de que lo haga la bujía.

Preload A thrust load applied to bearings that support a rotating part to eliminate axial play or movement.

Carga previa Una carga de empuje aplicada a los cojinetes que soportan una parte giratoria con el fin de eliminar el juego o movimiento axial.

Press fit Forcing a part into an opening that is slightly smaller than the part itself to make a solid fit.

Ajuste de presa Forzado de una parte en una abertura que es ligeramente más pequeña que la parte en sí para lograr un ajuste sólido.

Pressure The exertion of force upon a body in contact with it. Pressure is developed within the cooling system and is measured in pounds per square inch on a gauge.

Presión El esfuerzo de una fuerza sobre un cuerpo con el que esta en contacto. La presión se desarrolla dentro del sistema de enfriamiento y se mide en libras por pie cuadrado con un calibre.

Pressure cap A cap used to maintain pressure in a radiator. It also prevents liquid coolant from spilling out.

Tapa de presión Una tapa que se utiliza para mantener la presión en un radiador. También evita que se derrame el refrigerante líquido del motor.

Pressure modulation The process by which the hydraulic pressure applied to a component is quickly turned off and on.

Modulación de la presión El proceso por el cual la presión hidráulica aplicada a un componente se activa y desactiva rápidamente.

Pressure-regulating valves Valves used to maintain the pressure of the fluid by not allowing it to build beyond a specified amount.

Válvulas reguladoras de presión Válvulas utilizadas para mantener la presión del fluido al no permitir que se acumule más allá de una cantidad especificada.

Pressure relief valve A valve used prevent excessively high system pressures from a positive displacement pump.

Válvula de sobrepresión Una válvula utilizada evitar presiones excesivamente altas en el sistema desde una bomba de desplazamiento positivo.

Preventive maintenance Normally scheduled maintenance designed to prevent vehicle failures.

Mantenimiento preventivo El mantenimiento periódico con el fin de prevenir los fallos del vehículo.

Primary circuit The low-voltage circuit of an ignition system.

Circuito primario El circuito de bajo voltaje de un sistema de encendido.

Primary shoe The leading shoe in a duo-servo brake. The primary shoe is self-energizing and applies servo action to the secondary shoe.

Zapata principal La zapata primaria en un freno de dos servos. La zapata principal se activa automáticamente y aplica la acción del servo a la zapata secundaria.

Prismatic cells Voltaic cells with flat electrodes placed into a box with separators placed between them.
Células prismáticas Células voltaicas con electrodos planos colocados en la caja con separadores entre ellos.
Program A set of instructions or procedures that a computer must follow when controlling a system.
Programa Un conjunto de instrucciones o procedimientos que debe cumplir una computadora en el control de un sistema.
Programmable read-only memory (PROM) A computer memory IC chip that contains all the information about the vehicle and its systems so that the control system can make decisions that are based on that vehicle.
Memoria de solo lectura programable (PROM) Un chip IC de memoria de la computadora que contiene toda la información sobre el vehículo y sus sistemas de manera que el sistema de control pueda tomar decisiones que se basan en que dicho vehículo.
Proportioning valve A pressure reduction valve used in the rear brake circuit.
Válvula dosificadora Una válvula de reducción de presión que se usa en un circuito trasero de los frenos.
Proton Exchange Membrane (PEM) fuel cell The most commonly used fuel cell in vehicles. This fuel cell easily allows for adjustable outputs, is compact, and is capable of providing high outputs.
Celda de combustible de membrana de intercambio de protones (PEM) La celda de combustible más comúnmente utilizada en vehículos. Esta celda de combustible permite fácilmente las salidas regulables, es compacta y capaz de proporcionar salidas altas.
Pulley A wheel with a grooved rim in which a rope, belt, or chain runs to raise something by pulling on the other end of the rope, belt, or chain.
Polea Una rueda con un borde acanalado en el cual mueve una cuerda, una correa, o una cadena. Es posible levantar un objeto pesado tirando en el otro extremo de la cuerda, de la correa, o de la cadena.
Pulse width The length of time in milliseconds that an injector is energized.
Anchura de impulso La cantidad del tiempo en milisegundos en la cual se acciona un inyector.
Pulse width modulation (PWM) The characteristic of a continuous on-and-off cycling of a solenoid for a fixed number of times per second. While the frequency of the cycles remains constant, the ratio of on-time to total cycle time varies, or is modulated.
Modulación de ancho de pulso (PWM) La característica de un ciclo de encendido y apagado continuo de un solenoide una cantidad fija de veces por segundo. Si bien la frecuencia de los ciclos permanece constante, la relación del tiempo de encendido con el tiempo de ciclo total varía o es modulada.
Pulse-modulated injector A type of fuel injection system that relies on two separate drivers in the PCM, both drivers open the circuit and then one turns off while the other keeps the injector open until it is time for it to close.
Inyector de pulso modulado Un tipo de sistema de inyección de combustible que se basa en dos conductores separados en el PCM; ambos conductores abren el circuito y entonces uno se apaga mientras que el otro mantiene el inyector abierto hasta que sea momento de que se cierre.
Pumping loss A term used to describe the difficulty that a piston has in moving air into the cylinder and moving it out on the exhaust stroke. Pumping losses are a major reason that engines consume a disproportionately large amount of fuel in city driving.
Pérdida de bombeo Término utilizado para describir la dificultad que tiene un pistón para mover aire hacia el cilindro y mover aire hacia fuera en el tiempo de escape. Las pérdidas de bombeo son una razón muy importante de porqué los motores consumen una cantidad inmensa de combustible cuando se conduce en una ciudad.
Purge To separate or clean by carrying off gasoline fumes. The carbon canister has a purge line to remove impurities.
Purgar Separar o limpiar al vaciar los vapores de la gasolina. El recipiente lleno de carbón tiene una línea de purgar para quitarle las impurezas.
Purge control valve A valve in some evaporative emission-control system charcoal canisters to limit the flow of vapor and air to the carburetor during idle.
Válvula de control de purga Una válvula de algunos recipientes de carbón del sistema de control de emisiones de evaporación para limitar el flujo de vapor y aire al carburador durante la marcha de vacío o en punto muerto.
Pyrometer An electrical test instrument that measures temperature.
Pirómetro Un instrumento de prueba eléctrica que mide la temperatura.
Quad driver A group of transistors in a computer that controls specific outputs.
Ejecutor cuarteto Un grupo de transistores en una computadora que controla las salidas específicas.
Quenching The cooling of gases by pressing them into a thin area.
Templar El enfriamiento de los gases al oprimirlos en una area pequeña.
Quick take-up A dual master cylinder that supplies a large volume of fluid to the front disc brakes on initial brake application, which takes up the clearance of low-drag calipers.
Cilindro de tasa de cambio rápida Un cilindro maestro doble que proporciona un gran volumen de líquido a los frenos de disco delanteros al momento de la aplicación inicial del freno, que ocupa el espacio libre de las mordazas de freno de baja resistencia.
R-12 An air-conditioning system refrigerant that contains chlorofluorocarbons. When released into the atmosphere, this refrigerant is harmful to the earth's ozone layer.
R-12 Un refrigerante del sistema de aire acondicionado que contiene los clorofluorocarbonos. Al descargarse este refrigerante a la atmósfera, causa daños a la capa de la ozona de la tierra.
R-134a An air-conditioning system refrigerant that replaces R-12. R-134a has little effect on the earth's ozone layer.
R-134a Un refrigerante del sistema del aire acondicionado que reemplaza el R-12. R-134a tiene po efecto sobre la tierra capa ozono.
Race A channel in the inner or outer ring of an antifriction bearing in which the balls or rollers operate.
Pista Un canal en el anillo interior o exterior de un cojinete antifricción en el cual operan las bolas o los rodillos.
Rack and pinion steering A steering system in which the end of the steering shaft has a pinion gear that meshes with a rack gear.
Dirección de piñón y cremallera El extremo del eje de dirección tiene un piñón que se endenta con un engranaje de cremallera.
Radial Perpendicular to the shaft or bearing bore.
Radial Perpendicular a la flecha o al taladro del cojinete.
Radial loading A load that is applied at 90 degrees to an axis of rotation.
Carga radial Una carga aplicada a 90 grados del eje de la rotación.
Radial ply Tire construction in which the cords in the body plies of the carcass run at an angle of 90 degrees to the steel beads in the inner rim of the carcass. Each cord is parallel to the radius of the tire circle.
Capa radial Estructura de neumático en la cual los hilos de refuerzo de la carcasa se extienden en un ángulo de 90 grados a los hilos de acero en el borde interior de dicha carcasa. Cada hilo es paralelo al radio de la circunferencia del neumático.
Radial runout An out-of-round condition in which the radius of the wheel or tire is not consistent from the wheel center to any point on the rim or the tread.
Variación radial Una condición de deformación circunferencial en la que el radio de la rueda o del neumático no es uniforme desde el centro de la rueda a cualquier punto en el borde o la banda de rodadura.
Radiation The transfer of heat by rays, such as heat from the sun.
Radiación La transferencia del calor por medio de los rayos, tal como el calor del sol.
Radiator A coolant-to-air heat exchanger. The device that removes heat from coolant passing through it.
Radiador Un intercambiador de calor hacia el aire fresco. El dispositivo que remueve el calor del refrigerante que pasa atraves de él.
Radio frequency interference (RFI) A narrow band of frequencies within the electro magnetic interference spectrum.

Interferencia de radiofrecuencia (RFI) Una estrecha banda de frecuencias en el espectro de la interferencia electromagnética.
Random-access memory (RAM) A type of memory used to store information temporarily.
Memoria de acceso aleatorio Un tipo de memoria que sirve para archivar la información temporalmente.
Raster pattern The display on a scope that shows individual events separately.
Patrón raster La representación en un alcance que muestra eventos individuales por separado.
Ratio The relation of proportion that one number bears to another.
Relación La relación entre la proporción de un número a otro.
Ravigneaux geartrain A compound gearset that combines two planetary units with a common ring gear.
Tren de engranaje Ravigneaux Conjunto compuesto de engranajes que combina dos unidades planetarias con una corona de engranaje común.
Reach A design feature of a spark plug. It is the length of the threaded portion of a spark plug.
Alcance Un rasgo del diseño de una bujía. Se trata de la longitud de la porción fileteada de una bujía.
Reactance The opposition of a circuit component to a change of electrical current or voltage, due to its capacitance or inductance.
Reactancia La oposición de un componente de circuito a un cambio de la corriente eléctrica o voltaje, debido a su capacitancia o inductancia.
Reactivity The characteristic of a material that enables it to react violently with water or other materials. Materials that release cyanide gas, hydrogen sulfide gas, or similar gases when exposed to low pH acid solutions are also said to possess reactivity, as are materials that generate toxic mists, fumes, vapors, and flammable gases.
Reactividad La característica de una materia que facilita que reacciona violentamente con el agua o con otras materias. Las materias que descargan el gas cianuro, el gas sulfhídrico, o los gases semejantes al exponerse a las soluciones de bajo pH se consideran tener la propriedad de reactividad, así como son las materiales que crean la toxicidad en forma de la llovizna, el humo y el vapor y los gases inflamables.
Read-only memory (ROM) A type of memory in an automotive microcomputer used to store information permanently.
Memoria de sólo lectura Un tipo de la memoria en una computador automotríz que sirve para archivar la información permanentemente.
Reaming A technique used to repair worn valve guides either by increasing the guide hole size to take an oversize valve stem or by restoring the guide to its original diameter.
Escariado Un método para reparar las guías de las válvulas gastadas sea por aumentar el tamaño del hoyo de la guía para que accepta un vástago más grande o por restaurar el diámetro original de la guía.
Rebound An expansion of a suspension spring after it has been compressed as the result of jounce.
Repercusión Una expansión de un muelle de suspensión después de que se haya comprimido por razón de un sacudo.
Receiver/dryer A refrigerant reservoir and dryer that supplies liquid refrigerant to the expansion valve.
Colector desecador Un depósito desecador de refrigerante líquido que suministra éste último a la válvula de dilatación (expansión).
Recess A shaped hollow space on a part.
Muesca Un espacio hueco formado en una parte.
Recirculating ball steering gear A popular low friction steering gear box. A sector gear meshes with a ball nut that rides on ball bearings on the worm shaft to provide a smooth steering feel.
Engranaje de dirección de rótula de recirculación Un cárter de dirección de baja fricción muy usado. Un sector dentado se engancha en una tuerca esférica que va sobre cojinetes de bolas (baleros) en el eje sinfín para proporcionar una sensación de manejo suave.
Reciprocating An up-and-down or back-and-forth motion.
Reciprocante Un movimiento de arriba y abajo o de un lado a otro.
Recombinant battery A completely sealed maintenance-free lead-acid battery that uses an electrolyte in a gel form.
Batería recombinante Una batería de plomo-ácido sin mantenimiento completamente sellada que utiliza un electrolito en forma de gel.
Recovery tank See Expansion tank.
Depósito de recuperación Ver Tanque de expansión.
Rectifier An electrical device used to convert alternating current to direct current.
Convertidor estático (rectificador) Un dispositivo eléctrico que se usa para convertir la corriente alterna en continua.
Rectify To change one type of voltage to another.
Rectificar Cambiar un tipo del voltaje por otro.
Reductant The agent that causes oxygen to be removed from a substance.
Reductor El agente que causa la eliminación del oxígeno de una sustancia.
Reduction The removal of oxygen from exhaust gases.
Reducción Remover el oxígeno de los gases de escape.
Reduction catalyst A catalyst that removes oxygen from a substance.
Catalizador de reducción Un catalizador que elimina el oxígeno de una sustancia.
Reference When applying for a job, a reference is someone who will be glad to tell a potential employer about you. A reference can be anyone who knows you, other than a family member or close friend.
Referencia Al solicitar un trabajo, una referencia es alguien que estará encantado de decirle a un empleador potencial cosas acerca de usted. Una referencia puede ser cualquier persona que lo conoce, que no sea un familiar o un amigo cercano.
Reference voltage A voltage provided by a voltage regulator to operate potentiometers and other sensors at a constant level.
Voltaje de referencia Un voltaje proporcionado por un regulador de voltaje para operar a los potenciómetros u otros detectores en un nivel constante.
Reference voltage (Vref) sensor Sensors that provide input to the computer by modifying or controlling a constant, predetermined reference voltage signal.
Sensor de voltaje de referencia (Vref) Sensores que aportan información a la computadora mediante la modificación o el control de una señal de voltaje de referencia constante predeterminada.
Reformer An in-vehicle device that extracts hydrogen from a fossil fuel to provide fuel for a fuel cell or a hydrogen fueled engine.
Reformador Un dispositivo en el vehículo que extrae hidrógeno de un combustible fósil para proporcionar combustible a una celda de combustible o a un motor alimentado mediante hidrógeno.
Reformulated gasoline (RFG) Gasolines that have had their compositions and/or characteristics altered to reduce vehicular emissions of pollutants, particularly pursuant to the EPA regulations under the CAA.
Gasolina reformulada (RFG) Gasolinas a las que se les han alterado sus composiciones y/o características para reducir las emisiones vehiculares contaminantes, particularmente siguiendo las regulaciones de la EPA bajo la CAA.
Refrigerant The chemical compound used in a refrigeration system to produce the desired cooling.
Refrigerante El compuesto químico utilizado en un sistema de refrigeración para producir el enfriamiento deseado.
Regenerative braking A method that captures a vehicle's kinetic energy while it is slowing down or is being stopped. This captured energy is used to charge batteries and/or an ultracapacitor.
Frenado regenerativo Método que captura la energía cinética mientras disminuye o se detiene la velocidad. Esta energía capturada se usa para cargar baterías y/o un ultra capacitador.
Reid vapor pressure (RVP) A standard measurement of a liquid's vapor pressure in psi at 100 degrees Fahrenheit. It is an indication of the propensity of the liquid to evaporate.
Presión de vapor Reid (RVP) Una medida estándar de la presión de vapor de un líquido en psi a 100 grados Fahrenheit. Es una indicación de la propensión de evaporación del líquido.
Relay An electrical switching device that uses a low-current circuit to control a high-current circuit.

Relé Un dispositivo interruptor eléctrico que usa un circuito de bajo corriente para controlar un circuito de alta corriente.
Relief The amount one surface is set below or above another surface.
Relieve La cantidad por el cual una superficie queda arriba o abajo de otra superficie.
Reluctance A term used to indicate a material's resistance to the passage of magnetic lines of flux.
Reluctancia Un término que indica la resistencia de una materia al pasaje de las líneas de flujo magnético.
Renewable fuels Fuels derived from nonfossil sources and produced from plant or animal products or wastes (biomass).
Combustibles renovables Combustibles derivados de fuentes no fósiles y producidos con plantas o productos o desechos de animales (biomasa).
Repair order (RO) A legal document written for every vehicle brought into the shop for service. It gives detailed information about the customer, the vehicle, the customer's concern or request, and an estimate of the cost of the services and when the services should be completed.
Pedido de reparación (RO) Un documento legal escrito para cada vehículo que se ingresa al taller para su reparación. Proporciona información detallada sobre el cliente, el vehículo, la inquietud o solicitud del cliente y una estimación del costo de los servicios y cuándo se deben completar dichos servicios.
Replenishing port The rearward port in the master cylinder bore; it lets fluid pass between each pressure chamber and its fluid reservoir during operation.
Puerto de reposición El puerto ubicado hacia atrás en el orificio del cilindro maestro que permite el paso de fluido entre cada cámara de presión y su depósito de líquido durante el funcionamiento.
Reserve capacity (RC) rating A battery rating system that expresses the length of time, in minutes, that a fully charged starting battery at 80°F (26.7°) can be discharged at 25 amperes before battery voltage drops below 10.5 volts.
Capacidad nominal de reserva (RC) Un sistema de clasificación de baterías que expresa la cantidad de tiempo, en minutos, que una batería completamente cargada a 80°F (26.7°) se puede descargar a 25 amperios antes de que el voltaje de la batería caiga por debajo de los 10.5 voltios.
Residual Remaining or leftover pressure.
Residual La presión que queda o sobra.
Residue Surplus or what remains after a separation takes place.
Residuo Lo que sobra o se queda después de que se efectúa una separación.
Resilience Elastic or rebound action.
Resiliencia La acción elástica o de repercusión.
Resistance The opposition offered by a substance or body to the passage of electric current through it.
Resistencia La oposición que ofrece una sustancia o un cuerpo al pasaje de la corriente eléctrica que lo atraviesa.
Resolver A sensor that monitors the position of the magnetic fields of the rotor in an electric motor.
Dispositivo sincrónico Un sensor que supervisa la posición de los campos magnéticos del rotor en un motor eléctrico.
Resonator A second muffler in line with the other muffler.
Resonador Un silenciador secundario en linea con el primario.
Resume A written summary of who you are, what you have done, and what you plan. It is used when seeking employment.
Currículum Un resumen escrito de quién es, lo que ha hecho y lo que planea hacer. Se utiliza en la búsqueda de empleo.
Return spring A strong spring that retracts a drum brake shoe when hydraulic pressure is released.
Resorte de retorno Un resorte fuerte que retrae una zapata del tambor de freno cuando se libera la presión hidráulica.
Reverse bias A positive voltage applied to N-material and a negative voltage applied to P-material in a semiconductor.
Polarización inversa Un voltaje positivo aplicado a un cristal N y un voltaje negativo aplicado al cristal P en un semiconductor.
Rheostat A two-terminal variable resistor used to regulate electrical current.
Reóstato Un resistor variable con dos terminales que sirve para regular al corriente eléctrico.
Rich An air-fuel mixture that has more fuel than is required for a stoichiometric mixture.
Rica Una mezcla de aire-combustible que contiene más combustible de lo que requiere una mezcla estoquiométrica.
Right-To-Know laws Laws requiring employers to provide employees with a safe workplace as it relates to hazardous materials.
Leyes de derechos de los empleados Las leyes que requieren que los patrones proveen sus empleados con un ambiente del trabajo libre de los peligros asociados con las materiales tóxicas.
Ring gear (1) The gear around the edge of a flywheel. (2) A large, circular gear such as that in the final drive assembly.
Engranaje anular (anillo dentado) (1) El engranaje en torno al borde de un volante. (2) Un gran engranaje circular como el del ensamblaje de transmisión final.
Ring lands The high parts of a piston between the grooves.
Tierras de las coronas Las partes altas de un pistón entre las ranuras.
Road crown The slant of a road that allows water to drain off. Road crown causes a vehicle steering to drift to the right.
Corona de la carretera Inclinación transversal de la carretera que permite el escurrimiento del agua. La corona de la carretera provoca que la dirección de un vehículo se mueva hacia la derecha.
Rolling resistance A term used to describe the amount of resistance a tire has to rolling on the road. Tires that have a lower rolling resistance usually get better gas mileage. Typically, radial tires have lower rolling resistance.
Resistencia a la rotación Un término que describe la cantidad de resistencia que tiene un neumático a rodar en el camino. Los neumáticos que tienen una resistencia a rodar más baja suelen proporcionar un kilometraje más económico.
Room temperature vulcanizing (RTV) A formed-in-place gasket product used in place of conventional paper, cork, and cork/rubber gaskets.
Vulcanizado a temperatura ambiente (RTV) Una junta que se forma in situ en lugar de juntas convencionales de papel, corcho y corcho/caucho.
Root mean square (RMS) A common expression for stating the amount of alternating current measured by a meter.
Media cuadrática (RMS) Una expresión común para indicar la cantidad de corriente alterna medida por un medidor.
Rotary A circular motion.
Rotativo Un movimiento circular.
Rotary oil flow Torque converter oil flow associated with the coupling stage of operation.
Flujo rotativo El flujo del aceite del convertidor de par que se asocia con la etapa de acoplamiento de su operación.
Rotor The rotating or freewheeling portion of a clutch; the belt slides on the rotor.
Rotor La parte giratoria o con marcha libre de un embrague; la correa/banda se desliza sobre el rotor.
Rotor-type oil pump A type of oil pump that utilizes two rotors, a four-lobe inner, and a five-lobe outer; output per revolution depends on rotor diameter and thickness.
Bomba de tipo rotor Un tipo de bomba de aceite que utiliza dos rotores, uno interior con cuatro resaltes, y uno exterior con cinco rebajes; la producción por revolución depende del diámetro y espesor del rotor.
RTV Room temperature vulcanizing. A formed-in-place gasket product used in place of conventional paper, cork, and cork/rubber gaskets.
Sellador RTV Un empaque que se forma en sitio que se usa en vez de los sellos más convencionales del papel, del caucho o de caucho con corcho.
Running gear The parts that are used to control the vehicle, which includes the wheels and tires and the suspension, steering, and brake systems.
Tren de rodaje Las partes que se utilizan para controlar el vehículo, que incluye las ruedas y los neumáticos y la suspensión, la dirección y los sistemas de freno.
Runout Out-of-round or wobble.
Corrimiento Ovulado o con una oscilación irregular.
Rust The result of a chemical reaction that takes place when iron and steel are exposed to oxygen and moisture.
Óxido El resultado de una reacción química que se produce cuando el hierro y el acero se exponen al oxígeno y a la humedad.
Rzeppa joint The most commonly used ball-type CV joint.
Junta Rzeppa La junta homocinética de tipo esférica que se utiliza más comúnmente.

Safety data sheets These detail the chemical composition and precautionary information for all products that can present a health or safety hazard.
Fichas de datos de seguridad En estas fichas se detalla la composición química de todos los productos que pueden presentar un peligro para la salud o la integridad física y se indica cómo manejarlos de manera segura.
Safety stands These stands are supports of various heights that sit on the floor, are placed under a sturdy chassis member, such as the frame or axle housing, to support the vehicle.
Soportes de seguridad Estos soportes de seguridad tienen varias alturas y se colocan sobre el piso, debajo de un miembro resistente del chasis, tal como los largueros o la caja del eje, para apoyar el vehículo.
Sampling The act of periodically collecting information, as from a sensor. A microcomputer samples input from various sensors in the process of controlling a system.
Muestreo Coleccionar la información periódicamente, tal como de un detector. Una microcomputadora toma las muestras de varios detectores en el proceso de controlar a un sistema.
Saturation The point reached when current flowing through a coil or wire has built up the maximum magnetic field.
Saturación El punto en que el corriente que fluye por una bobina o un alambre llega a lo máximo de un campo magnético.
Scale A flaky deposit occurring on steel or iron. Ordinarily used to describe the accumulation of minerals and metals in an automobile cooling system.
Incrustación Un depósito que ocurre en el acero o el hierro. Típicamente se usa para describir la acumulación de los minerales y los metales en un sistema de enfriamiento automotríz.
Scan tool A microprocessor designed to communicate with a vehicle's on-board computer to perform diagnosis and troubleshooting.
Herramienta de exploración Un microprocesador diseñado para comunicar con una computadora a bordo de un vehículo para efectuar los prognósticos y localización de fallas.
Schematics Wiring diagrams used to show how circuits are constructed.
Esquemáticos Los dibujos de los conexiones que sirven para enseñar cómo se han construídos los circuitos.
Schmitt trigger A type of A/D converter, where an analog signal is digitized and conditioned into a clean square wave.
Disparador Schmitt Un tipo de convertidor A/D, en el cual una señal analógica se digitaliza y se acondiciona en una onda cuadrada limpia.
Schrader valve A valve that allows air to flow when the closing pin is depressed.
Válvula Schrader Una válvula que permite que el aire fluya cuando se presiona el pasador de cierre.
Score A scratch, ridge, or groove marring a finished surface.
Rayo Un rasguño, una arruga, o una muesca que echa a perder una superficie acabada.
Scrub radius The distance from the tire contact patch centerline to the point where the steering axis intersects the road.
Radio de pivotamiento La distancia desde la línea central de la zona de contacto del neumático hasta el punto donde el eje de la dirección se cruza con la carretera.
Scuffing Scraping and heavy wear from the piston on the cylinder walls.
Rozamiento La raspadura y el gasto extremo de un pistón en los paredes del cilíndro.
Seal Generally refers to a compressor shaft oil seal; matching shaft-mounted seal face and front head-mounted seal seat to prevent refrigerant and/or oil from escaping. May also refer to any gasket or O-ring used between two mating surfaces for the same purpose.
Junta hermética Generalmente se refiere a la junta hermética en el eje del compresor; el eje hace juego con el montaje de la cara del sello y el sello instalado con la cabeza mirando hacia adelante se asienta para prevenir que el refrigerante y/o aceite se escape. Puede referirse también a cualquier junta o sello de tipo anillo O utilizada entre dos superficies que hacen juego para el mismo propósito.
Sealant Material used as a seal between two mating objects.
Sellante Una material que sirve de empaque entre dos objetos de contacto.
Seat A surface, usually machined, on which another part rests or seats; for example, the surface on which a valve face rests.
Asiento Una superficie, típicamente maquinada, sobre la cual otra parte descanza o se asienta; por ejemplo, una superficie en la que descansa la cara de la válvula.
Secondary circuit A circuit in the ignition system that uses 20,000 or more volts to operate. It includes the secondary coil windings, the rotor, distributor cap, coil and spark plug wires, and spark plugs.
Circuito secundario Circuito del sistema de encendido que utiliza 20,000 voltios o más para funcionar. Incluye devanados secundarios de la bobina, rotor, tapa del distribuidor, bobina, bujías y sus cables.
Secondary shoe The trailing shoe in a duo-servo brake. The secondary shoe receives servo action from the primary shoe to increase its application force. Secondary shoes provide the greater braking force in a duo-servo brake and have longer linings than primary shoes.
Zapata secundaria La zapata de arrastre en un freno de servo doble. La zapata secundaria recibe la acción del servo de la zapata primaria para aumentar su fuerza de aplicación. Las zapatas secundarias proporcionan la fuerza de frenado mayor en un freno de servo doble y tienen recubrimientos más largos que las zapatas primarias.
Seize When one surface moving on another scratches. An example is a piston score or abrasion in a cylinder due to a lack of lubrication or overexpansion.
Agarrotar Cuando una superficie moviendo en otra la raya. Otro ejemplo sería un rayo o abrasión en un cilindro debido a la falta de lubricación o la sobreexpansión.
Selective catalytic reduction (SCR) To clean diesel exhaust, an ammonia-like substance is injected into the exhaust stream.
Reducción catalítica selectiva (RCS) Para limpiar el escape de diesel, una sustancia como amoníaco se inyecta al caudal del escape.
Self-energizing force The action of a drum brake shoe when drum rotation increases the application force of the shoe by wedging it tightly against the drum.
Fuerza de activación automática La acción de una zapata del tambor de freno cuando la rotación del tambor aumenta la fuerza de aplicación de la zapata al acuñarla firmemente contra el tambor.
Semifloating axle A design of live axle in which only part of the vehicle's weight is supported by the axles.
Semiflotante Un diseño de un eje motor en el que sólo una porción del peso del vehículo se soporta por los ejes.
Semimetallic lining Brake friction materials made from a mixture of organic or synthetic fibers and certain metals; they do not contain asbestos.
Recubrimiento semimetálico Materiales de fricción de freno hechas de una mezcla de fibras orgánicas o sintéticas y determinados metales. No contienen asbesto.
Sending unit A device that sends a signal to a gauge regarding oil pressure or coolant temperature.
Unidad emisora (detectora) Un dispositivo que envía una señal a un medidor sobre la temperatura del refrigerante o la presión del aceite.
Sensing voltage The voltage returned to a computer after it has been altered by a sensor.
Voltaje de detección El voltaje que vuelve a una computadora después de su alteración por parte de un sensor.
Sensor Any device that provides an input to the computer.
Detector Cualquier dispositivo que provee una entrada para la computadora.
Separator Material used as insulation between electrodes of opposite polarity.
Separador Material utilizado como aislante entre los electrodos de polaridad opuesta.
Serial data The communications to and from the computer.
Datos seriales Las comunicaciones hacia y desde la computadora.
Serial data bus The communications to and from the computer.
Información serial Comunicación desde y hacia la computadora.
Series circuit An electrical circuit that only allows current to flow through one path.

Circuito en serie Un circuito eléctrico que solo permite que la corriente fluya a través de una vía.
Series motor A type of electric motor in which the armature is wired in series with the field coils. These motors develop maximum torque at start-up and develop less torque as speed increases.
Motor en serie Un tipo de motor eléctrico en el que el rotor está conectado en serie con las bobinas de campo. Estos motores desarrollan un torque máximo en el arranque y disminuyen su torque a medida que aumenta la velocidad.
Series-parallel circuit An electrical circuit that has the characteristics of both a series and a parallel circuit.
Circuito en serie-paralelo Un circuito eléctrico que tiene las características de un circuito en serie y de un circuito en paralelo.
Serpentine belts Multiple-ribbed belts used to drive water pumps, power-steering pumps, air-conditioning compressors, alternators, and emission control pumps.
Correa serpentín Las bandas dentadas que sirven para propulsar las bombas de agua, las bombas de dirección hidráulica, los compresores acondicionadores, las alternadores y las bombas de control de emisiones.
Service advisor The person who greets customers at a service center is the service advisor, sometimes called a service writer or consultant.
Asesor de servicio La persona que da la bienvenida a los clientes en un centro de servicio es el asesor de servicio, en ocasiones se lo conoce como redactor de servicios o consultor.
Servo The part of a cruise control system that maintains the desired car speed by receiving a controlled amount of vacuum from the transducer.
Servo La parte de un sistema de control crucero que mantiene la velocidad deseada por medio de una cantidad de vacío que recibe y se controla por el transconductor.
Setback A condition where one front or rear wheel is moved rearward in relation to the opposite wheel.
Retroceso Una condición en la cual una rueda delantera o trasera se mueve hacia atrás en relación a la rueda del lado opuesto.
Shift feel The quality of a shift into another forward gear.
Cambio suave La calidad del cambio a otra marcha hacia adelante.
Shift forks Semicircular castings connected to the shift rails that help control the movement of the synchronizer.
Horquillas de cambio de velocidades Partes moldeadas de forma semicircular conectadas a las palancas de cambio para ayudar en el control del movimiento del sincronizador.
Shift rails The parts of a transmission shift linkage that transfer motion from the driver-controlled gear shift lever to the shift forks.
Palancas de cambio Las partes de una biela de desembrague de una transmisión que transfieren el movimiento de la palanca del desembrague manual a las horquillas de desembrague.
Shift schedule Best described as a three-dimensional graph that plots engine speed and load as well as other operating conditions. Certain parts of the graph have designated gear ranges. When the conditions fall into a range, the computer causes the transmission to shift into that gear.
Programa de cambios Se describe mejor como una grafica tridimensional que marca la velocidad y carga del motor así como otras condiciones de operación. Ciertas partes de la grafica tienen rangos de engranajes designados. Cuando las condiciones caen en un rango, la computadora provoca que la transmisión cambie a esa velocidad.
Shim Thin sheets, usually metal, which are used as spacers between two parts, such as the two halves of a journal bearing.
Chapa Las hojas delgadas, por lo regular del metal, que sirven de arandelas entre dos partes, tal como las dos mitades de un cojinete de contacto plano.
Shock absorber A device that dampens spring oscillations by converting the energy from spring movement into heat energy.
Amortiguador Un dispositivo que absorbe las oscilaciones de los muelles, convirtiendo la energía del movimiento de estos últimos en energía térmica.
Shoe anchor The large pin, or post, or block against which a drum brake shoe pivots or develops leverage.
Anclaje de la zapata El pasador de gran tamaño, o poste o bloque contra el que la zapata del tambor de freno pivotea o desarrolla apalancamiento.
Shop foreman The person in the service department that helps technicians with more difficult tasks and serves as the quality control expert.
Jefe de taller La persona en el departamento de servicio que ayuda a los técnicos con las tareas más difíciles y presta la función de experto en control de calidad.
Short Of brief duration; for example, short cycling. Also refers to an intentional or unintentional grounding of an electrical circuit.
Breve/corto De una duración breve; funcionamiento cíclico breve. Se refiere también a una aplicación a tierra previsto o imprevista de un circuito eléctrico.
Short–long arm (SLA) suspension A suspension system using an upper and lower control arm. The upper arm is shorter than the lower arm. This is done to allow the wheel to deflect in a vertical direction with a minimum change in camber.
Suspensión de brazo corto y largo Un sistema de suspensíon que usa un brazo de control superior e inferior. El brazo superior es más corto que el brazo inferior. Este arreglo permite que la rueda se desvía en una dirección vertical con un cambio mínimo del camber.
Short block A basic short block consists of a cylinder block, crankshaft, bearings, connecting rods, pistons and rings, and oil galley and core plugs.
Bloque corto Un bloque corto básico consiste en un bloque de cilindro, cigüeñal, cojinetes, bielas, pistones y anillos, y la galería de aceite y el tapón del bloque de cilindros.
Shrink fit The shaft or part is slightly larger than the hole in which it is to be inserted. The outer part is heated above its normal operating temperature or the inner part chilled below its normal operating temperature and assembled in this condition. Upon cooling, an exceptionally tight fit is obtained.
Calado por contracción La flecha o la parte que se debe insertar es un poquito más grande que el orificio. La parte exterior se calienta a una temperatura más alta de lo normal al funcionar, o la parte interior se enfría a una temperatura más baja de lo normal al funcionar y se asamblea en estas condiciones. Al regresar a la temperatura normal, se obtiene un ajuste extremadamente apretado.
Shudder Momentary shake or quiver; can sometimes be severe.
Estremecimiento Un sacudo o temblor momentáneo; a veces puede ser severo.
Shunt More than one path for current to flow, such as a parallel part of a circuit.
Shunt (en derivación) Cuando hay más que una senda en que puede fluir un corriente, tal como una parte paralela de un circuito.
Shunt circuits The branches of the parallel circuit.
Circuitos en desviación Las ramas del circuito paralelo.
Siamese ports On some engines, the ports for the intake or exhaust valves are combined. With Siamese ports, individual ports around each valve mesh together to form a larger single port that is connected to a manifold.
Puertos gemelos En algunos motores, los puertos de las válvulas de admisión y escape se combinan. En el caso de los puertos gemelos, los puertos individuales alrededor de cada válvula se combinan para formar un solo puerto más grande que está conectado a un colector.
Simpson geartrain A compound gearset in which two planetary units work together through a common sun gear.
Tren de engranajes Simpson Conjunto de engranajes compuesto en el cual dos unidades planetarias trabajan a través de un engranaje planetario.
Sine wave Basically, this wave is a circle drawn over time. It appears as a wave with equal positive and negative magnitudes and amplitudes.
Onda senoidal Basicamente, esta onda es un círculo que se dibuja a través del tiempo. Aparece como una onda con magnitudes y amplitudes positivos y negativos iguales.
Sleeving A means of reconditioning an engine by boring the cylinder oversize and installing a thin metal liner called a sleeve. The inside diameter of the sleeve is then bored, usually to the original or standard piston size.
Restaurar con manguito Un metodo de recondicionar a un motor por medio de taladrar más grande al cilindro e instalar un forro de

metal delgado llamado un manguito. Luego se taladra al diámetro interior del manguito al tamaño normal o indicado según el pistón.

Sliding caliper A caliper that is mounted to its support on two fixed sliding surfaces, or ways. The caliper slides on the rigid ways and does not have the flexibility of a floating caliper.

Calibrador corredizo Un calibrador que está montado a su soporte sobre dos superficies corredizas o deslizadores. El calibrador corre sobre los deslizadores rígidos y no tiene la flexibilidad de una mordaza flotante.

Sliding fit Where sufficient clearance has been allowed between the shaft and journal to permit free running without overheating.

Ajuste deslizante Cuando una holgura suficiente grande se ha dejado entro la flecha y el muñón para permitir la operación sín que se sobrecalienta.

Slip A condition caused when a driving part rotates faster than a driven part.

Deslizamiento Una condición causada cuando una parte propulsor gira más rapidamente que la parte arrastrada.

Slip rings The rotor of an AC generator is fed current through brushes that ride on two smooth rings, slip rings, mounted at the end of the rotor shaft.

Anillos deslizantes El rotor de un generador de corriente alterna se alimenta de corriente a través de escobillas que se desplazan sobre dos anillos lisos, anillos deslizantes, montados en el extremo del eje del rotor.

Slip yoke A component having internal splines that slide on the transmission output shaft external splines, allowing the driveline to adjust for variations in length as the rear axle assembly moves.

Horqueta deslizante Un componente con ranuras externas que se desliza sobre las acanaladuras externas del eje de salida de la transmisión, permitiendo que la línea de propulsión se adapte a las variaciones de longitud del conjunto del eje posterior al moverse.

Sludge As used in connection with automobile engines, it indicates a composition of oxidized petroleum products along with an emulsion formed by the mixture of oil and water. This forms a pasty substance and clogs oil lines and passages and interferes with engine lubrication.

Sebo (grasa) En referencia con los motores automotrices, indica una composición de productos petróleos oxidados junta con una emulsión formada de una mezcla del aceite y el agua. Esto forma una sustancia pastosa y causa las obstrucciones en las lineas y pasajes del aceite preveniendo la lubricación.

Smart air bags Air bags that can vary their inflation rate according to the weight of the driver and passenger.

Bolsas de aire inteligentes Bolsas de aire que pueden variar su tasa de inflado en función del peso del conductor y del pasajero.

Smog Air pollution created by the reaction of nitrogen oxides to sunlight.

Smog La contaminación del aire producido por la reacción de los óxidos de nitrógeno a la luz del sol.

Solenoid An electromagnetic switch with a movable core.

Solenoide Un interruptor electromagnético con un núcleo portátil.

Solid oxide fuel cell (SOFC) Fuel cells comprised of a ceramic anode, ceramic cathode, and a solid electrolyte. Their high operating temperatures eliminate the need for expensive catalysts and therefore they have low production costs.

Celda de combustible de óxido sólido (SOFC) Las celdas de combustible constan de un ánodo de cerámica, un cátodo de cerámica y un electrolito sólido. Sus altas temperaturas de funcionamiento eliminan la necesidad de usar catalizadores costosos y, por lo tanto, tienen costos de producción bajos.

Solution Formed when a solid dissolves into a liquid; its particles break away from this structure and mix evenly in the liquid.

Solución Se forma cuando un sólido disuelve en un líquido. Las partículas del sólido se separan y se mezclan uniformemente en el líquido.

Solvent The liquid in a solution.

Solvente El líquido en una solución.

Spark duration The length of time current flows through the gap of a spark plug.

Duración de chispa El tiempo durante el cual la corriente fluye a través de la separación de una bujía.

Spark line A horizontal line shown in a scope pattern of the ignition cycle that represents the spark dutration.

Línea de chispa Una línea horizontal que se muestra en un patrón de alcance del ciclo de encendido que representa la duración de la chispa.

Spark plug A device used to plug a hole in the combustion chamber while allowing a spark to enter the chamber.

Bujía Un dispositivo que sirve para tapar un hoyo en la cámara de combustión mientras que permite pasar una chispa a la cámara.

Specific gravity The weight of a given volume of a liquid divided by the weight of the same volume of water.

Gravedad específica El peso de un volumen dado de un líquido dividido por el peso del mismo volumen del agua.

Speed The distance an object travels in a set amount of time. Speed is the relationship between the distance traveled and the time it takes to travel it.

Velocidad La distancia que viaja un objeto dividido por la medida del tiempo usada para viajar esa distancia. La velocidad es la relación entre el espacio recorrido y el tiempo empleado en recorrerlo.

Speed density A type of electronic fuel injection system in which the PCM calculates the amount of intake air based on MAP and rpm input signals.

Densidad de velocidad Un tipo de sistema electrónico de inyección de combustible en el que el PCM calcula la cantidad de aire de admisión en virtud de las señales de MAP y de entrada de rpm.

Speed ratio Comparison of the difference in speed between two moving parts, such as impeller speed and turbine speed.

Relación de la velocidad La comparación de la diferencia en velocidad entre dos partes en movimiento, tal como la velocidad del impulsor y la velocidad de la turbina.

Splay To spread or move outward from a central point.

Achaflanar Desplegar o moverse hacia afuera de un punto central.

Splice To join. Electrical wires can be joined by soldering or by using crimped connectors.

Empalmar Juntar. Los alambres eléctricos se pueden unir por soldado o por medio de los conectores de presión.

Splines External or internal teeth cut into a shaft that are used to keep a pulley or hub secured on a rotating shaft.

Espárragos Los dientes exteriores o interiores cortados en una flecha que sirven para fijar a una polea o un cubo en una flecha rotativa.

Split bearing A bearing made of two halves and used where the bearing must be assembled around the journal. Crankshaft bearings are the split type.

Cojinete partido Un cojinete formado por dos mitades que se utiliza donde el cojinete se debe montar alrededor del muñón. Los cojinetes del cigüeñal son el tipo partido.

Sponge lead (Pb) A porous material pasted onto the grids of the negative plates in a lead-acid battery.

Plomo (Pb) esponjoso Un material poroso pegado en las rejillas de las placas negativas en una batería de plomo-ácido.

Sponginess A feel of a soft brake pedal.

Esponjoso Una sensación blanda en un pedal de freno.

Spontaneous combustion Process by which a combustible material ignites by itself and starts a fire.

Combustión espontánea Un proceso por el cual una material combustible se encienda sí mismo y causa un fuego.

Spool valve A cylindrical sliding valve that uses lands and valleys around its circumference to control the flow of hydraulic fluid through the valve body.

Válvula de carrete Válvula cilíndrica móvil que usa planos y valles alrededor de su circunferencia para controlar el flujo de fluido hidráulico a través del cuerpo de la válvula.

Spring A device that changes shape when it is stretched or compressed but returns to its original shape when the force is removed.

Resorte Dispositivo que cambia de forma cuando se extiende o contrae, pero regresa a su forma original cuando se le retira la fuerza.

Spur gear A gear with teeth that are cut straight across the gear.

Engrenaje recto Un engrenaje cuyos dientes atraviesan el engranaje en una linea recta.

Square-cut seal A fixed seal that has a square cross section, commonly used on a brake caliper piston.

Sello de corte cuadrado Un sello fijo que tiene una sección transversal cuadrada, que se utiliza comúnmente en el pistón de la mordaza de freno.

Square wave Typically a digital waveform that shows the cycling of a circuit or device.

Onda cuadrada Típicamente una forma de onda digital que indica el ciclado de un circuito o un dispositivo.

Squib The igniter for an air bag.

Estopín Detonador de la bolsa de aire.

Squirm To wiggle or twist about a body. When applied to tires, squirm is the wiggle or movement of the tread against the road surface. Squirm increases tire wear.

Encorvadura Torcerse o doblar alrededor de un cuerpo. Al aplicarse a los neumáticos, la encorvadura se refiere a la torción o el movimiento de la banda contra la superficie del camino. La encorvadura aumenta el desgaste de los neumáticos.

Stainless steel An iron-carbon alloy with a minimum of 10.5 percent chromium content.

Acero inoxidable Aleación de carbón y hierro con un mínimo de 10.5% de contenido de cromo.

Stall speed With the engine operating at full throttle, the gear selection in D range, and the vehicle stationary, this speed can be read on a tachometer.

Velocidad de calar Al estar el motor en marcha a todo gas, el engrenaje selecionado en el rango D, el vehículo estacionario, este velocidad se lee en el taquímetro.

Stamping A piece of sheet metal cut and formed into the desired shape with the use of dies.

Estampar Una pieza de metal de hoja que se corta y se forma a lo deseado con los matrices.

Starter frame The housing that encloses the internal parts of an electric motor and protects them from damage, moisture, and foreign materials. It also supports the field coils. Also called the starter housing.

Chasis del arrancador La carcasa que encierra las partes internas de un motor eléctrico y los protege de daños, humedad y materiales extraños. También sirve de apoyo para las bobinas de campo. También se conoce como carcasa del arrancador.

Starter relay A magnetic switch, generally operated by the ignition switch, that uses low current to close a circuit to control the flow of very high current to the starter.

Relé (relevador) del motor de arranque Un interruptor magnético, activado generalmente por el interruptor de encendido, que usa una corriente baja para cerrar un circuito y controlar el flujo de corriente muy alta al motor de arranque.

Static balance Balance at rest; still balance. It is the equal distribution of weight of the wheel and tire around the axis of rotation such that the wheel assembly has no tendency to rotate by itself regardless of its position.

Balanceo estático El equilibreo en descanso; el balanceo inmóvil. Es la distribución equilibrada del peso de la rueda y el neumático alrededor del eje de rotación para que la asamblea de la rueda no tenga tendencia a girar por sí mismo, sin que importa su posición.

Static friction Friction between two stationary objects or surfaces.

Fricción estática La fricción entre dos objetos o superficies estacionarias.

Static pressure The pressure inside the hydraulic system.

Presión estática La presión dentro del sistema hydráulico.

Stator The name used to describe a part in a torque converter or the stationary windings of an AC generator.

Estátor El nombre que describe una parte en un convertidor de par o el devanado estático de un alternador.

Steam reforming A common procedure for extracting hydrogen from hydrocarbons.

Reformado por vapor Un procedimiento común para extraer hidrógeno de hidrocarburos.

Steering axis inclination (SAI) The angle of a line through the center of the upper strut mount and lower ball joint in relation to the true vertical centerline of the tire viewed from the front of the vehicle.

Inclinación del eje de dirección (SAI) El ángulo de una línea a través del centro de la montura superior de puntal y unión inferior de la junta esférica en relación con la línea central vertical real de la rueda vista del frente del vehículo.

Steering gear An assembly that connects the steering wheel to the steering linkage. It provides a gear reduction to make changing the direction of the wheels easier.

Engranaje de dirección Un conjunto que conecta el volante con el varillaje de dirección. Proporciona una reducción del engranajes que facilita el cambio de dirección de las ruedas.

Stellite An alloy of nickel, chromium, and tungsten and is nonmagnetic. It is a hard facing material that is welded to valve faces and stems.

Estelita una aleación de níquel, cromo, y tungsteno y no es magnética. Es un material de reforzado que se solda a la caras de las válvula y a los vástagos.

Stepped resistor A variable resistor that has fixed resistance values at specific points.

Resistor escalonado Un resistor variable que cuenta con valores de resistencia fijos en puntos específicos.

Step-up transformer A transformer in which the voltage created in a secondary coil is greater than the voltage in the primary, or first, coil.

Transformador elevador Una transformador en la cual el voltaje creado en la bobina secundaria es más alta que el voltaje en la bobina primaria.

Stoichiometric ratio Chemically correct. An air-fuel mixture is considered stoichiometric when it is neither too rich nor too lean; stoichiometric ratio is 14.7 parts of air for every part of fuel.

Estequiométrica Lo que es correcto químicamente. Una mezlca de aire-combustible se considera estequiométrica cuando no es demasiada rica o pobre; la relación estequiométrica es 14.7 partes del aire por cada parte del combustible.

Stress The force of strain to which a material is subjected.

Esfuerzo La fuerza de la tensión a la cual se somete una materia.

Stroke A term used to describe cylinder size that represents the amount of movement the piston has inside the bore.

Carrera Un término que describe el tamaño de un cilindro, representa la cantidad del movimiento que tiene el pistón dentro del orificio.

Strut Components connected from the top of the steering knuckle to the upper strut mount that maintain the knuckle position and act as shock absorbers to control spring action in a vehicle's suspension system. Used on most front-wheel drive cars and some rear-wheel drive cars.

Riostras Componentes conectados de la parte superior de la charnela de dirección a la montura de tirante superior para mantener la posición de la charnela y actuar como amortiguadores para controlar la acción de resorte del sistema de suspensión de un vehículo. Se utiliza en la mayoría de los automóviles de tracción delantera y en muchos de tracción posterior.

Stud A threaded shaft that resembles a bolt without a head.

Espárrago Un eje roscado que se parece a un perno sin cabeza.

Sublet repair A legal document written for every vehicle brought into the shop for service. It gives detailed information about the customer, the vehicle, the customer's concern or request, and an estimate of the cost of the services and when the services should be completed.

Reparación de traspaso Un documento legal que se redacta para cada vehículo que se trae al taller de reparaciones. Proporciona información detallada sobre el cliente, el vehículo, la inquietud o solicitud del cliente y una estimación del costo de los servicios y cuándo se deben completar dichos servicios.

Substrate A ceramic honeycomb grid structure coated with catalyst materials.

Sustrato Una estructura cerámica de rejilla agrietada cubierta con materiales de catalizador.

Suction Suction exists in a vessel when the pressure is lower than the atmospheric pressure.

Succión La succión existe en una vasija cuando la presión es más baja que la presión atmosférica.

Sulfation A potential condition of a lead-acid battery in which the battery operates only in a partially discharged condition. This condition results from excessive stop-and-go driving or a fault in the charging system, which causes the sulfate normally formed in the plates to become dense, hard, and chemically irreversible.

Sulfatación Estado potencial de una batería de ácido-plomo en la cual la batería opera en estado de descarga parcial. Este estado

resulta de manejar cuando se efectúan excesivas paradas y arranques o existe una falla en el sistema de carga, provocando que el sulfato que normalmente se forma en las placas se haga denso, duro y químicamente irreversible.

Sulfur dioxide (SO_2) An EPA criteria pollutant.

Dióxido de azufre (SO_2) Un contaminante según el criterio de la Agencia de Protección Ambiental (EPA).

Sun gear A gear located in the center of a planetary gearset and is the smallest of the gears in the set.

Engranaje central Un engranaje situado en el centro de un conjunto de engranajes planetarios y es el más pequeño de los engranajes en el conjunto.

Supercharger A belt-driven pump, also called a blower.

Sobrealimentador Una bomba de banda que se denomina también aventador.

Superimposed pattern The display on a scope that shows individual events stacked on top of each other.

Patrón superpuesto La visualización de una pantalla que muestra los eventos individuales apilados uno encima del otro.

Supplemental inflatable restraint (SIR) A commonly used term for safety-related air bags.

Dispositivo de retención inflable complementario (SIR) Un término comúnmente utilizado para las bolsas de aire instaladas por razones de seguridad.

Supplemental restraint system (SRS) See Supplemental inflatable restraint (SIR).

Sistema de retención complementaria (SRS) Consulte El término dispositivo de retención inflable complementario (SIR).

Surface tension The result of forces of attraction, which pull on the particles of a liquid in all directions. These forces create liquid bubbles and drops in a spherical shape.

Tensión de superficie El resultado de las fuerzas de atracción que halan las partículas de un líquido en todas las direcciones. Estas fuerzas crean burbujas y gotas líquidas en una forma esférica.

Surging A condition in which the engine speeds up and slows down with the throttle held steady.

Operación pulsatorio Una condición en la cual el motor acelera y desacelera mientras que la presión de admisión se mantiene fijo.

Sway bar Also called a stabilizer bar. It prevents the vehicle's body from diving into turns.

Barra de oscilación lateral Llamada también barra estabilizadora. Impide que la carrocería del vehículo se clave durante las curvas.

Synchronizer An assembly used in manual transmissions to bring components that are rotating at different speeds to one synchronized speed.

Sincronizador Ensamble usado en las transmisiones manuales para traer los componentes que están rotando a diferentes velocidades a una velocidad sincronizada.

Synthetic lining Brake friction materials made from nonorganic, nonmetallic, and nonasbestos materials; typically fiberglass and aramid fibers.

Recubrimiento sintético Materiales de fricción de freno hechos de materiales no orgánicos, no metálicos y que no contienen asbesto, por lo general fibra de vidrio y fibras de aramida.

Tailpipe The part of the exhaust system that allows the exhaust gases to leave the rear of the vehicle and go into the atmosphere.

Tubo de escape La parte del sistema de escape que permite que los gases se descarguen a la atmósfera por la parte trasera del vehículo.

Tap To cut threads in a hole with a tapered, fluted, threaded tool.

Roscar con macho Cortar las roscas en un agujero con una herramienta cónica, acanalada y fileteada.

Taper The difference in diameter between the cylinder bore at the bottom of the hole and the bore at the top of the hole, just below the ridge.

Ahuso La diferencia en el diámetro del orificio del cilindro en la parte inferior y del orificio en la parte superior de la apertura, justo abajo del reborde.

Tapered roller bearing A bearing containing tapered roller bearings mounted between the inner and outer races.

Balero de rodillos cónicos Los baleros que contienen rodillos cónicos montados entre las pistas interiores y exteriores.

Tapped resistor Resistors designed to have two or more fixed values, available by connecting wires to the several taps of the resistor.

Resistor con tomas Resistores diseñados para tener dos o más valores fijos, mediante la conexión de los cables a las diversas tomas del resistor.

TDI—Turbocharged Direct Injection The name of VW's clean diesel engine.

TDI—Inyección directa con turbocargador El nombre del motor diesel limpio de VW.

Telematics The technology of sending, receiving, and storing information through telecommunication devices to control or monitor remote devices.

Telemática La tecnología para el envío, la recepción y almacenamiento de información mediante dispositivos de telecomunicaciones para controlar o supervisar dispositivos a distancia.

Telemetry The transmission of measurements, through telecommunications, from one location to another to monitor remote devices without controlling the device.

Telemetría La transmisión de mediciones, a través de telecomunicaciones, de un lugar a otro para supervisar dispositivos a distancia sin controlar dicho dispositivo.

Telescoping gauges Tools used for measuring bore diameters and other clearances; also known as snap gauges.

Calibradores telescópicos Las herramientas que sirven para medir los diámetros de los orificios y otras holguras; tambien se conocen como calibres de ensarte.

Temperature An indication of an object's kinetic energy.

Temperatura La temperatura es el grado de calor, relacionado con la energía cinética de las moléculas de los mismos.

Tempering The heat treatment of metal alloys, particularly steel, to result in specific properties.

Templar El tratar de las aleaciones del metal, particularmente de acero, con calor para dar ciertas características al metal.

Tensile strength The amount of pressure per square inch the bolt can withstand just before breaking when being pulled apart.

Resistencia a la tracción La cantidad de presión por pulgada cuadrada que puede resistir un perno al estirarse justo antes de que se quiebra.

Tension Effort that elongates or stretches a material.

Tracción Un esfuerzo que alarga o estira a una materia.

Testlight A test instrument that illuminates its lamp when there is the presence of voltage at one of its leads and connected to ground at the other lead.

Luz de prueba Un instrumento de prueba que enciende su lámpara cuando existe voltaje en uno de sus conductores y está conectado a tierra en el otro conductor.

Thermal cleaning Cleaning that relies exclusively on heat to bake off or oxidize surface contaminants.

Limpieza termal La limpieza que cuenta exclusivamente con el calor para quemar u oxidar los contaminantes de una superficie.

Thermal contraction A decrease in the size of a mass due to the movement of atoms and molecules as heat moves out of a mass.

Contracción termal Una contracción termal es una disminución del volumen de una masa debido al movimiento de átomos y moléculas cuando el calor se mueve de una masa.

Thermal expansion An increase in the size of a mass due to the movement of atoms and molecules as heat moves into a mass.

Expansión termal Una expansión termal es un aumento en el volumen de una masa debido al movimiento de átomos y moléculas cuando el calor entra a una masa.

Thermistor A solid-state variable resistor made from semiconductor material that changes resistance in response to changes in temperature.

Termistor Un resistor variable de estado sólido hecho de material semiconductor que cambia su resistencia según los cambios de la temperatura.

Thermo efficiency A gallon of fuel contains a certain amount of potential energy in the form of heat when burned in the combustion chamber. Some of this heat is lost and some is converted into power. The thermal efficiency is the ratio of work accomplished compared to the total quantity of heat contained in the fuel.

Rendimiento térmico Un galón del combustible contiene una cierta cantidad de energía potencial en la forma de calor cuando se quema en la cámara de combustión. Algo de éste calor se pierde y algo se convierte a la fuerza. El rendimiento térmico es la

relación del trabajo que se efectúa comparado con la cantidad total del calor que contiene el combustible.

Thermostat A device used to cycle the clutch to control the rate of refrigerant flow as a means of temperature control. The driver has control of the temperature desired.

Termostato Un dispositivo utilizado para ciclar el embrague para regular la proporción del flujo de refrigerante como medio de regulación de temperatura. El accionador puede regular la temperatura deseada.

Thermostatic expansion valve (TEV or TXV) An airconditioning control valve used to maintain evaporator pressure.

Válvula de expansión termostática (TEV o TXV) Una válvula de control de aire acondicionado que se utiliza para mantener la presión del evaporador.

Thread pitch The number of threads in 1 inch of threaded bolt length. In the metric system, thread pitch is the distance in millimeters between two adjacent threads.

Paso de rosca El número de las cuerdas por pulgada de un perno con rosca. En el sistema métrico, el paso de las roscas es la medida de la distancia entre dos pasos contiguos en milímetros.

Three-phase voltage A power system comprised of three conductors carrying voltage waveforms that are out of phase with each other. Normally the phase difference is 120 degrees.

Voltaje trifásico Un sistema de potencia que consta de tres conductores portadores de formas de onda de voltaje que están fuera de fase entre sí. Normalmente, la diferencia de fase es de 120 grados.

Three-quarter floating axle A drive axle arrangement in which the axle shaft supports 25 percent of the vehicle's weight. The bearing is outside the axle housing.

Eje flotante de tres cuartos Disposición del eje de tracción en la que el eje axial soporta el 25% del peso del vehículo. El balero está fuera de la carcasa del eje.

Throttle body injection (TBI) An injection system that has the injectors placed above the intake manifold and at the throttle body.

Inyección al cuerpo del acelerador (TBI) Un sistema de inyección que tiene los inyectores ubicados encima del múltiple de admisión y en el cuerpo del acelerador.

Throttle position (TP) sensor A potentiometer used to monitor changes in throttle plate opening. The position of the throttle plate determines the voltage drop at the sensor's resistor and the resultant voltage signal is sent to a computer system.

Sensor de posición del acelerador (TP) Un potenciómetro que se utiliza para controlar los cambios en la abertura de la placa del acelerador. La posición de la placa del acelerador determina la caída de voltaje en la resistencia del sensor y la señal de voltaje resultante se envía a un sistema informático.

Throttle valve A valve that responds to throttle position and/or engine load.

Válvula de la mariposa del carburador Una válvula que responde a la posición del acelerador o a la carga del motor.

Throw With reference to an automobile engine, usually the distance from the center of the crankshaft main bearing to the center of the connecting rod journal.

Recorrido Al referirse a un motor de automóvil, típicamente es la distancia del cojinete principal del cigueñal al centro de los muñones de la biela.

Throwout bearing In the clutch, the bearing that can be moved inward to the release levers and clutch-pedal action to cause declutching, which disengages the engine crankshaft from the transmission. A common name for a clutch release bearing.

Cojinete de desembrague En el embrague, el cojinete que puede moverse hacia adentro hasta las palancas de liberación, por medio de la acción del pedal del embrague, para logar el desembrague, desenganchando el cigüeñal del motor de la transmisión. Es un nombre común para designar una chumacera de liberación del embrague.

Thrust angle The angle between the geometric centerline of a vehicle and the thrust line.

Ángulo de empuje El ángulo entre la línea central geométrica de un vehículo y la línea de empuje.

Thrust line A line that divides the total toe angle of the rear wheels.

Línea de empuje Una línea que divide el ángulo total de la convergencia de las ruedas traseras.

Thrust loading Load placed on a part that is parallel to the center of the axis.

Carga de empuje Una carga en una parte que queda paralela al centro del eje.

Tie-rod A rod connected from the steering arm to the rack or center link, depending on the type of steering linkage.

Barra de acoplamiento Una varilla conectada desde el brazo de la dirección a la cremallera o a la barra central, dependiendo del tipo de varilla de la dirección.

Toe A suspension dimension that reflects the difference in the distance between the extreme front and extreme rear of the tires. It also refers to the inside diameter of the ring gear.

Convergencia/divergencia Una dimensión de suspensión que refleja la diferencia en la distancia entre el extremo delantero y el extremo trasero de los neumáticos. También se refiere al diámetro interior de la corona.

Tolerance A permissible variation between the two extremes of a specification or dimension.

Tolerancia Una variación permitible entre dos extremos de una especificación o una dimensión.

Top Dead Center (TDC) A common term used to denote with the piston of a cylinder is at the most upper point of its bore.

Punto muerto superior (TDC) Un término común usado para denotar cuándo el pistón de un cilindro está en el punto más alto de su recorrido.

Torque A twisting force applied to a shaft or bolt.

Par de ajuste Una fuerza torcedura que se aplica a una flecha o un perno.

Torque converter A turbine device utilizing a rotary pump, one or more reactors (stators), and a driven circular turbine or vane whereby power is transmitted from a driving to a driven member by hydraulic action. It provides varying drive ratios; with a speed reduction, it increases torque.

Convertidor del par de torsión o de torque Una turbina que utiliza una bomba giratoria, uno o más reactores (estator) y una turbina circular accionada o paleta; la fuerza se transmite desde el mecanismo de accionamiento al mecanismo accionado mediante una acción hidráulica. Provee relaciones de accionamiento variadas; con una reducción de velocidad, aumenta el par de torsión.

Torque converter clutch (TCC) A valve that responds to throttle position and/or engine load.

Embrague convertidor de torque (TCC) Una válvula que responde a la posición del acelerador o a la carga del motor.

Torque steer A twisting axle movement in front-wheel-drive automobiles that causes a pulling action under acceleration toward the side with the longer driving axle.

Dirección de torsión Un movimiento de torsión del eje en un automóvil de tracción delantera que causa que jale mientras que accelera hacia el lado con un eje motor más largo.

Torque-to-yield (TTY) Bolts that are intentionally torqued just barely into a yield condition, although not far enough to distort the bolt. This type of bolt will provide 100 percent of its intended strength compared to 75 percent when torqued to normal values.

Torque a rendimiento (TTY) Los tornillos son enroscados intencionalmente justamente a condición de entrada, aunque no lo suficiente como para distorsionar el tornillo. Este tipo de tornillo proporcionará el 100% de su fuerza intencionada, comparada con el 75% cuando se enrosca a valores normales.

Torque wrench A tool used to measure how tight a nut or bolt is.

Llave de torque Una herramienta que se utiliza para medir el grado de tensión de una tuerca o perno.

Torrington bearing A thrust washer fitted with roller bearings.

Rodamiento Torrington Arandela de empuje con rodamientos rodantes.

Torsion bar A steel bar connected from the chassis to the lower control arm. As the vehicle's weight pushes the chassis downward, the torsion bar twists to support this weight. Torsion bars are used in place of coil springs.

Barra de torsión Una barra de acero conectada del chasis al brazo de control inferior de la suspensión. Mientras el peso del vehículo presiona el chasis hacia abajo, la barra de torsión se tuerce para soportar este peso. Las barras de torsión se utilizan en lugar de los resortes espirales.

Total indicator reading (TIR) The total deflection of the dial indicator as the object is rotated through one complete rotation. It is

equal to the amount greater than zero plus the amount less than zero.

Lectura total del indicador (TIR) La deflexión total del indicador de carátula conforme el objeto es rotado a una rotación completa. Es igual a la cantidad mayor de cero más la cantidad menor de cero.

Trace A lab scope converts electrical signals to a visual image representing voltage changes over a specific period. This information is displayed in the form of a continuous voltage line called a trace.

Rastro Un ámbito de laboratorio convierte las señales eléctricas a una imagen visual representando cambios durante un período específico de tiempo. Esta información se despliega en la forma de una línea continua de voltaje llamado rastro.

Tracking The travel of the rear wheels in a parallel path with the front wheels.

Seguimiento El progreso de las ruedas traseras en una senda paralela con las ruedas delanteras.

Traction A tire's ability to hold or grip the road surface.

Tracción La abilidad de un neumático para agarrar o mantenerse en la superficie del camino.

Traction motor An AC or DC electric motor designed for vehicle propulsion.

Motor de tracción Motor eléctrico de CA o CD diseñado para vehículos a propulsión.

Tractive effort Pushing force exerted by the vehicle's driving wheels against the road's surface.

Esfuerzo de tracción Una fuerza de empujo que resulta de tracción de las ruedas contra la superficie del camino.

Tramp Wheel hop caused by static balance.

Pisoteo Un brinquito de la rueda causado por el balanceo estático.

Transaxle A unit that combines a transmission and differential.

Eje de transmisión Una unidad que combina una transmisión y un diferencial.

Transducer A device that converts a pressure or mechanical movement to an electrical signal.

Transductor Un dispositivo que convierte una presión o movimiento mecánico en una señal eléctrica.

Transfer case An additional component added to a four-wheel-drive vehicle in which the power from the engine is divided between both the front and rear wheels equally.

Caja de transferencia Componente adicional que se agrega a un vehículo de tracción en las cuatro ruedas, donde la potencia del motor se divide por igual entre las ruedas delanteras y las traseras.

Transistor An electronic device produced by joining three sections of semiconductor materials. A transistor is very useful as a switching device, functioning as either a conductor or an insulator.

Transistor Un dispositivo electrónico producido al unir tres secciones de materiales de semiconductor. Un transistor es muy útil como dispositivo interruptor, funciona como un conductor o como aislador.

Transmission control module (TCM) A valve that responds to throttle position and/or engine load.

Módulo de control de la transmisión (TCM) Una válvula que responde a la posición del acelerador o a la carga del motor.

Transverse Perpendicular, or at right angles, to a front-to-back centerline.

Transverso Perpendicular, o en ángulo recto, a una línea central de delantero a trasero.

Tread The area of a tire that designed to make contact with the road.

Trocha El área de un neumático que está diseñada para hacer contacto con la carretera.

Trickle charge A method of recharging in which a battery is either continuously or intermittently connected to a constant current supply that maintains the battery in a fully or near full charged condition.

Carga de mantenimiento Un método de recarga en el que una batería está conectada ya sea de forma continua o intermitente a un suministro de corriente constante que mantiene la batería en un estado de carga completa total o aproximada.

Trimmer A resistor or capacitor that is adjusted to meet the needs of a circuit.

Compensador Un resistor o capacitor que se ajusta para satisfacer las necesidades de un circuito.

Trip An OBD II drive cycle that includes all of the conditions (enable criteria) required for a monitor to run.

Viaje Ciclo de transmisión OBD II que incluye todas las condiciones (habilitar criterios) requeridos para que un monitor funcione.

Tripod-type joint A CV joint that uses a central hub or tripod with three trunnions placed inside housing.

Junta de tipo trípode Una junta homocinética que utiliza una maza central o un trípode con tres muñones colocados dentro de la carcasa.

Trouble codes Output of the self-diagnostics program in the form of a numbered code that indicates faulty circuits or components. Trouble codes are two- or three- digit characters that are displayed in the diagnostic display if the testing and failure requirements are both met.

Códigos indicadores de fallas Los datos del programa autodiagnóstico en forma de código numerado que indica los circuitos o los componentes defectuosos. Los códigos de problemas son compuestos de dos o tres caracteres digitales que se muestran en el despliegue de diagnóstico si se llenan los requisitos de prueba y de falla.

Tucson FCEV Hyundai's hydrogen fuel cell powered crossover available for sale in the United States.

Tucson FCEV El vehículo *crossover* de Hyundai impulsado por pila de combustible de hidrógeno que está a la venta en los Estados Unidos.

Turbine A valve that responds to throttle position and/or engine load.

Turbina Una válvula que responde a la posición del acelerador o a la carga del motor.

Turbo boost The positive pressure increase created by a turbocharger.

Reforzar de turbo Un aumento del presión positivo creado por un turbocargador.

Turbocharger A small radial fan pump driven by the energy of the exhaust flow.

Turbosobrealimentador Un pequeño ventilador radial impulsado por la energía del flujo del escape.

Turbo lag A condition that causes poor acceleration until the turbocharger builds up ample speed to boost the intake charge.

Retardo del turbo Un estado que causa poca aceleración hasta que el turbocargador acumula suficiente velocidad para aumentar la carga de admisión.

Turbulence A very rapid movement of gases in a combustion chamber that causes better combustion because the mixture is thoroughly mixed.

Turbulencia Movimiento rápido de gases en una cámara de combustión que provoca mejor combustión porque la mezcla es totalmente homogénea.

Turning torque Amount of torque required to keep a shaft or gear rotating; measured with a torque wrench.

Torsión giratoria La cantidad de torsión requerida para mantener girando a una flecha o un engrenaje; se mide con una llave de torsión.

Tweeter A speaker that responds well to high frequencies.

Altavoz de agudos Un altavoz que responde bien a las altas frecuencias.

Two-mode hybrid system A hybrid transmission that fits into a standard housing and is basically two planetary gearsets coupled to two electric motors. This results in a continuously variable transmission and motor/generator for hybrid operation. This also allows for two distinct modes of hybrid drive operation: low speed/low load and cruising at highway speeds.

Sistema híbrido de dos modos Transmisión híbrida que cabe en una carcasa estándar y es básicamente dos engranajes planetarios unidos a dos motores eléctricos. Esto trae como resultado una transmisión continuamente variable y motores/generadores para operación híbrida. También permite que dos distintos modos de operación híbrida de manejo: velocidad baja/carga baja y manejo a las velocidades de carretera.

Ultracapacitors Used in hybrid vehicles and in some fuel cell electric vehicles, they are capacitors with a large electrode surface area and a very small distance between the electrodes, which gives them very high capacitance.

Capacitadores ultra Usado en vehículos híbridos y en algunos vehículos con combustible de pila eléctrica, son capacitadores con área de superficie grande de electrodos y muy pequeña distancia entre los electrodos, lo cual les da muy alta capacidad.

Ultrasonic cleaning Method of cleaning that utilizes high-frequency sound waves to create microscopic bubbles that work to loosen soil from parts.

Limpieza ultrasónica Un método de limpieza que usa las ondas de sonido de alta frecuencia para crear las burbújas microscópicas que hacen el trabajo de aflojar la suciedad de las partes.

Undersquare A term used to describe an engine that has a larger stroke than bore.

Undersquare Usado para describir un motor que tenga un cilindro con un diámetro interior más pequeño que la longitud del movimiento del pistón.

Unibody A stressed hull body structure that eliminates the need for a separate frame.

Monocasco Una estructura de casco arriostrada que elimina la necesidad de un chassis aparte.

Union A hydraulic coupling used to connect two brake lines.

Unión Un acoplador hidráulico que sirve para conectar dos lineas de freno.

Universal joint A joint that allows the driveshaft to transmit torque at different angles as the suspension moves up and down.

Junta universal Una junta que permite que la flecha motríz transmite el par en los ángulos diferentes mientras que la suspensión mueve hacia arriba y hacia abajo.

Urea An ammonia-like substance that is injected in the exhaust stream of a diesel engine to reduce emissions.

Urea Sustancia similar al amoníaco que se inyecta en el caudal de escape de un motor diésel para reducir las emisiones.

Vacuum The absence of atmospheric pressure; commonly used to refer to any pressure less than atmospheric pressure.

Vacio La ausencia de la presión atmosférica; palabra que se utiliza comúnmente para referir a cualquier presión que es menos que la presión atmosférica.

Valve Device that controls the flow of gases into and out of the engine cylinder.

Válvula Un dispositivo que controla el flujo de los gases entrando y saliendo del cilindro del motor.

Valve body The hydraulic control assembly of the transmission.

Cuerpo de válvula El conjunto del control hidráulico de la transmisión.

Valve guide An opening in the cylinder head that serves to guide and center the valve stem as it moves up and down. The valve guide is either machined into (integral type) or pressed into the head (insert type).

Guía de válvula Una abertura en la culata del cilindro que sirve para guiar y centrar el vástago de la válvula mientras este sube y baja. La guía de la válvula se maquina en (tipo integral) o se comprime en la culata (tipo de inserción).

Valve lifter A cylindrically shaped hydraulic or mechanical device in the valve train that rides on the camshaft lobe to lift the valve off its seat.

Filtro de válvula Un dispositivo hidráulico o mecánico de forma cilíndrica, en el tren de la válvula, que va sobre el lóbulo del árbol de levas para levantar la válvula a partir de su asiento.

Valve keeper Made of two wedge-shaped parts, the keeper locks the valve spring retainer and valve spring to the valve stem.

Armadura de válvula Hecha de dos partes en forma de cuña, la abrazadera bloquea el retén de resorte de válvula y el resorte de la válvula al vástago de la válvula.

Valve lash The distance between the top of a valve and cam lobe or rocker arm when there is no contact between the two.

Juego libre de la válvula La distancia entre la parte superior de una válvula y un lóbulo de leva o balancín cuando no hay contacto entre los dos.

Valve seat Machined surface of the cylinder head that provides the mating surface for the valve face. The valve seat can be either machined into the cylinder head or a separate component that is pressed into the cylinder head.

Asiento de la válvula La superficie rectificada a máquina en la cabeza del cilindro que provee una superficie de contacto para la cara de la válvula. El asiento puede ser rectificado a máquina en la cabeza del cilindro o puede ser un componente aparte para prensarlo en la cabeza de la válvula.

Valve spring A coil of specially constructed metal used to force the valve closed, providing a positive seal between the valve face and seat.

Resorte de la válvula Es un espiral de metal de construcción especial que provee la fuerza para mantener cerrada la válvula, así proveyendo un sello positivo entre la cara de la válvula y el asiento.

Valve stem The part of a valve that guides the valve during its up-and-down movement and serves to connect the valve to its spring through its valve spring retainers and keepers.

Vástago de la válvula La parte de una válvula que la guía durante su movimiento ascendente y descendente, y sirve para conectar la válvula a su resorte a través de sus retenes de resorte de válvula y la armadura.

Valve train The parts used to open and close the intake and exhaust ports. A valve is a movable part that opens and closes a passageway. A camshaft controls the movement of the valves and related parts, causing them to open and close at the proper time. Springs are used to help close the valves.

Tren de válvulas Las piezas utilizadas para abrir y cerrar los puertos de admisión y de escape. Una válvula es una parte móvil que abre y cierra una vía de acceso. Un árbol de levas controla el movimiento de las válvulas y de sus piezas relacionadas, haciendo que se abran y se cierren en el momento adecuado. Se utilizan resortes para ayudar a cerrar las válvulas.

Valve-regulated lead-acid (VRLA) batteries A type of recombinant battery, in which the oxygen produced on the positive plates of this lead-acid battery is absorbed by the negative plate. That, in turn, decreases the amount of hydrogen produced at the negative plate. The combination of hydrogen and oxygen produces water, which is returned to the electrolyte.

Baterías de plomo-ácido reguladas por válvula (VRLA) Un tipo de batería recombinante, en el que la placa negativa absorbe el oxígeno generado en las placas positivas de esta batería de plomo-ácido. Eso, a su vez, disminuye la cantidad de hidrógeno que se produce en la placa negativa. La combinación de hidrógeno y oxígeno genera agua, que se devuelve al electrolito.

Vapor A substance in a gaseous state. Liquid becomes a vapor when brought above the boiling point.

Vapor Una substancia en un estado gaseoso. El líquido se convierte en un vapor al superar el punto de ebullición.

Vapor lock A condition wherein the fuel boils in the fuel system, forming bubbles that retard or stop the flow of fuel to the carburetor.

Tapón de vapor Una condicion en la cual el combustible hierve en el sistema de combustible, formando unas burbújas que retrasan o detienen al flujo del combustible al carburador.

Vaporization The last stage of carburetion in which a fine mist of fuel is created below the venturi in the bore.

Vaporización La última etapa del carburacíon en la cual una llovizna muy fina del combustible se crea en el orificio abajo del venturi.

Variable force solenoid (VFS) An electro-hydraulic actuator made of a variable force solenoid and a regulating valve. It controls main line pressure by moving a pressure regulator valve against spring pressure.

Solenoide de fuerza variable (VFS) Un actuador electrohidráulico compuesto por un solenoide de fuerza variable y una válvula reguladora. Controla la presión de la línea principal al mover una válvula reguladora de presión contra la presión del resorte.

Variable-rate coil spring Rather than having a standard spring deflection rate, these springs have an average spring rate based on load at a predetermined deflection.

Resorte espiral de capacidad variable En vez de tener una capacidad de desviación de resorte estándar, estos resortes tienen un valor promedio de elasticidad basado en la carga a una desviación predeterminada.

Variable resistor A resistor that allows for a change in resistance based on the physical movement of a control. The control can be moved by an individual or a component.

Resistor variable Resistor que permite un cambio de resistencia basado en el movimiento físico de un control. El control puede moverse a través de una persona o un componente.

Variable valve timing (VVT) A system that controls intake valve opening to provide for the optimum performance and fuel economy according to operating conditions.

Ajuste de válvula variable (VVT) Un sistema que controla la apertura de la válvula de admisión para proporcionar el rendimiento y

el ahorro de combustible óptimos de acuerdo con las condiciones de funcionamiento.

Varnish A deposit in an engine lubrication system resulting from oxidation of the motor oil. Varnish is similar to, but softer than, lacquer.

Barníz Un depósito en el sistema de lubricación de un motor que resulta de una oxidación del aceite del motor. El barníz parece a la laca, pero es más blando.

VAT A tester used to measure the voltage and amperage of batteries, generators, and starter motors.

VAT Un probador que se utiliza para medir el voltaje y el amperaje de baterías, generadores y motores de arranque.

V-belt A rubberlike continuous loop placed between the engine crankshaft pulley and accessories to transfer rotary motion of the crankshaft to the accessories.

Correa/banda en V Un ciclo de caucho continuo parecido a una liga de caucho ubicada entre la polea del cigüeñal del motor y los accesorios para transferir el movimiento giratorio del cigüeñal a los accesorios.

Vehicle emission control information (VECI) This information is normally used to identify and calibrate the emission controls on a vehicle.

Información de control de emisiones del vehículo (VECI) Esta información se utiliza normalmente para identificar y calibrar los controles de las emisiones de un vehículo.

Vehicle identification number (VIN) The number that is made up of seventeen characters and contains all pertinent information about the vehicle.

Número de identificación de vehículo Este número se compone de 17 caracteres y contiene toda la información pertinente del vehículo.

Vehicle speed sensor (VSS) A sensor used to track the current speed and the total miles traveled by a vehicle. This input is used by many computer systems in the vehicle.

Sensor de velocidad del vehículo (VSS) Un sensor utilizado para realizar un seguimiento de la velocidad actual y el total de millas recorridas por un vehículo. Muchos de los sistemas informáticos del vehículo utilizan este dato de entrada.

Velocity The speed of an object in a particular direction.

Velocidad Velocidad es el índice de movimiento de un objeto en una dirección particular.

Ventilation The act of supplying fresh air to an enclosed space such as the inside of an automobile.

Ventilación El proceso de suministrar el aire fresco a un espacio cerrado, como por ejemplo al interior de un automóvil.

Vent port The forward port in the master cylinder bore; it lets fluid pass between each pressure chamber and its fluid reservoir during operation.

Puerto de ventilación El puerto delantero en el orificio del cilindro maestro; que permite el paso de fluido entre cada cámara de presión y su depósito de líquido durante el funcionamiento.

Ventilated rotor A rotor that has cooling fins cast between the braking surfaces to increase the cooling area of the rotor.

Rotor ventilado Un rotor que tiene aletas de refrigeración moldeadas entre las superficies de frenado para aumentar el área de refrigeración del rotor.

Viscosity The resistance to flow that is exhibited by a liquid. Thick oil has greater viscosity than thin oil.

Viscosidad Resistencia al flujo mostrada por un líquido. El aceite pesado tiene mayor viscosidad que aceite ligero.

Viscous clutch A clutch assembly that is enclosed in a drum-filled thick fluid. It houses one set of the steel discs connected to the front wheels and another set connected to the rear. A viscous coupling splits torque according to the needs of each axle.

Embrague viscoso Ensamble de embrague dentro de un tibor lleno de fluido pesado que alberga un juego de discos de acero conectados a las llantas anteriores y otro conjunto conectado a la parte posterior. Un acoplamiento viscoso divide el torque según las necesidades de cada eje.

VNT Variable nozzle turbine turbocharger. Designed to reduce turbo lag time.

VNT La unidad de turbina con boquilla variante diseñada para permitir que un turbocargador se acelerara rápidamente, así disminuyendo el tiempo del retraso.

Volatile liquid A liquid that vaporizes very quickly.

Líquido volátil Un líquido que se vaporiza muy rápidamente.

Volatility The tendency for a fluid to evaporate rapidly or pass off in the form of vapor. For example, gasoline is more volatile than kerosene because it evaporates at a lower temperature.

Volatilidad La tendencia de un flúido a evaporarse rápidamente o escaparse en la forma de un vapor. Por ejemplo, la gasolina es más volátil que el kerosén porque se evapora en las temperatura más bajas.

Volt A unit of measurement of electromotive force. One volt of electromotive force applied steadily to a conductor of 1-ohm resistance produces a current of 1 ampere.

Voltio Una unidad de medida de la fuerza electromotor. Un voltio de la fuerza electromotor aplicado constantemente a un conductor que tiene una resistancia de un ohmio produce una corriente de un amperio.

Voltage Electrical pressure resulting from a difference in electrical potential at one point and another.

Voltaje Presión eléctrica que resulta de una diferencia en el potencial eléctrico en un punto y otro.

Voltage drop Voltage lost by the passage of electrical current through resistance.

Caída de voltaje El voltaje que se pierde al pasarse un corriente eléctrico por la resistencia.

Voltage-generating sensors Sensors that are capable of producing their own input voltage signal. This varying voltage signal enables the computer to monitor and adjust for changes in the computerized control system.

Sensores que general voltaje Sensores capaces de producir su propia señal de voltaje. Este voltaje variante le permite a la computadora controlar y ajustar cambios en el sistema computarizado de control.

Voltage regulator A device that controls the strength of the electromagnetic field in the rotor of an alternator.

Regulador del voltaje Un dispositivo que controla la fuerza del campo electromagnético en el rotor de un alternador.

Voltmeter A tool used to measure the voltage available at any point in an electrical system.

Voltímetro Una herramienta que sirve para medir el voltaje disponible en cualquier punto del sistema eléctrico.

Volume The measure of space expressed as cubic inches, cubic feet, and so forth.

Volumen La medida del espacio expresado como pulgadas cúbicas, pies cúbicos, etc.

Volumetric efficiency A measure of how well air flows in and out of an engine.

Rendimiento volumétrico Una medida de lo fácil que circula el aire en un motor.

Vortex flow A swirling, twisting motion of fluid.

Flujo vórtice Un movimiento como remolino o giratorio de un flúido.

Vortex oil flow A valve that responds to throttle position and/or engine load.

Flujo de aceite de vórtice Una válvula que responde a la posición del acelerador o a la carga del motor.

V-ribbed belt A belt that has multiple ribs on one side and is flat on the other side.

Banda encostillada en V Una banda que tiene varias nervaduras en un lado y esta plana en el otro.

Vulcanized A process of heating rubber under pressure to mold it into a special shape.

Vulcanizado Un proceso de calentar al caucho bajo presión para moldearlo en una forma especial.

VVT Variable valve timing A system that automatically changes the valve timing according to operating conditions.

La distribución variable VVT Un sistema que cambia automáticamente la sincronización de la válvula de acuerdo con las condiciones de funcionamiento.

Warehouse distributors (WDs) These carry substantial inventories of many part lines. They serve as large distribution centers. WDs sell and supply parts to part wholesalers.

Distribuidores de depósito (WD) Ellos mantienen inventarios considerables de muchas líneas de repuestos. Actúan como grandes centros de distribución. Los WD venden y suministran repuestos a mayoristas.

Warpage Bending.
Alabeo Doblando.
Wastegate The boost regulator for a turbocharger. This valve allows exhaust gas to bypass the turbocharger when boost pressure exceeds a predetermined limit.
Válvula de expulsión El regulador de impulso para un turbocargador. Esta válvula permite que el gas de escape se desvíe del turbocargador cuando la presión de impulso supera un límite predeterminado.
Waste spark A spark occurring during the exhaust stroke on a computerized ignition system.
Chispa de desperdicio Chispa que se produce durante el ciclo de escape de un sistema de encendido computarizado.
Water jacket Passages in the cylinder block and head, through which coolant flows to remove heat from the area around the cylinders' combustion chambers.
Camisa de agua Pasajes en el bloque y culata de cilindros por donde fluye el refrigerante del motor para extraer el calor de la zona alrededor de las cámaras de combustión de los cilindros.
Water pump A device, usually located on the front of the engine and driven by one of the accessory drive belts, that circulates the coolant by causing it to move from the lower radiator-outlet section into the engine by centrifugal action of a finned impeller on the pump shaft.
Bomba de agua Un dispositivo, situado por lo común en la parte delantera del motor e impulsado por una de las bandas para accesorios, que hace circular el refrigerante, haciéndolo pasar de la sección de salida inferior del radiador al motor, mediante la acción centrífuga de un propulsor de aletas en el eje de la bomba.
Water soluble A type of contaminant that is the easiest to clean and that includes dirt, dust, and mud.
Soluble en agua Tipo de contaminante que es el más fácil de limpiar, tal como la tierra, el polvo y el lodo.
Watt A unit of measure of electric power.
Watt Unidad de medida de energía eléctrica
Watt's law A basic law of electricity used to find the power of an electrical circuit expressed in watts. It states that power equals the voltage multiplied by the current (in amperes).
Ley de Watt Una ley básica de la electricidad que sirve para expresar la potencia de un circuito eléctrico en vatios. Declara que la potencia iguala al voltaje multiplicado por el corriente (en ampérios).
Wave Any single swing of an object back and forth between the extremes of its travel through matter or space.
Onda Cualquier movimiento único de un objeto hacia adelante y hacia atrás entre los extremos de su recorrido a través de materia o de espacio.
Waveform (Trace) A lab scope converts electrical signals to a visual image representing voltage changes over a specific period of time. This information is displayed in the form of a continuous voltage line called a waveform.
Rastro – Ondas Un ámbito de laboratorio convierte señales eléctricas a imágenes visuales que representan cambios en el voltaje durante un período específico de tiempo. Esta información se despliega en la forma de una línea continua de voltaje llamada una forma de onda.
Wavelength The distance between each compression of a sound or electrical wave.
Longitud de onda La distancia entre cada compresión de un sonido u onda eléctrica.
Web The inner part of a brake shoe that is perpendicular to the table and to which all of the springs and other linkage parts attach.
Alma La parte interna de una zapata de freno que es perpendicular a la mesa y a la que todos los resortes y otras partes del varillaje se conectan.
Wedge-type combustion chamber A combustion chamber design that has the spark plug located at the wide part of a wedge-shaped chamber. The flame front moves to the narrow portion.
Cámara de combustión de tipo cuña Un diseño de cámara de combustión que tiene la bujía situada en la parte ancha de una cámara en forma de cuña. El frente de llama se desplaza a la parte estrecha.
Weight A force exerted on a mass by the gravitational force.
Peso El peso es una fuerza ejercida en una masa por la gravedad.
Wet sump A valve used prevent excessively high system pressures from a positive displacement pump.
Cárter húmedo Una válvula utilizada para evitar presiones excesivamente altas del sistema desde una bomba de desplazamiento positivo.
Wheatstone bridge A series-parallel arrangement of resistors between an input terminal and ground.
Puente Wheatstone Un arreglo en series-paralelo de los resistores entre un terminal de entrada y la tierra.
Wheelbase The distance between the center of a front wheel and the center of a rear wheel.
Batalla (empate) La distancia entre el centro de una rueda delantera y el centro de una rueda trasera.
Wheel cylinder A device used to convert hydraulic fluid pressure to mechanical force for brake applications.
Cilindro de rueda Un dispositivo que sirve para convertir la presión de flúido hidráulico en una fuerza mecánica para aplicaciones de frenos.
Wheel shimmy Tire wobble felt through the steering system.
Trepidación de rueda Oscilación del neumático que se siente a través del sistema de dirección.
Wheel spindle The short shaft on the front wheel upon which the wheel bearings ride and to which the wheel is attached.
Husillo de rueda El eje corto de la rueda delantera sobre el que se asientan los cojinetees y al que va acoplada la rueda.
Wheel tramp Wheel hop caused by static imbalance.
Movimiento irregular de la rueda Salto de la rueda causado por un desequilibrio estático.
Woofer A speaker that responds well to low frequencies.
Altavoz de graves Un altavoz que responde bien a las frecuencias bajas.
Work What is accomplished when a force moves a certain mass a specific distance.
Trabajo Lo que se logra cuando una fuerza mueve una cierta masa una distancia específica.
Wrist pin See Piston pin.
Perno de articulación Consulte Perno de pistón.
Wye winding A type of stator winding connection that connects three windings in parallel and has the appearance of the letter "Y." AC generators with wye windings are capable of putting out higher voltages.
Devanado en forma de Y Un tipo de conexión del devanado del estator que conecta tres devanados en paralelo y tiene el aspecto de la letra "Y". Los generadores de corriente alterna con bobinados en forma de Y pueden producir voltajes más altos.
Yaw A swinging motion to the left or right of the vertical centerline or rotation around the vertical centerline.
Desviación o derrape Se define como un movimiento a la izquierda o derecha de la línea vertical del centro o rotación alrededor de la línea vertical del centro.
Yield Commonly refers to the point where a bolt is stretched to its limit and is unable to return to its original shape.
Rendimiento Se refiere comúnmente al punto donde un tornillo se extiende a su límite y no puede regresar a su forma original.
Zener diode A diode that allows reverse current to flow above a set voltage limit.
Diodo zener Un diodo que permite que el corriente en reverso fluye en cantidades más altas del límite de voltaje predeterminado.
Zerk fitting A small check valve that allows grease to be injected into a part without letting grease out and dirt in.
Racor de engrase Una pequeña válvula unidireccional que permite la inyección de grasa en una pieza sin dejar que la grasa salga y la suciedad entre.
Zeronic potassium perchlorate (ZPP) A chemical that reacts to ignition and causes the air bag to inflate.
Perclorato de potasio Zeronic (ZPP) Un producto químico que reacciona a la ignición y hace que se infle la bolsa de aire.

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